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

Board of Studies: Modeling and Simulation
Faculty: Faculty of Technology

Approved by
BoS | Faculty | Academic Council
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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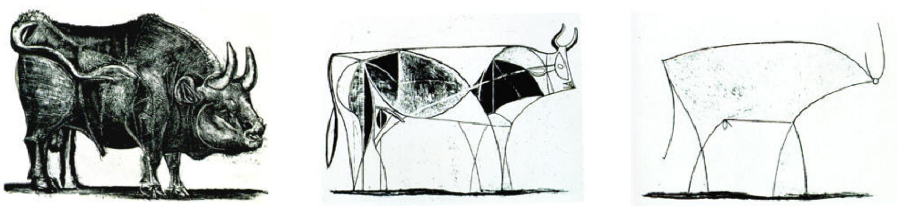
Organizational Support: Professors Anjali Kshirsagar and Aditya Abhyankar.

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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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 and Simulation, Faculty of 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.

Credit Breakup Semester 1: 17 core and 8 choice-based credits.
Semester 2: 12 core and 13 choice-based credits.
Semester 3 and 4: 50 core credits (internship).

Structure and Syllabus This document, Sec. 1 onwards.

Medium of Instruction English.

Number of Seats 20.

Eligibility

1. B.E./B.Tech. (any branch of engineering), with mathematics at the Savitribai Phule Pune University M1+M2+M3 level; **AND**
2. Nomination/sponsorship by (a) a nationally recognized research institute, or (b) industry/organization.

Admissions

1. First Year: Through interview.
2. Second Year: Pass or better grade in at least 50% of the first-year credits.

Fees For the two categories of student, namely,

1. candidates nominated/sponsored by a nationally recognized research institute, and
2. candidates nominated/sponsored by industry/organization;

see Sec. 10.

1 Background, Rationale, Intended Audience

The Centre for Modeling and Simulation, Savitribai Phule Pune University, started a highly multidisciplinary programme called the M.Tech. Programme in Modeling and Simulation in 2005 (Public Document CMS-PD-20160121 of the Centre for Modeling and Simulation, 2016). The academic outlook and content, together with the innovative nature of this programme, correctly anticipated the rise of computing in academia, research, and industry. This made it attractive not only to fresh graduates from science, engineering, and other streams, but also to individuals working in academia, research institutes, and industry. In particular, these individuals realized the wider applicability of modeling and simulation (M&S) methodologies (and the utility of the multidisciplinary problem-centric approaches advocated by the programme) in their own domains of activity. Indeed, over the years, the Centre for Modeling and Simulation, Savitribai Phule Pune University, has received innumerable queries about deploying this programme in part-time and web-based modes (which, currently, is not feasible due to space and faculty strength constraints). These individuals have, typically, sufficient maturity and experience in their own fields through hands-on work, focus, and high levels of motivation to fill-in gaps in their prior education in areas of applied mathematics, applied statistics, and computing.

The programme outlined in the present document, namely, the *Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research)*, is designed to cater to this group of working individuals. Currently, we have limited this programme to working individuals nominated/sponsored by (a) nationally recognized research institutes 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 constraints to some extent, and to cater to the aspirations of this intended audience, without compromising on academic rigour. One important constraint for this audience is *to be able to complete the programme in a self-paced manner*. (See Sec. 10 for one important implication of this essentially *academic* requirement.)

2 Eligibility

1. B.E./B.Tech. (any branch of engineering), with mathematics at the Savitribai Phule Pune University M1+M2+M3 level; **AND**
2. Nomination/sponsorship by (a) a nationally recognized research institute, or (b) industry/organization.

We require the student's organization to appoint one coordinator (preferably a technical person) to monitor the progress of their student/s as well as to act as liaison with the Centre for Modeling and Simulation. Centre for Modeling and Simulation will appoint one or more faculty coordinators for the same purpose.

3 Admissions

1. First Year: Through interview.
2. Second Year: Pass or better grade in at least 50% of the first-year credits.

4 Structure of the Programme

The programme consists of two semesters of course work consisting of core and choice-based elective courses at the Centre for Modeling and Simulation, Savitribai Phule Pune University.

