Master of Technology (M.Tech.)
in Modeling and Simulation

Approved by the University of Pune
Board of Studies: Scientific Computing

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About This Document

This document outlines an academic programme, the Master of Technology (M.Tech.) in Modeling and Simulation, designed by the people at the Centre for Modeling and Simulation, University of Pune. This academic programme has been approved by the University of Pune.

Feedback Requested. The utility of modeling and simulation as a methodology is extensive, and the community that uses it, both from academics and from industry, is very diverse. We would thus highly appreciate your feedback and suggestions on any aspect of this programme – We believe that your feedback will help us make this programme better.

Citing This Document

This is a public document available at http://cms.unipune.ac.in/reports/. Complete citation for this document is as follows:


Acknowledgments

Many people have contributed to the creation of this this programme and this document. Their time and effort, contributions and insights, and comments and suggestions have all gone a long way towards bringing this programme to its present form. The Centre values, appreciates and acknowledges all these forces that shaped this document and this programme, and would like to extend profound and sincere thanks to all of them.

About the Centre

The Centre for Modeling and Simulation, University of Pune was established in August 2003 with a vision to promote awareness about 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 scientific disciplines.

As a part of fulfilling this vision, the Centre designed a novel and highly interdisciplinary academic programme called the Advanced Diploma Programme in Modeling and Simulation; in the academic year 2005-06. The M.Tech. in Modeling and Simulation programme outlined in this document incorporates insights gained from the operation of this diploma programme and became operational beginning with academic year 2008-09.

Collectively, the Centre possesses expertise in the areas of mathematical and computational physics, materials modeling, statistical data modeling and analysis, mathematical modeling, scientific computing, and numerics. The Centre also possesses excellent computing facilities, some of which are managed and maintained by the Centre as a campus-wide computing resource. The greatest strength of the Centre is its competent and highly motivated staff, both academic as well as non-academic. The resulting academic, work, and intellectual environment at the Centre is an open, vibrant, lively, and non-hierarchical one.

For more information, visit our website http://cms.unipune.ac.in/.
Administrative Summary of the M.Tech.(M&S)

Title of the Programme
Master of Technology (M.Tech.) in Modeling and Simulation.
M.Tech.(M&S) for short.

Designed By
Centre for Modeling and Simulation, University of Pune, Pune 411 007, INDIA.

Status of the Programme
The M.Tech.(M&S) will be run as an Autonomous Programme under the Faculty of Science, University of Pune, by the Centre for Modeling and Simulation, University of Pune.

Board of Studies
Interdisciplinary School of Scientific Computing, University of Pune.

Modes of Operation
Full-time, part-time, and distance-learning modes.
The Centre plans to deploy the part-time and the distance-learning modes upon availability of sufficient faculty and other resources.

Duration of the Programme
Full-time mode: 2 years.
Part-time mode: minimum 3 years (10CH per week).
Distance-learning mode: as per the progress of the student.

Total Number of Credits
100.

Credit Breakup
Year 1: 11 core (45CR) and 1 elective (5CR) courses.
Year 2: 4 core (20CR) and 1 elective (5CR) courses.
minimum 6-month full-time project (25CR).

Structure and Syllabus
Enclosed (as Sec. 4 of this document).

Eligibility
1. B.E. or equivalent in any branch of engineering
   OR
   Master’s degree in any science/arts/commerce discipline.
   AND
2. Background in mathematics equivalent to the University of Pune F.Y.B.Sc. mathematics syllabus as ascertained via the applicable selection criterion below.

Selection Criteria
Regular Admissions
1. Academic record, AND 2. Performance in an entrance test, with the selection threshold on performance set appropriately to match the vigorous and intensive nature of the programme, and applied uniformly across all candidates. AND 3. A statement of purpose, if necessary.

Industry-Sponsored Candidates
To be decided in consultation with the interested industry or organisation on a case-by-case basis.

Foreign Candidates
To be decided on a case-by-case basis.

Number of Seats
Not more than 30.

Fees
As per University rules, policies, and norms.
The M.Tech.(M&S) at a Glance

Aims and Objectives. The Master of Technology (M.Tech.) in Modeling and Simulation, also called the M.Tech.(M&S), is a unique, fast-paced, and vigorous academic training programme that aims at creating a breed of problem-solvers:

- who have a breadth and perspective on mathematical modeling, a solid training in simulation methods, impeccable computational skills, and the ability to generate reasonable solutions, algorithmic or otherwise, for problems not necessarily encountered earlier;
- who are familiar with the current state of relevant technologies, and from familiar to skilled in a variety of relevant software tools and methodologies; and
- who, outside of their native knowledge domain, have sufficiently broad background and skills to interface between domain experts and coders in a multidisciplinary team.

Academic Structure. This is a highly interdisciplinary programme that focuses on mathematical modeling formalisms and simulation methodologies by integrating applied mathematics, statistics, and computing in a coherent package. *This is not a programme in the traditional domain of computer science.* This programme may, however, be thought of as a computational science programme.

The M.Tech.(M&S) consists of core courses, elective courses, and a project. In the full-time mode, the duration of the M.Tech.(M&S) is 2 years (4 semesters). Each semester is broken up into 18 weeks of instruction, 1 week for preparation, and 1 week for actual end-semester examinations. The credit total of the entire programme is 100 credits: The first year is devoted to coursework consisting of 11 core courses (45 credits) and 1 specialized elective (5 credits); the second year is devoted to 4 core courses (20 credits), 1 specialized elective (5 credits), and a minimum 6-month full-time project/internship/industrial training (25 credits). Evaluation is based on (a) continuous assessment throughout a semester, and (b) an end-semester examination. Evaluation of the project is based on continuous assessment, a project report, and a presentation cum open defense.

Part-Time and Distance-Learning Modes. The academic structure of the M.Tech.(M&S) is flexible enough so that it could in principle be run in full-time, part-time, and distance-learning modes. *In the foreseeable future, however, the Centre plans to run the M.Tech.(M&S) only in the full-time mode.* With additional faculty, manpower, infrastructure, and resources, it may be possible to run the programme in a part-time or distance-learning mode. The part-time and distance-learning modes will make the programme most attractive to working individuals in the industrial sector and R&D organisations.

Historical Underpinnings. The Centre for Modeling and Simulation, University of Pune, has gathered considerable experience in designing and running academic programmes in modeling and simulation from the operation of its Advanced Diploma Programme in Modeling and Simulation. The M.Tech.(M&S) expands upon, and incorporates academic, logistic, and operational insights obtained from, this diploma programme.

The M.Tech.(M&S) may be considered a thoroughly revamped and modernized version of an existing University of Pune M.Tech. Programme in Modeling and Simulation. This existing M.Tech. programme used to be run in collaboration with the Institute for Armament Technology (IAT). IAT, now renamed DIAT, the Defense Institute for Advanced Technology, is now a deemed University.

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1The current University of Pune credit system defines one credit as one clock hour of contact between faculty and students per week for 15 consecutive weeks.
Contents

1 Introduction 7
   1.1 The Modeling and Simulation Enterprise ......................... 7
   1.2 Need for a Programme in Modeling and Simulation .............. 9
   1.3 Programme Design Considerations ................................ 9
       1.3.1 From an Academic Perspective ............................ 9
       1.3.2 From a Student’s Perspective ............................ 11
   1.4 Historical Underpinnings ....................................... 11
   1.5 Outline of This Document ..................................... 11

2 Specific Objectives and Outcomes 12

3 The Prospective Student 12
   3.1 Eligibility .................................................. 12
   3.2 Selection .................................................... 12
       3.2.1 Regular Admissions .................................... 12
       3.2.2 Industry-Sponsored Candidates .......................... 13
       3.2.3 Foreign Candidates .................................... 13

4 The Curriculum 14
   4.1 Structure at a Glance: Semester 1 (Year 1) ..................... 15
   4.2 Structure at a Glance: Semester 2 (Year 1) ..................... 16
   4.3 Structure at a Glance: Semester 2 (Year 1) Electives ........... 17
   4.4 Structure at a Glance: Semester 3 (Year 2) ..................... 19
   4.5 Structure at a Glance: Semester 3 (Year 2) Electives ........... 20
   4.6 Structure at a Glance: Semester 4 (Year 2) ..................... 22
   4.7 Rationale for Individual Course Themes ........................ 23
       4.7.1 Computing .............................................. 23
       4.7.2 Perspectives on Mathematical Modeling .................... 23
       4.7.3 Perspectives on Probability Modeling ...................... 23
       4.7.4 Technical Communication ................................ 23
       4.7.5 Overview of M&S ....................................... 24
       4.7.6 Fundamentals .......................................... 24
       4.7.7 Project Management .................................... 24
       4.7.8 Elective .............................................. 25
       4.7.9 Project (Internship/Industrial Training) ................... 26

M Modulewise Syllabi 27
   M.1 Semester I Modules ........................................... 27
       M.1.1 Programming for Modelers I ............................... 27
       M.1.2 Practical Computing I .................................... 28
       M.1.3 Finite-Precision Arithmetic ............................... 28
       M.1.4 Introduction to Matlab/Octave ............................ 29
       M.1.5 Ordinary Differential Equations .......................... 29
       M.1.6 Partial Differential Equations ............................ 30
       M.1.7 Introduction to R ....................................... 30
       M.1.8 Probability Theory ...................................... 31
       M.1.9 Technical Reading, Writing, and Presentation .......... 31
       M.1.10 Overview of M&S I ..................................... 33
       M.1.11 Basics of Analysis ..................................... 34
## M.1 Semester I Modules

### M.1.12 Vector Analysis
- Page 35

### M.1.13 Complex Analysis
- Page 35

### M.1.14 Linear Algebra
- Page 36

## M.2 Semester II Modules

### M.2.1 Programming for Modelers II
- Page 37

### M.2.2 Practical Computing II
- Page 37

### M.2.3 A Survey of Numerical Mathematics
- Page 37

### M.2.4 Optimization
- Page 38

### M.2.5 Stochastic Simulation
- Page 39

### M.2.6 Reasoning Under Uncertainty
- Page 40

### M.2.7 Term Paper
- Page 41

### M.2.8 Overview of M&S II
- Page 41

## M.3 Semester III Modules

### M.3.1 Practical Computing III
- Page 41

### M.3.2 High-Performance Computing
- Page 42

### M.3.3 Numerical Linear Algebra
- Page 43

### M.3.4 Transforms
- Page 43

### M.3.5 Statistical Models and Methods
- Page 44

### M.3.6 Stochastic Optimization and Evolutionary Computing
- Page 45

### M.3.7 Elements of Management
- Page 46

### M.3.8 M&S Hands-On
- Page 47

## M.4 Elective Modules: Sample Syllabi

### M.4.1 Computational Fluid Dynamics
- Page 48

### M.4.2 Machine Learning
- Page 49

### M.4.3 Geographic Information Systems
- Page 49

### M.4.4 Modeling for Materials Science and Engineering
- Page 50

### M.4.5 Theory of Computation
- Page 50

### M.4.6 Traffic Modeling
- Page 50

### M.4.7 Public Transport System Modeling
- Page 51

### M.4.8 Logistical and Transportation Modeling
- Page 51

### M.4.9 System Optimization and Analysis for Manufacturing
- Page 52

### M.4.10 Financial Modeling and Optimization
- Page 52

### M.4.11 Digital Processing I
- Page 54

### M.4.12 Digital Processing II
- Page 54

### M.4.13 Simulation of Control Theory I
- Page 55

### M.4.14 Simulation of Control Theory II
- Page 55

## M.5 The Project (Internship/Industrial Training)

### M.5.1 Project
- Page 57
1 Introduction

This document outlines a multidisciplinary academic programme, the Master of Technology (M.Tech.) in Modeling and Simulation, designed by the Centre for Modeling and Simulation, University of Pune. For the purpose this document, this programme may be referred to as the M.Tech.(M&S) or, simply, as the Programme. The Centre for Modeling and Simulation, University of Pune, may similarly be referred to as the Centre.

In this section, we first present (Sec. 1.1) our perspective and outlook on the modeling and simulation enterprise which forms the basis for the structure of the M.Tech.(M&S), followed by a comprehensive discussion on design considerations and possibilities for a programme of this kind (Sec. 1.3) and the need for such a programme (Sec. 1.2), and finally, a historical perspective on the programme (Sec. 1.4). An outline of the rest of this document is presented in Sec. 1.5.

1.1 The Modeling and Simulation Enterprise

Model, n. 1 a usually miniature representation of something; also : a pattern of something to be made 2 an example for imitation or emulation 3 archetype 4 a description or analogy used to help visualize something (as an atom) that cannot be directly observed 5 a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs.

Simulation, n. 1 The imitative representation of the functioning of one system or process by means of the functioning of another <a computer simulation of an industrial process> 2 Examination of a problem often not subject to direct experimentation by means of a simulating device.

A model tries to capture the essential features of a system under scrutiny. A simulation, on the other hand, attempts to represent a model of the system under study using some other well-understood system, the simulation system, wherein features of interest of the system under study are represented using properties of the simulation system. The correctness of representation of features of interest embodied by the model, and whether one system could at all be simulated by another should be the principal concerns of a “theory” of simulation. Assuming that the model did capture essential ingredients of the system being studied, and that the simulation system is capable of representing the model to sufficient accuracy, the corresponding simulation could be expected to mimic the behaviour of the underlying real-life system.

Most often, mathematics is used to model the system under study. Usually, the need to understand the system in a quantitative fashion and the ability to make quantitative
predictions about the system are the key reasons for using mathematics in this fashion. From a purist point-of-view, patterns of behaviour of a system are oftentimes perceived as having some sort of inherent mathematical structure: Either deciphering that structure and expressing it in the most concise fashion, or developing a mathematical structure inspired by the observed behaviour of the system, is of great interest to some. Indeed, all scientific theories can be thought of as models representing aspects of “reality” to within their own respective domains of applicability.

Conceivably, one could attempt a naïve classification of mathematical models into two very broad classes, namely, probabilistic vs. non-probabilistic. Probabilistic (or stochastic) models, which are based on the formalism of probability theory, are perhaps the only known way to model situations where noise, randomness, complexity, uncertainty, or ignorance dominate either the behaviour of the system or the observation process. Non-probabilistic (sometimes called deterministic) models are based on the assumption of absence of these confounds.

The most challenging modeling and simulation problems arise when the system under study is neither well-understood nor, possibly, mathematised. For example, in comparison with physical systems, complex phenomena such as human social behaviour are neither as well-understood, nor are as mathematised, in microscopic detail, as physical theories. Construction of a simulation system for such phenomena may have somewhat nebulous boundaries between an art and a science. Furthermore, the bounds of validity of the mathematical model for a system have a direct influence on the reliability of the simulation system. The degree of identity (or similarity) between the behaviour of the real system and the simulated system needs to be determined so as to enable making of valid inferences based on observations of the simulated system.

A mathematical model typically extracts essential features of the system under study from the knowledge domain. For example, the mathematical model of air flight would have to incorporate fluid dynamical statements about the properties of air as a fluid system. A typical modern scientific team working on a challenging real-life problem consists of domain experts (e.g., experts in fluid dynamics), mathematical modeling experts, and experts from the field that is being used to construct the simulation system. In case modern digital computers are used to perform a simulation, the field of expertise for constructing a simulation system would be computer science and engineering. Other cases, for example, a full-scale flight simulation system, could involve expertise from almost every branch of engineering and robotics just to construct the simulation system.

A simulation is thus built using these three principal components; namely, (a) domain expertise, (b) mathematical modeling strategies, and (c) methodologies and technologies specific to the simulation system.

In modern times, digital computers have emerged as the preferred simulation system to perform simulations on. Usually, a mathematical model of the system under scrutiny is programmed into a computer and then run, and the behaviour of the model as observed in this simulation is used to make inferences about the real system that is being modeled and simulated. It appears that the use of computers saves costs because employing them in place of full-scale physical simulation systems reduces the engineering overheads (although the scientific principles at the base still need to be incorporated).