Semester 1
Core credits: 19, choice-based/elective credits: 6

Code (Section)	Course Name	Credits
C101 (A.1)	Real Analysis and Calculus	2
C102 (A.2)	Vector Analysis	2
C103 (A.3)	Linear Algebra	2
C106 (A.4)	Probability Theory	3
C107 (A.5)	Computing with R	1
C109 (A.6)	Computing with C	2
C110 (A.7)	Algorithms	2
C111 (A.8)	M&S Hands-On 1	5

Semester 2
Core credits: 10, choice-based/elective credits: 15

Code (Section)	Course Name	Credits
C201 (A.9)	Complex Analysis	2
C206 (A.10)	Statistical Inference	3
C207 (A.11)	M&S Hands-On 2	5

Semester 3
Core credits: 25, choice-based/elective credits: 0

Code (Section)	Course Name	Credits
C300 (A.12)	Internship I	25

Semester 4
Core credits: 25, choice-based/elective credits: 0

Code (Section)	Course Name	Credits
C400 (A.13)	Internship II	25

Table 1: Structure of the Programme

This is followed by two semesters of internship (with internship considered a part of the core courses). The structure of the programme is outlined in Table 1.

5 Core Courses

Syllabi for the core courses are available in Sec. A. Given the nature of the intended audience (Sec. 1), if a student has adequate knowledge/skill/expertise in a core course, (s)he may be exempt, after examination/testing, from doing that particular course in exchange for another course of her/his interest.

6 Choice-Based Elective Courses

A selection of choice-based credit courses is detailed in the curriculum document (Public Document CMS-PD-20160121 of the Centre for Modeling and Simulation, 2016) for the original/sister programme, namely, M.Tech. Programme in Modeling and Simulation.

A student in the present programme is required to take appropriate number of choice-based or elective credits (see Sec. 1 for semesterwise number of such credits) from elective courses offered at the Centre for Modeling and Simulation, or from credit courses offered by Savitribai Phule Pune University campus departments.

Organizations sponsoring students may wish to float elective courses in areas of their interest and expertise. This is most certainly welcome, with approval from Centre's faculty and appropriate University bodies. Some advance planning is required for this to materialize, as University approval procedures may take a few months' time. Such courses, if offered, will be open to students in other programmes at the Centre for Modeling and Simulation, and also to campus students as credit courses.

7 Internships

Internships may be undertaken by a student at her/his place of work, at the Centre for Modeling and Simulation, or any other appropriate organization — after approval from the Centre for Modeling and Simulation.

8 Interpreting Syllabi

The syllabi in Sec. 1 are to be considered indicative of the overall focus and scope of the respective courses. Actual coverage of topics, their relative emphasis, and choice of modeling contexts may vary at the discretion of a competent instructor without compromising upon the essential content and the goals for the course. Topics marked Optional may be covered or not covered at the discretion of the instructor, the consideration here being the batch-to-batch variation in the students' backgrounds, capabilities, and interests. The overall outlook on pedagogy (e.g., emphasizing concept and clarity over mathematical rigour; see Sec. I.2 of the original programme document (`http://cms.unipune.ernet.in/reports/pd-20070223/`) continues to underline the programme. Individual courses have been assigned two types of course attribution: (a) Exactly one out of the set {Core, CBC}; and (b) one or more out of the set of {C (classroom), T (tutorial), L (laboratory), S (seminar), W (workshop)}. The (b)-attributions are suggestive of the pedagogic distribution of the course and of how the course may be conducted.[1]

9 Grading, Evaluation, Assessment

We follow prevailing University policies and practices in this regard. Currently, continuous and final assessments have 50% weight each. It is also customary in the University to grade students using marks and then convert the resulting percentages to grades as per the University-prescribed norms. Beyond this, the teacher is the best judge of the mode/model of assessment for her/his course. On academic grounds, we refrain from making rigid and un-academic connections between nominal marks and duration of examination. Following the spirit of the choice-based credit system, and in the best interest of the student, we also believe that final assessment/examination for a credit course should be at the end of the course, and not necessarily at the end of the semester. Grades will be reported on the University-recommended 10-point

[1] This section is taken (almost) verbatim from the curriculum document CMS-PD-20160121 for the M.Tech. Programme in Modeling and Simulation.

grade scale[2], or as per the prevailing rules and norms of the University.[3]

10 Fees

For either category of student, namely, students nominated/sponsored by (a) a nationally recognized research institute, or (b) industry/organization, it is important to adopt a credit-based fee structure *so as to enable a student to complete the programme in a self-paced manner*.