If we choose to use a computer to perform simulations, then its behaviour and properties as a simulation system must be “well-understood”: this implies that an academic programme designed around the use of computers as simulation systems of choice must have sufficient theoretical and practical content to ensure strong foundations in computation.
1.2 Need for a Programme in Modeling and Simulation

The rapid pace of advances in computer and computation-related technologies over last few decades and the ever-increasing availability of comparatively inexpensive raw computing power have encouraged the use of computation and simulation methods (via mathematical modeling) in all domains of the human enterprise where quantitative reasoning has a significant role to play. This includes all branches of the scientific and technological endeavour.

Typical degree programmes (such as a two-year Masters programme in physical sciences mathematics and statistics, or Bachelors/Masters programmes in an engineering discipline) often include an introductory course on programming, and perhaps another one on domain-specific computational methods. On the other hand, typical degree programmes in disciplines such as computer science and software engineering that are expected to develop good programming skills and computing expertise, do not focus on the mathematical foundations of modeling and simulation. As a result, a sound and solid foundation in all three aspects of modeling and simulation is usually impossible to develop during such degree programmes given their focus, workload, and constraints.

The M.Tech.(M&S), designed by the Centre, is geared towards creating a breed of problem-solvers with a breadth and perspective on modeling, solid training in simulation methods, good problem-solving skills and versatility and, finally, the ability to generate reasonable solutions for problems not necessarily encountered previously. Specifically, the Programme is expected to fill the gaps between, e.g.,

- a conventional degree programme and industrial R&D work requiring substantial background in modeling and simulation, and
- a conventional degree programme and a research (Ph.D.) programme involving extensive computational and simulational research.

We would like to emphasize that the M.Tech.(M&S) is a highly interdisciplinary programme that focuses on mathematical modeling formalisms and simulation methodologies by integrating applied mathematics, applied statistics, and applied computing in a coherent package. As such, this is not a programme in the traditional arena of computer science. This programme may, however, be thought of as a computational science programme.

1.3 Programme Design Considerations

1.3.1 From an Academic Perspective

As we saw earlier, a simulation is built on

- domain expertise,
- mathematical modeling formalisms and strategies, and
- methodologies and technologies specific to the simulation system.

A Master of Technology (M.Tech.) such as the present one may be designed such that at the successful completion of training, a student may be one of the following:

1. Converseant with the basic principles in all the three components, or
2. Converseant with basic principles in the mathematical and simulational components, but unaware of any domain expertise, or
3. Converseant with only the simulational components, but unaware of domain expertise and mathematical methods, or
4. Be **skilled**, as opposed to **conversant**, with the basic principles of all the three components, but be **aware/conversant** with a few advanced techniques from the three, or

5. Be **skilled**, as opposed to **conversant**, with the basic principles of mathematical and simulational components, but be **aware/conversant** with a few techniques from the first, or

6. Be **skilled**, as opposed to **conversant**, with the basic principles of simulational components, but be **aware/conversant** with a few techniques from the first and the second.

All possibilities other than those above are intuitively judged to be more intensive and hence most likely to be out of the time bound of a two-year programme with 1–1.5 year coursework. (1)–(3) have been included because given that the programme is a post-graduate degree programme, it may find favour to be licensed to outside entities for a wider spread. (4)–(6) are a set of levels of decreasing intensity, but admissible for a University post-graduate degree programme spanning 12-24 months. The alternative (4) is the most intense one, requiring active involvement of experts in all the three components, thus unsuitable for operation by the Centre in its current state.

Alternative (5) is the most practical alternative for the M.Tech.(M&S); we have thus designed a curriculum based on this alternative. Nevertheless, we would like to build provisions into the programme structure to offer specialized expert-level courses as and when domain experts become available. The reason for this design choice is threefold:

1. Although domain expertise is ultimately what is necessary for generating the best possible solution to a problem, specific domain expertise is very difficult to develop in a short span of 1.5 years (3 semesters) of coursework *in addition to* methodological training in the basics of mathematical modeling and computational simulation methods.

2. A prerequisite for admission in this programme is either a Master’s degree in any discipline or a Bachelor’s degree in Engineering, plus an adequate mathematical background, problem-solving and algorithmic thinking skills. We expect that students admitted to the programme will have some domain expertise in the area of their prior academic training programme.

3. We believe in developing strong problem-solving, algorithmic thinking and computational skills, and an interdisciplinary and problem-centric approach in our students which, coupled with broad background and training in mathematical modeling and computational simulation, should enable them to become *versatile*. By *versatility*, we mean

   - The ability to learn, and to develop domain-specific expertise in a new field as and when required; and
   - The ability to generate reasonable solutions (algorithmic/computational or otherwise) to a problem not necessarily encountered before.
   - The ability to make connections across domains so as to generate useful solutions.

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2This last alternative is most suitable for an institution like the Department of Computer Science, where the focus is quite different, and simulation is one part of the many aspects that need to be covered. We disregard this alternative for the M.Tech.(M&S).
1.3.2 From a Student’s Perspective

Most candidates tend to evaluate degree programmes from the point of view of job prospects and value addition. Employment opportunities for a graduate of the M.Tech.(M&S) are most likely to come from:

- R&D centres and analysis organisations (in the industrial, defense, academic, government, and other sectors), that use modern computational and simulation methodologies in their design, development, and research/analysis initiatives. Such initiatives include all areas of engineering, science and technology including (but not limited to) materials science and engineering, nanotechnology, bioinformatics and biotechnology, computational fluid dynamics, molecular modeling and drug design, process engineering, etc.

- Research- and computing-oriented support positions in research-and-analysis organisations.

- Research programmes leading to an advanced degree such as Ph.D.

Though some of our students may find careers in the IT-related and conventional software industry, that is not the focus of the M.Tech.(M&S). However, we envisage that the skill-set being developed through the M.Tech.(M&S), specifically, problem-solving and programming skills, and versatility, will enable a student to migrate easily to such careers.

1.4 Historical Underpinnings

The M.Tech.(M&S), as outlined in this document, has evolved from and incorporates considerable academic, logistic, and operational expertise and insights accumulated from the operation of the Centre’s existing academic programme, the Advanced Diploma Programme in Modeling and Simulation.

From another perspective, the M.Tech.(M&S) may be considered a thoroughly revamped and modernized version of an existing University of Pune M.Tech. Programme in Modeling and Simulation. This existing M.Tech. programme used to be run in collaboration with the Institute of Armament Technology (IAT), Pune. The IAT, which is now called Defense Institute of Advanced Technology (DIAT), is a Deemed University. The Centre for Modeling and Simulation, University of Pune, has modified, broadened, and thoroughly modernized the scope this somewhat dated programme so as to keep it in pace with modern developments in computing technologies and computational methodologies, and to promote an interdisciplinary computational approach to science, technology, and other fields of the human endeavour where quantitative reasoning plays any role.

1.5 Outline of This Document

The rest of this document is organised as follows. Sec. 2 states the specific objectives and the expected outcome of the Programme. Sec. 3 is devoted to eligibility and selection criteria. Sec. 4 presents the academic structure and curriculum of the M.Tech.(M&S). Finally, individual module wise syllabi are included in Sec. M in a semester wise order.
2 Specific Objectives and Outcomes

Assuming design alternative (5) in Section 1.3.1, we expect a graduate of the M.Tech.(M&S) to be the following after undergoing the training of the programme:

- She or he is a problem solver with a breadth and perspective on modeling, good training in computation and simulation methods, and the ability to generate reasonable solutions for problems not necessarily encountered earlier.
- Outside of his or her knowledge domain, (s)he is able to create a computer representation of a specific detailed description of the problem domain given that a domain expert has distilled the mathematical essence for him or her.
- She or he is up-to-date with the current state of relevant technologies, and from familiar to skilled in a variety of relevant software tools and methodologies.

3 The Prospective Student

Structure of the M.Tech.(M&S) is built around the assumption that a prospective student satisfies these three principal prerequisites:

- Domain expertise at least at the level of a B.E., B.Tech. or equivalent degree in any technological knowledge domain, or a Masters degree in a science, commerce or arts discipline in which quantitative reasoning plays a major role;
- A demonstrable background in mathematics at the level of the current University of Pune F.Y.B.Sc. mathematics syllabus. This is to be assessed via an entrance examination and the academic record (see Section 3.2 below); and
- Basic computer usage skills preferably with some programming experience and algorithmic skills. This is to be assessed via an entrance examination and the academic record (see Section 3.2 below).

Furthermore, it is crucial to select candidates with the right background and aptitude so that they are able to cope up with the vigorous and intensive nature of this programme. We thus propose the following eligibility and selection criteria for a prospective candidate who desires admission in the programme.

3.1 Eligibility

1. B.E. or equivalent in any branch of engineering OR Master’s degree in any science, arts, commerce discipline.

AND

2. Background in mathematics equivalent to the University of Pune F.Y.B.Sc. mathematics syllabus as ascertained via the applicable selection criterion below.

3.2 Selection

3.2.1 Regular Admissions

Selection Criteria. Candidates will be selected for regular admission in the programme on the basis of

1. Their academic record,
2. An entrance examination, and
3. A statement of purpose, if necessary.

The purpose of the entrance examination is to assess basic analytical, reasoning, and algorithmic skills, and the required mathematics background and computer literacy. Given the intensive and vigorous nature of the programme, it is essential to set the selection threshold on the entrance examination score appropriately, and to apply it to all candidates uniformly.

**Number of Seats.** Consistent with University of Pune rules, norms and policies on reservation, the Centre will select not more than 30 best or top-scoring candidates.

### 3.2.2 Industry-Sponsored Candidates

The Centre will welcome a small number of candidates sponsored by an industry or organisation every academic year. Interests of the sponsoring organisation in sponsoring a candidate could vary; however, we envisage the following as the most likely scenarios:

1. Primary interest of the sponsoring organisation and the candidate is in outsourcing the core training of the first 1.5 years (the first 3 semesters) of the programme, and the sponsored candidate is not necessarily interested in obtaining a degree certificate from University of Pune. In this case, a simple certificate of completion that includes the grade-point average (or some assessment of the performance of the candidate) issued by the Centre at the end of the first 1.5 years (the first 3 semesters) should suffice.

2. A sponsored candidate is indeed interested in completing the full programme and in obtaining a degree certificate from University of Pune at the end of the programme, and the sponsoring organisation is willing to support the candidate to that extent.

Therefore, the details of such admissions, including eligibility and selection, fee structure, *modus operandi* for the minimum 6-month project, etc., will need to be decided in consultation with the interested industry or organisation on a case-by-case basis without compromising on the spirit, intensity, and depth of the programme.

### 3.2.3 Foreign Candidates

The Centre will welcome a small number of applications from foreign candidates every academic year, consistent with the policies, norms, and guidelines of the University of Pune. Given that a centralized evaluation mechanism (similar to GRE, AGRE, etc.) for admission into Indian Universities does not exist, we propose to make a decision about admission of a foreign applicant in the programme on a case-by-case basis, so as to ensure that the background and abilities of the applicant are appropriate, and that the spirit, intensity, and depth of the programme is not compromised upon.
4 THE CURRICULUM

4 The Curriculum

Programme Content. As discussed in Sec. 1.3, design alternative 5 is the most suitable alternative for this programme. As a consequence, the curriculum of the M.Tech.(M&S) focuses almost exclusively on methodologies from the mathematical modeling and simulation domains. Broadly speaking, practical and often-used mathematical modeling and simulation methodologies have been developed in the field of Applied Mathematics and Applied Statistics. Constructing a simulation on a modern digital computer, on the other hand, needs a detailed knowledge of computing technologies, computation in general, and, to make things work, programming. The M.Tech.(M&S) curriculum can be thought of, to a good approximation, as a mixture in equal parts of Applied Mathematics, Applied Statistics, and Computing.

Timeline. The first 3 semesters (initial 1.5 years) of this programme are devoted to coursework consisting of 15 core courses and 2 specialized electives. In the fourth semester (second year) of the programme, a student is expected to undergo hands-on, rigorous, and application-oriented training involving substantial independent work in the form of a project (same as internship or industrial training). The required duration for a project is six months. However, more extensive and longer-than-six-months projects are allowed.

Curriculum Organisation. We have envisioned a hierarchical organisation of academic curricula in which an academic programme consists of courses which in turn consist of modules. A module is an instructional unit that consists of subject matter related to a single topic at the intended level for the target audience. In other words, a module is a logical entity of subject matter organisation that cannot be broken up further into smaller pieces in a meaningful fashion. Modules can thus be shared, in principle, across academic programmes targeted at similar audiences. A course consists of one or more modules organised around a coherent theme. Course codes used in this document are of the form CMS-MT-Nnn, where CMS stands for Centre for Modeling and Simulation, MT for M. Tech., N for the Semester in which the course is offered, and nn is a unique number assigned to a course.

Organisation of this Section. This section presents a crisp overview of the academic structure of the M.Tech.(M&S) in the full-time mode. In Sec. 4.1–4.6, we present a semester wise summary of the curriculum: To highlight the structure, we have relegated detailed module wise syllabi to Sec. M. The last column of the semester wise tabular summaries indicates section numbers for individual module wise syllabi and rationales. In Sec. 4.7, we present the rationale and outlook on each course-theme individually.
## 4.1 Structure at a Glance: Semester 1 (Year 1)

<table>
<thead>
<tr>
<th>Course Name</th>
<th>Credits</th>
<th>Rationale Section</th>
</tr>
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4.2  Structure at a Glance: Semester 2 (Year 1)

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4.3 Structure at a Glance: Semester 2 (Year 1) Electives

Apart from these electives, student may choose electives from other departments (with prior approval of CMS and the concerned department).

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Structure at a Glance: Semester 2 (Year 1) Electives

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### 4.4 Structure at a Glance: Semester 3 (Year 2)

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4.5 Structure at a Glance: Semester 3 (Year 2) Electives

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## Structure at a Glance: Semester 3 (Year 2) Electives

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4.7 Rationale for Individual Course Themes

4.7.1 Computing

**Course Code/s:** CMS-MT-101, CMS-MT-201, CMS-MT-301.

**Rationale and Outlook.** A solid background in basic computing methodologies and software technologies, together with ample hands-on experience, is essential to be able to work with one’s own hands and effectively utilize the training imparted in the rest of the Programme.

4.7.2 Perspectives on Mathematical Modeling

**Course Code/s:** CMS-MT-102, CMS-MT-202, CMS-MT-302.

**Rationale and Outlook.** The utility of Applied Mathematics as a formalism for modeling needs no justification. This group of modules is intended to cover areas of Applied Mathematics most commonly encountered in modeling and simulation contexts.

In order to emphasize the modeling perspective and maintain focus on applications, we suggest a three-component structure for each of these modules; this structure consists of: (a) basic theory and pertinent mathematical results, (b) perspective on modeling by way of real-life contexts, examples and applications, and (c) relevant numerical methods.

At the discretion of the instructor, a tutorial on matlab/octave could be included in this course. Use of a computing environment such as matlab/octave has the advantage of letting a student without refined programming skills to focus on the mathematics and the modeling context of a topic. However, we recommend that at least a part of the computational exercises should be geared towards enhancing the student’s programming skills in a low-level, imperative language such as C.

4.7.3 Perspectives on Probability Modeling

**Course Code/s:** CMS-MT-103, CMS-MT-203, CMS-MT-303.

**Rationale and Outlook.** Probability is the mathematical language for quantifying uncertainty or ignorance, and is the foundation of statistical inference and all probability-based modeling.

In order to emphasize the modeling perspective and maintain focus on applications, we suggest a three-component structure for each of these modules; this structure consists of: (a) basic theory and pertinent mathematical results, (b) perspective on modeling by way of real-life contexts, examples and applications, and (c) relevant numerical methods.

At the discretion of the instructor, a tutorial on R could be included in this course. Use of a computing environment such as R has the advantage of letting a student without refined programming skills to focus on the mathematics and the modeling context of a topic.