Recommended Fees. Tuition fees Rs. 1000 per credit. Other fees as applicable.

[2] http://www.unipune.ac.in/university_files/pdf/CBCS-Handbook-28-7-15.pdf
[3] See footnote 1.

A Syllabi

A.1 C101 Real Analysis and Calculus

Credits. 2

Prerequisites. None

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. None

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. None

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, 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 and linear ODEs, normal matrices and diagonalizability, spectral theorem for normal matrices.
7. Quadratic forms. 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. None

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 C107 (A.5). 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 C107 Computing with R

Credits. 1

Prerequisites. None

Attributions. Core; L

Rationale, Outlook, Purpose, Objectives, and Goals. The R (http://cran.r-project.org/) statistical computing environment, built around the S programming language, is rich in computational statistics primitives. It is open-source and supported by an ever-growing community of users and contributors. It allows a variety of programming styles from quick-and-dirty explorations to elaborate imperative, procedural, object-oriented, and functional coding. It is ideally suited for statistical modeling and data analysis, graphics and visualization, as well as a platform for teaching/learning probability and statistics through hands-on exploration. As such, R is a must for any broad-based M&S curriculum with a statistical modeling/data analysis component. Goals: proficiency in computational problem-solving using R; specifically, decent algorithmic, coding, and scripting skills.

Syllabus.

1. Overview of R and S. History of R. Why use R? When not to use R? GUIs for R. Invoking and exiting the R interpreter environment. Getting help and finding information. `demo()`. The six atomic types. Assignment operators. Standard arithmetic and logical operators. Comments. Conditionals and loops. Parenthesis and braces. Expressions. Every expression has a value. Common composite data types: `vector`, `list`, `matrix`, and `data.frame`. The elementwise operations rule for `vector` and related container types. `functions`. Writing and executing R scripts: `source()` and `Rscript`.
2. Case studies illustrating R capabilities, in-built functions, and common packages. Overview of R graphics. Probability distributions and random number generators. Creating numerical and graphical data summaries, and exploratory data analysis. Complex numbers, numerical methods, etc. Character strings. Set operations. Interface to the operating system shell. Data input and output.
3. Installing R and R packages locally into a linux user account. Installing R from source: `configure` – `make` – `make install` sequence. Installing packages: `install.packages()` and the `R CMD INSTALL` mechanism.
4. Migrating from C to R. Automatic type identification in an assignment vs. explicit declaration of data type. `;` and `\n` as expression terminators. Explicit loops vs. vectorization.
5. Getting performance from R codes. Coding style guidelines. Explicit loops vs. vectorization. The `compiler` package. Debugging and profiling tools. Interfacing with `C`, `C++`, `fortran`.
6. Hands-on explorations using R. Any reasonable set of hands-on problems designed to enhance computational problem-solving and algorithmic abilities. Such problems may be related to M&S in general, or specifically to topics from other courses (e.g., probability theory, statistical inference) in the programme or the instructor's field of expertise.

Suggested Texts/References.

1. W. N. Venables, D. M. Smith, and the R Development Core Team, *An Introduction to R*. The R Project, latest available edition. http://cran.r-project.org/doc/manuals/R-intro.html

2. John Verzani, *Using R for Introductory Statistics*. Chapman & Hall/CRC, 2005.
3. Daniel Navarro, *Learning Statistics with R: A Tutorial for Psychology Students and Other Beginners*. Self-published, 2013. http://learningstatisticswithr.com/
4. Paul Murrell, *R Graphics*. Chapman & Hall/CRC, 2011.
5. Patrick Burns, *The R Inferno*. http://www.lulu.com/, 2012. Available at http://www.burns-stat.com/documents/books/the-r-inferno/.
6. W. N. Venebles and B. D. Ripley, *Modern Applied Statistics with S-Plus*. Springer, 2002.
7. R. G. Dromey, *How to Solve It By Computer*. Prentice-Hall, 1982.