4.7.4 Technical Communication

**Course Code/s:** CMS-MT-104, CMS-MT-204.

**Rationale and Outlook.** This group of courses aims at developing

1. resourcefulness, independence, self-study and time-management skills,
2. the ability to read technical and research literature, and finally,
3. proficiency in making effective technical presentations.
During the second course, a student is expected to take on an independent study of a topic that is not studied by him or her before, learning enough about it to be able to write a technical report (term paper) and make an oral presentation.

4.7.5 Overview of M&S


Rationale and Outlook. Since the rest of the curriculum focuses primarily on methodological aspects of M&S, it is highly desirable to include courses that attempt at developing a perspective on

1. the wide world of M&S as a whole,
2. the process of going from a problem to a simulation/computation via a model,
3. common pitfalls, sanity checks, etc., and
4. the “art” aspects of mathematical modeling by way of examples

These two courses are expected to strike a balance between generalities and specific examples, between stochastic and deterministic models, and between describing finished work and actual hands-on modeling on the part of a student. These two courses can be thought of as the heart of this programme, as they attempt to put the diversity of topics in the Programme curriculum in a unified perspective. Given the diversity of the M&S enterprise, these courses are expected to be pedagogically most demanding and a challenge to the instructor.

4.7.6 Fundamentals

Course Code/s: CMS-MT-106.

Rationale and Outlook. This group of modules serves to (a) to establish a common denominator for mathematical training keeping in mind the students’ diverse and nonuniform mathematical training, (b) to equip the student to read through, and to be able to grasp, elementary mathematical treatment of specialized topics, (c) to cover common mathematics prerequisites of other modules, and (d) to generate a broad perspective on mathematical modeling and computational simulation.

4.7.7 Project Management

Course Code/s: CMS-MT-304.

Rationale and Outlook. This full 5-credit course is intended as a hands-on preparation for the 4-th semester project/internship/industrial training. Here, a student is expected to exercise his or her M&S skills by taking up a sufficiently complex real-life problem, making appropriate analysis and modeling decisions to come up with a useful model of the underlying system, and eventually extract relevant information about the system possibly through the use of computation and simulation. This course is intended as a testing ground where qualities that matter for a modeler, namely, independence, resourcefulness, thoroughness, innovativeness in building (mathematical) models, and computational skills, are put to a thorough and rigorous test.

This course may be thought of as an in-house project. However, a project in close collaboration with an external organisation may be allowed with the approval of the Centre’s academic team, after a realistic assessment of the feasibility of such a project.
4.7.8 Elective


**Rationale and Outlook.** Given the core training of the first two semesters, a student is expected to be in a position to assimilate material from advanced, specialized, or domain-specific elective modules of his or her choice. The choice and syllabi of elective modules offered may vary from year to year depending on the availability of specialist instructors. Elective modules could be organised around a variety of loosely-defined themes:

- **Methodology-Oriented Electives.** The focus here is on advanced methodologies or technologies. Examples are:

- **Formalism-Oriented Electives.** A formalism-oriented elective attempts to develop somewhat deeper understanding of a specific mathematical formalism. Examples of this kind are
  2. Theory of Computation.

- **Domain-Oriented Electives.** A domain-oriented elective is one that develops domain-specific formalisms for modeling and simulation, and illustrates them via real-life problems, models, and applications. Examples of this kind are
  1. Computational Fluid Dynamics.
  2. Computational Materials Modeling.
  5. Evolutionary and Agent-Based Modeling in Social Sciences.
  7. Six Degrees of Separation: an Introduction to Networks.

Sample syllabi by for some of the above electives are included in Appendix M.4.

**Policy on Failure in an Elective.** Instructors for electives are likely to come from other departments on the campus, from non-University organisations, or from the industry. As such, instructors for electives may not be available for re-examinations in case a student fails in an elective. In general, such a student needs to opt afresh for an elective offered during the next academic year. We, however, suggest that (s)he may be given one chance, if possible, to be evaluated on the same elective (in which (s)he failed) during the upcoming semester.
4.7.9 Project (Internship/Industrial Training)

Course Code/s: CMS-MT-41.

Rationale and Outlook. Given the highly applied nature of the M.Tech.(M&S), it is natural to emphasize substantial hands-on, independent work in the form of a project or industrial training. We have thus included a heavy, full-time project component of minimum 6-month duration. There is no fixed syllabus for this module; what is expected is substantial hands-on work in consultation with a project advisor on the chosen project topic.

Modus Operandi. Project advisor and the project topic needs to be approved by the academic team at the Centre for Modeling and Simulation, University of Pune. The project duration may be extended beyond the formal requirement of the M.Tech.(M&S) (i.e., 6 months minimum) by mutual agreement between a student and his/her project advisor, and subject to approval by the Centre’s academic team. Ideally, a student should begin his or her search for a project (and a suitable project advisor) in the second semester (first year) of the programme. Networking with the industry on part of the Centre needs to be initiated sufficiently early on. Project work should begin on day one of semester 4 (year 2) with full gusto.

Prerequisites. A student is allowed to go for a project in the fourth semester (second year) provided (s)he has at least a passing grade in at least 30CR worth of course work of the first year.

Evaluation. Evaluation of a project is based on (a) a written report, (b) a presentation cum open defense, and (c) continuous evaluation by the project advisor and the Centre’s academic team throughout the project duration.
M Modulewise Syllabi

M.1 Semester I Modules

M.1.1 Programming for Modelers I

Contact Hours: 50  Prerequisites: None

Syllabus

1. Introduction to Python. The interpreter. Simple expressions and calculations. More complex data types (e.g. Strings, Tuples, Lists, Dictionaries). Expressions involving complex data types. List comprehension. Interconversions between various data types.


Suggested Texts and References

- Online Python documentation at http://www.python.org/doc/

Syllabus contributed by Abhay Parvate
M.1.2 Practical Computing I

**Contact Hours:** 20

**Prerequisites:** None

**Syllabus**

1. **Linux Preliminaries.** Logging in and out. Passwords. Files and directories; path and filename conventions. Controlling access to files and directories. Shell and shell facilities. Environment variables. Emails and the internet; etiquette and guidelines on acceptable use. Various editors; in particular vi and emacs. Shell scripting: creating your own commands. Tasks of an operating system.


**Suggested Texts and References**

- A variety of online resources such as Unix/Linux man and info pages, internet resources, etc.

Syllabus contributed by Abhay Parvate

M.1.3 Finite-Precision Arithmetic

**Contact Hours:** 5

**Prerequisites:** None

**Syllabus**


3. **Finite-Precision Arithmetic with Floating-Point Numbers.** How elementary arithmetic operations are performed. Subtraction and loss of precision. Illustrative examples.

4. **A User’s Perspective on IEEE 754.** The IEEE 754 specification. All about NaNs and Infs. Tracking floating-point exceptions. Outlook on IEEE 754.

**Suggested Texts and References**


Syllabus contributed by Mihir Arjunwadkar
M.1.4 Introduction to Matlab/Octave

Contact Hours: 5  
Prerequisites: None

Syllabus

- The `matlab/octave` programming language and the `matlab/octave` computing environment.

Suggested Texts and References

- A large number of resources available over the internet.

Syllabus contributed by Mihir Arjunwadkar

M.1.5 Ordinary Differential Equations

Contact Hours: 35  
Prerequisites: M.1.11, M.1.12, M.1.13, M.1.3, M.1.4

Syllabus

1. A brief introduction to Functional Analysis.
3. General analytic solutions for first order differential equations with variable coefficients, and higher-order linear ODEs with constant coefficients.
4. Higher-order differential equations in brief. Their connection to first-order systems of ODEs.
5. The stability of 2-D systems of first order linear ODEs linearization of non-linear systems. Liapunov functions and their use in determining stability of general ODEs.
6. The numerical initial value problem for \( n \)-dimensional systems. Numerical methods. Classification into single-/multi-step, explicit/implicit. Definition of the order of the method. Definition of the method’s stability region. Predictor/corrector methods and the use of the error predictor inherent to these methods. Adams-Moulton schemes (implicit and explicit) Runge-Kutta schemes along with their derivation for second and third order. Advantages and disadvantages of these methods. Stiff ODEs and their inherent problems: stiffness, definition of absolute and stiff stability, several methods particularly suited for stiff ODEs such as certain extrapolation methods (e.g. Gear’s method).
7. The definition of the ODE boundary value problem. Numerical methods suited for its solution. The shooting method (especially for non-linear problems) and finite difference methods (predominantly for linear problems).
8. A brief introduction to expansion methods (finite element and spectral methods).

Suggested Texts and References


Syllabus contributed by William B. Sawyer
M.1.6 Partial Differential Equations

Contact Hours: 35

Syllabus

1. Classification of PDEs: hyperbolic, parabolic, elliptic; stationary, non-stationary; Eulerian, Semi-Lagrangian formulations; initial- and boundary-value problems.

2. Hyperbolic problems, one-dimensional advection equation. Simple finite-difference methods, stability and convergence using Von Neumann’s (Fourier’s) method.

3. First order, second order, and higher order schemes in space and time.

4. Solving parabolic and elliptic problems using finite differences. The linear wave, heat diffusion, and Laplace equations. Various alternative techniques, such as the Method of Lines.

5. A brief introduction to finite volume methods, conservative methods, the shallow water and Euler equations.

6. Analytic solutions to linear PDEs using the method of separation of variables and Fourier analysis.

Notes

- This module deals primarily with the numerical treatment of partial differential equations (PDEs).

Suggested Texts and References

- The course text “Numerical Solution of Partial Differential Equations”, given in the Fourth Year of Honours Mathematics at the University of Glasgow, contains much of the material given in this module. In particular, there is a good treatment of the Fourier Method for stability analysis (referred to in this module as the Von Neumann Method).

- An good discussion of Finite Difference methods for PDEs can be found in Chapter 3 of the excellent on-line book by Nick Trefethen: “Finite Difference Methods”. This text has not yet been completed by the author, so there are many omissions.

- The lectures on the numerical treatment of PDEs can be based on Chapter 13 of H. M. Antia, Numerical Methods for Scientists and Engineers. Hindusthan Book Agency (second edition, 2002).

- The lectures on analytic solutions to PDEs can be based on Richard Haberman, Elementary Applied Partial Differential Equations. Prentice-Hall, Inc. (Second Edition, 1987). This is an outstanding introduction to the method of Separation of Variables, Fourier Analysis, the treatment of linear PDEs for various domains, Green’s functions, etc.

Syllabus contributed by William B. Sawyer

M.1.7 Introduction to R

Contact Hours: 37

Syllabus

- The S programming language and the R computing environment.
Suggested Texts and References

- A large number of resources available over the internet.

Syllabus contributed by Mihir Arjunwadkar

M.1.8 Probability Theory

Contact Hours: 38

Prerequisites: M.1.11, M.1.7

Syllabus

4. Inequalities for Probabilities and Expectations.

Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.1.9 Technical Reading, Writing, and Presentation

Contact Hours: 30

Prerequisites: None

Syllabus

1. Making Effective Presentations. Importance of being confident, of getting over stage fright, of eye contact. Clarity of expression, need for good language skills. Audience analysis. Anticipating and handling questions from audience. Listening to the audience. Primer on information design and its cognitive impact. Presentation slides.
2. English as a Second Language. Exercises designed to develop a functional understanding of the grammar and correct usage of English; e.g., on adjectives and adverbs, articles (*a*, *an*, *the*), appositives, prepositions, pronouns, relative pronouns, verb tenses, irregular verbs, two-part (phrasal) verbs (idioms), verbals: gerunds, participles, and infinitives; punctuation, capital letters, numbers; sentence clarity, sentence fragments, independent and dependent clauses, dangling modifiers, sentence punctuation patterns, subject/verb agreement, etc.; on pronunciation, spelling conventions, diction, vocabulary, and etymology; on text-level as against sentence-level grammar.
3. **Resource Hunt and Technical Reading.** Evaluating sources of information, resources for documenting sources in the disciplines, searching the world wide web, documenting conventional and electronic sources of information. Fast reading and comprehension of key ideas. Making sense out of technical documents (research papers, technical reports, manuals, etc.).


**Notes**

- This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.
- This is basically a remedial and need-based module to enhance the communication skills and proficiency in English of an average Indian student. Thus, e.g., learning grammatical terminology is not important. What is important is, e.g., learning correct usage of English, developing good communication skills, and moreover, developing an attitude and outlook that will help a student improve him(her)self.

**Suggested Texts and References**

- The Online Writing Labs (OWL) family of websites [http://owl.english.purdue.edu/](http://owl.english.purdue.edu/); specifically, [http://owl.english.purdue.edu/workshops/hypertext/](http://owl.english.purdue.edu/workshops/hypertext/)
- Books by Edward Tufte; specifically, *Visual Explanations, Envisioning Information, Beautiful Evidence*, and *Visual Display of Quantitative Information*. See also: *The

Syllabus contributed by Abhay Parvate and Mihir Arjunwadkar

M.1.10 Overview of M&S I

Contact Hours: 45  Prerequisites: None

Syllabus


2. The Life Cycle of a Model. Problem = a question about a system waiting to be answered. The modeling life cycle: problem → model → infer behaviour of the model → validation against reality → refined model → ... Formulation of a model: abstraction, qualitative vs. quantitative, stochastic vs. deterministic, etc. Deciphering the behaviour of the model: analytical reasoning and mathematical analysis, approximation, numerical computation, simulation: computational and non-computational. Handy tools for mathematical modeling: dimensional analysis, scaling, conservation laws and balance principles, ... Parsimony and Occam’s razor: choosing the best from multiple models for the same problem. The dark side: misuses of models (See Bender in Suggested Texts and References below).

3. Case Studies in Modeling. A wide range of case-studies from diverse fields of science and technology that illustrate (a) the spirit of mathematical modeling and the “art” aspects of the modeling process, (b) the use of a number of formalisms of applied mathematics and applied statistics (deterministic and probabilistic), and (c) the problem-oriented outlook and multidisciplinary approach.

Notes

1. Please see Sec. 4.7.5 for the rationale of this and the companion course Overview of M&S II. This duo is expected to be pedagogically the most challenging pair of courses in this programme. As such, these courses would need to be handled in the most delicate fashion by the instructor. Substantial preparation would be needed given that these two courses are expected to convey the spirit of mathematical modeling in the most coherent manner, through a proper mix of discussion on principles with aptly chosen case-studies from diverse fields, thus putting the methodological training of the rest curriculum in a unified perspective.

2. The syllabus above is only indicative of the topics to be discussed in these two courses. Arguably, two instructors with distinct backgrounds may wish to accomplish the goals of these two courses following very different pedagogic paths.

3. A huge amount of useful literature on M&S is available in the form of books, lecture notes, tutorials, etc. The list of Suggested Texts and References below is again only indicative of its diversity.

4. The division of course material across these two courses is again left to the instructor.
Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.1.11 Basics of Analysis

Contact Hours: 15  
Prerequisites: None

Syllabus


Suggested Texts and References


Syllabus contributed by Abhay Parvate
M.1.12 Vector Analysis

Contact Hours: 15  Prerequisites: M.1.11, M.1.14

Syllabus


Suggested Texts and References


Syllabus contributed by Abhay Parvate and Mihir Arjunwadkar

M.1.13 Complex Analysis

Contact Hours: 15  Prerequisites: M.1.11

Syllabus


**Suggested Texts and References**


Syllabus contributed by Mihir Arjunwadkar

### M.1.14 Linear Algebra

**Contact Hours: 30**  
**Prerequisites:** None

**Syllabus**

6. **Determinants.** Properties of determinants.

**Suggested Texts and References**


Syllabus contributed by Mihir Arjunwadkar

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**M.2 Semester II Modules**

**M.2.1 Programming for Modelers II**

**Contact Hours: 50**

**Prerequisites:** M.1.1, M.1.3

**Syllabus**

- A programming language and/or environment suitable for modeling and simulation, and commonly used in industry or academics. Choice during a particular academic year depends upon current industry standards, preferences of the students, and availability of instructors. A few possible choices are C, C++, C#, and Fortran.