Notes on Pedagogy. This syllabus is based on an outline for a longer course that was refined over several course deliveries by the contributor (see below). Depending on the background and capabilities of the students, this outline may need to be somewhat diluted or intensified – without compromising upon the essentials and goals for the course. Apart from familiarizing a student with R, a major emphasis of this course is on tinkering and exploration, on computational problem-solving, and on translating a problem into a computational framework leading to either a solution or a better understanding of the problem, and on how R can be used as a M&S tool, and for exploring/visualizing probability and statistics concepts. Assignments often consist of problems that are exploratory in nature (e.g., illustrating formal results that may be difficult to grasp, such as the central limit theorem; see C106 (A.4)), or require a student to understand an algorithm from its plain-English or pseudocode description (e.g., generating the next permutation given a permutation of n objects). Examinations may consist of problems not necessarily discussed in the class: Here, adequate information about the method of solution or algorithm is provided.

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

A.6 C109 Computing with C

Credits. 2

Prerequisites. None

Attributions. Core; L

Rationale, Outlook, Purpose, Objectives, and Goals. Upon successful completion of this course, the student is expected to be able to

1. Understand basics of procedural/functional programming, syntax, semantics of C.
2. Design an algorithm to solve problems of various kinds in modeling and simulation and implement using C programming language.
3. Debug the code to spot logical errors, exceptions etc.
4. Write reasonably complex C code for solving various problems in modeling and simulation.

Syllabus.

- ANSI C. Syntax, data types, concept of void, variables, operators, expressions and statements, character input and output, console input and output, inclusion of standard header files, pre-processor directives.
- Control flows. If-else, for, while, do-while, switch-case, break and continue, code blocks and nesting of blocks.
- Functions. Basics of functions, return statement, recursion, function blocks, static variables
- Memory management. Dynamic versus static memory allocation, freeing memory, arrays, memory layout of multidimensional arrays.
- Pointers. Concept of pointers, pointer arithmetic, pointers versus arrays, array of pointers.
- Program compilation and debugging techniques. Introduction to tools like `gdb` together with `ddd`, `GNU make` and profiler `gprof`. Code organization across files. Version/revision control using `svn` or `git`.
- Structures and Unions. Structures and unions, bit fields, typedef, self referential structures, their use in link-list, queue, stack *etc.*
- Input and output in `C`. Files, file operations.

Suggested Texts/References.

- Kernighan and Ritchie, *The C Programming Language.* PHI, 1990.
- R. L. Kruse, B. P. Leung, C. L. Tondo, *Data Structures And Program Design In C.* Pearson Education, 2007.

Notes on Pedagogy. Although finite-precision arithmetic is covered at length in the course C201 (A.9), the student may be exposed here to the bare-basics of finite-precision representations and arithmetic if time permits, and at the discretion of the instructor.

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

A.7 C110 Algorithms

Credits. 2

Prerequisites. None

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. However, `C` is highly recommended so as to give student a closer feel of computer system organization. Please see the sister course C109 (A.6). 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.

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A.8 C111 M&S Hands-On 1

Credits. 5

Prerequisites. None

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.

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A.9 C201 Complex Analysis

Credits. 2

Prerequisites. None

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.

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A.10 C206 Statistical Inference

Credits. 3

Prerequisites. C106 (A.4), C107 (A.5)

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.11 C207 M&S Hands-On 2

Credits. 5

Prerequisites. C111 (A.8)

Attributions. Core; C, L, S

Rationale, Outlook, Purpose, Objectives, and Goals. Same as that for the sister course C111 (A.8).

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.8). This may be achieved by assigning, say, group projects as part of C111 (A.8) 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.12 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.13) 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.13 C400 Internship II

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) 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.12). Details can be found in the syllabus page for C300 (A.12).

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