**Suggested Texts and References**

- As recommended by the instructor for this module and the specific language.

Syllabus contributed by Abhay Parvate and Mihir Arjunwadkar

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**M.2.2 Practical Computing II**

**Contact Hours: 25**

**Prerequisites:** M.1.2

**Syllabus**

1. **Programming in the Linux Environment.** Compilation and interpretation: Stages, units (source files, object files, etc.), libraries. Distinction between standards and implementations. Running programs in background, nice values. Scripting Tools and Languages (awk, sed, etc.).


**Suggested Texts and References**

- A variety of online resources such as Unix/Linux man and info pages, internet resources, etc.

Syllabus contributed by Abhay Parvate
M.2.3  A Survey of Numerical Mathematics

Contact Hours: 37  Prerequisites: M.1.11, M.1.12, M.1.1, M.1.3

Syllabus

1. Miscellaneous Topics in Numerical Mathematics. Topics of practical importance that are not covered elsewhere in the curriculum, such as: function approximation, interpolation, integration, nonlinear algebraic equations, integral equations.

Notes

• This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.

Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.2.4  Optimization

Contact Hours: 37  Prerequisites: M.1.11, M.1.12, M.1.14, M.2.1

Syllabus

1. Computing Guidelines. Coding style recommendations for efficient large-scale numerics: code organization, modularity and reusability; readability and self-explanatory documentation; making assumptions explicit; printing floating-point numbers. GSL, BLAS and LAPACK. Visualization in 2D and 3D: contours, surfaces, isosurfaces; visualization tools.

2. Preliminaries. Why optimize? A survey of optimization problems and their modeling contexts; system/behaviour → model or formulation as an optimization problem, the objective function, domain of the objective function, applicable optimization methods. Some terminology (with lots of pictures): a minimizer, local and global minima, constrained and unconstrained minimization,


**Suggested Texts and References**


Syllabus contributed by Mihir Arjunwadkar

**M.2.5 Stochastic Simulation**

**Contact Hours:** 37  
**Prerequisites:** M.1.8, M.1.1, M.1.3

**Syllabus**

1. **A Tutorial on R.**
2. **Randomness.** When do we perceive a sequence of objects as being random? Randomness, complexity, unpredictability, and ignorance. Cognitive biases. Randomness in natural processes: decaying nuclei, chaotic oscillators, leaky faucets, cosmic ray showers, ...
3. **Simulating Randomness.** Generating sequences of numbers that appear random. Uniform pseudo-RNGs: properties, breaking correlations by shuffling, the Mersenne Twister, simple transformations from the Uniform. Other distributions as transformations from the Uniform: transformations of random variables, strictly monotone transformations of the Uniform, graphical illustration of the transformation method, exponential, Cauchy, ..., $N(0, 1)$ using the Box-Müller method, $\chi^2_p$ from $N(0, 1)$. Arbitrary distributions and acceptance-rejection sampling: sampling the area below a curve uniformly, $N(0, 1)$ using Cauchy as the envelope. Testing for randomness: how random is random enough? RNGs based on natural processes. Correlated random numbers: normal random numbers with prespecified correlations, Nataf transformation.
4. **Monte Carlo Integration.** Estimating $\pi$ and $\log(x)$ using a dartboard. Estimating one-dimensional integrals: basic MC integration. Importance sampling: better estimators, tighter errorbars.


**Suggested Texts and References**


Syllabus contributed by Mihir Arjunwadkar

**M.2.6 Reasoning Under Uncertainty**

**Contact Hours: 38**

**Prerequisites:** M.1.8

**Syllabus**

1. **Models, Statistical Inference and Learning.** Parametric and nonparametric models. Fundamental concepts in inference: point estimation, confidence sets, hypothesis testing.


Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.2.7  Term Paper

Contact Hours: 30  Prerequisites: M.1.9

Syllabus

- There is no fixed syllabus for this module. The Term Paper is an exercise in (a) developing independence, resourcefulness, and literature survey skills, (b) developing perspective on a topic not studied before and understanding the state-of-the-art in the chosen term paper topic through literature survey and internet search, and (c) developing presentation skills, in consultation with an in-house term-paper adviser (and possibly an external expert) on the chosen topic. Evaluation to be based on a written report plus a presentation cum open defense. Please refer to Sec. 4.7.4 for a discussion on the term paper.

Suggested Texts and References

- No Texts. Resource hunt and reading work as recommended by the project adviser.

Syllabus contributed by Mihir Arjunwadkar

M.2.8  Overview of M&S II

Contact Hours: 45  Prerequisites: M.1.10

Notes

1. See the syllabus for the sister course Overview of M&S I (Sec. M.1.10) for a detailed discussion of this pair of courses. The division of this suggested course material across these two courses is again left to the instructor.

Syllabus contributed by Mihir Arjunwadkar

M.3  Semester III Modules

M.3.1  Practical Computing III

Contact Hours: 50  Prerequisites: M.2.1

Syllabus

- Java for Modelers.
- The Eclipse Development Environment.
- The .NET Framework. .NET and Mono. .NET vs. Java.
Suggested Texts and References

- Texts/references to be recommended by the instructor.
- Eclipse project website: http://www.eclipse.org/
- Mono project website: http://www.mono-project.com/
- .NET developer’s centre: http://msdn.microsoft.com/netframework/

Syllabus contributed by Abhay Parvate

M.3.2 High-Performance Computing

Contact Hours: 25

Prerequisites: M.2.1

Syllabus


3. Programming for Parallel Computing. Shared memory parallel computers and programming with OpenMP. Distributed memory parallel computers and message passing basics with MPI. Advanced message passing with MPI.


Notes

- Ideally, upon successful completion of this module a student should be able to: design a parallel algorithm for distributed or shared memory machines, implement a parallel algorithm on a collection of networked workstations using MPI, implement a parallel algorithm on supercomputers using MPI (distributed memory) and OpenMP (shared memory), analyze the performance of parallel algorithms using a variety of performance measures/tools, describe conceptually the various paradigms of parallel computing, and report on the diverse applications of parallel and high performance computing in diverse fields such as science, engineering, technology, finance, etc.

- This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.
Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.3.3 Numerical Linear Algebra

Contact Hours: 37 Prerequisites: M.1.11, M.1.12, M.1.14, M.1.1, M.1.3

Syllabus


Notes

• This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.

Suggested Texts and References


Syllabus contributed by Mihir Arjunwadkar

M.3.4 Transforms

Contact Hours: 38

Prerequisites: M.1.11, M.1.12, M.1.13, M.1.14, M.2.1

Syllabus

1. **Background and Overview.** Function spaces in engineering and science. Integral transforms as linear operators on function spaces and as metric products on basis vectors. Domain and co-domain of transform, integral limits. Inverse transform and its limits. Special functions and transforms involving orthogonal functions.


3. **The Laplace Transform.** Laplace transform, inverse transform, linearity. Laplace transforms of derivatives and integrals. Shifting the $s$- and $t$-axes; unit step function. Differentiation and integration of transforms. Convolution. Partial fractions. Applications along with their modeling contexts: e.g., periodic functions, LCR circuit equations, spring-dashpot model for polymers, etc.


5. **A Plethora of Other Integral Transforms.** Hartley transform as modified Fourier transform. Mellin transform and its Scaling and exponential sampling properties; Mellin transforms in image and audio processing. Bessel functions and the Hankel transform, and its applications in cylindrical symmetry and axisymmetry, cylindrical electromagnetic waves, small angle X-ray scattering, etc. Abel transform and axial symmetry; geometrical interpretation as a projection of a 3D image on a plane. Hough transform in image analysis for identifying objects like lines, circles, etc. Radon transform as integration along a line, applications in cross-sectional images using CAT scans, hyperbolic differential equations, tomographic reconstruction, projection slice theorem, inverse radon transform and its sensitivity to noise. Hilbert transform and signal processing, filtering out negative frequency modes, amplitude modulation and demodulation, amplitude envelope followers and Hilbert transforms.


Notes

- This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.

Suggested Texts and References


Syllabus contributed by Sukratu Barve and Mihir Arjunawdkar

M.3.5 Statistical Models and Methods

Contact Hours: 37

Prerequisites: M.2.6

Syllabus


3. Inference about Independence. Two binary variables. Two discrete variables. Two continuous variables. One continuous variable and one discrete variables.


Suggested Texts and References


M.3.6 Stochastic Optimization and Evolutionary Computing

Contact Hours: 38

Prerequisites: M.1.8, M.2.1, M.2.5

Syllabus


2. Monte Carlo Methods. Detailed discussion of random walk, simple Monte Carlo, Metropolis Monte Carlo, and simulated annealing for the two problems. Comparison of these methods in terms of dynamics and acceptance criteria.


5. Ant-Colony Optimization. Ants finding the shortest path and pheromone trails. Ant-colony algorithms. Application to TSP.

Notes

- This syllabus as outlined above should be considered indicative of the focus of the module. Selection of topics and emphasis may be varied at the discretion of a competent instructor.

Suggested Texts and References


Syllabus contributed by V. Sundararajan

M.3.7 Elements of Management

Contact Hours: 30  
Prerequisites: None

Syllabus


Syllabus contributed by C. M. Chitale and Supriya Patil

M.3.8 M&S Hands-On

Contact Hours: 45  
Prerequisites: As decided by the Instructor/s

Syllabus

- No fixed syllabus: Please refer to Sec. 4.7.7 for the outlook on this course.

Syllabus contributed by Mihir Arjunwadkar
M.4 Elective Modules: Sample Syllabi

M.4.1 Computational Fluid Dynamics

Contact Hours: 75  Prerequisites: As decided by the instructor/s

Syllabus

1. **Elementary Concepts.** Background space, coordinate systems. Fields, scalars, vectors, tensors, transformations, distance metric. Concepts of vector calculus (flux, line integral, Gauss and Stokes theorems). Index notation and Einstein convention. Total derivative, integral curves, velocity field and co-moving derivative.


3. **Constitutive Relations.** Introduction. Thermodynamic stimulus and response, rate of response. Darcy’s, Fourier’s, Ohm’s and Fick’s laws, Hooke’s law, Newton’s law of viscosity. Shear, rotation and dilation of velocity field, Navier-Stokes equation, boundary conditions and their importance.

4. **Examples of Flow.** Hagen-Poiseuille flow, Couette flow and other special cases.


8. **Application to Multiphase Flows.**

9. **Higher-Order Methods for CFD.**


11. **Problem-Solving Through CFD.** Implementation of codes in CFD. Computational environments for CFD (such as Phoenix).

12. **Advanced Fluid Dynamics.** Intermediate structures like vortices, boundary layers, shocks, waves and caustics, stream filaments.

13. **Numerical Methods.** Grid generation techniques for structures and unstructured grids.

14. **Hands on.** OpenFOAM architecture, solvers cases and utilities. Writing cases and solvers. CFDEXpert problems.

**Suggested Texts and References**


Syllabus contributed by Sukratu Barve and Prof. K. C. Sharma
M.4.2 Machine Learning

**Contact Hours: 75**

**Prerequisites: As decided by the instructor/s**

**Syllabus**


2. **Computational Environments for Machine Learning.** Setting up of modeling frameworks (Weka, Orange and R), I/O formats, basic introduction to interfaces.


4. **Supervised Learning.** Additive model: logistic regression. Generative model: naïve Bayes classifier. Discriminative model: neural network (NN) and support vector machine (SVM). Laboratory: models using Weka or Orange on UCI benchmark data sets. Writing interfaces for a classifier as derived from a learner.


6. **Reinforcement Learning.**

7. **Ensemble Methods.** Boosting and bagging.

8. **Intelligent Agents.**

**Suggested Texts and References**


Syllabus contributed by Ashutosh

M.4.3 Geographic Information Systems

**Contact Hours: 75**

**Prerequisites: As decided by the instructor/s**

**Syllabus**


3. Digital Representation of Geographic Data. GIS data Sources. GIS data models. GIS data manipulation.


7. Customization. Introduction to customization. Introduction to GIS Application Development. Internet GIS.

8. Project Work.

9. Practical Sessions related to the above topic using open source GIS software. KOSMO DESKTOP GIS. Quantum GIS. SAGA.

Syllabus contributed by Gauri

M.4.4 Modeling for Materials Science and Engineering

Contact Hours: 75

Prerequisites: As decided by the instructor/s

Syllabus


2. Materials Modeling at different length scales.

3. Materials design, high-throughput computations and data mining.

4. Engineering Aspects.

5. Open-source simulation software.

6. Materials for different usages based on their electronic properties (3 of these can be taken at any one time). for energy harvesting, storage and conversion. for high-performance electronic, optical and magnetic materials. nanoscience, nanotechnology and nanomaterials. biological and biomimetic materials. pharmaceutical materials.

7. Phenomena to be understood for different usages based on the mechanical properties. fractures and their propagation. hardness. coatings.

Syllabus contributed by Anjali Kshirsagar

M.4.5 Theory of Computation

Contact Hours: 75

Prerequisites: As decided by the instructor/s

Syllabus

1. Theory of Computation as a Modeling Formalism. Symbolic dynamics of dynamical systems, biological sequence analysis and stochastic grammars, computational musicology, etc.


5. **Turing Machines.** Examples which are not context free. Chomsky hierarchy. Another look at symbolic dynamics and coding theory for examples of dynamical systems in various levels of Chomsky hierarchy. Computing with dynamical systems. Functions with “external memory” and Turing machines. Computing with Turing machines. Extensions of Turing machines. Random access Turing machine. Non-deterministic Turing machines. Chaotic systems as Turing machines.


**Suggested Texts and References**


Syllabus contributed by Ashutosh and Abhijat Vichare

**M.4.6 Traffic Modeling**

**Contact Hours: 75**

**Prerequisites:** As decided by the instructor/s

**Syllabus**

1. Microscopic, Mesoscopic and Macroscopic modeling methos for traffic.
2. Stream parameters for traffic problems. Density, Flow, Speed,
3. Kerner’s three phase theory.
4. Nagel Schrekenberg Model.
5. Payne-Whitham Model.
6. Aw-Rascle Model.
8. Comparison of vehicular and other traffic like network and telecom.
9. Analogies between traffic, granular flow and suspension dynamics.

Syllabus contributed by Sukratu Barve

M.4.7 Public Transport System Modeling

Contact Hours: 75  
Prerequisites: As decided by the instructor/s

Syllabus

1. Introduction.
2. Alternative services and models.
3. P T Organizational models.
4. Service planning process.
5. Data Collection.
7. Ridership forecast.
8. Fare.
9. Vehical and crew scheduling.
10. Transit signal priority.
11. Real time control Strategies.

Syllabus contributed by Sukratu Barve

M.4.8 Logistical and Transportation Modeling

Contact Hours: 75  
Prerequisites: As decided by the instructor/s

Syllabus

1. Functions of random variables.
2. Queuing system.
3. Congestion pricing.
4. Spatial Queue.
5. Networks.
6. TSP Heuristics.

Syllabus contributed by Sukratu Barve

M.4.9 System Optimization and Analysis for Manufacturing

Contact Hours: 75  
Prerequisites: As decided by the instructor/s

Syllabus

1. Introduction and Overview.
2. Linear Programing.
3. Integer programing.
5. Simulation and stochastic modeling.
6. Monte-Carlo theory.
8. Discrete event theory. framework and examples, experimental design and simulation analysis.

M.4.10 Financial Modeling and Optimization

Contact Hours: 75
Prerequisites: As decided by the instructor/s

Syllabus

3. Basic ideas of risk analysis.
7. Software Used. Learn to use state of the art optimization and simulation software including the following: Excel and the Excel Solver for optimization, @RISK for Monte Carlo Simulation, Precision Tree for Decision Tree analysis, The GAMS algebraic modeling language.

This software, and the concepts underlying it, has applications in all areas of business.

Suggested Texts and References


M.4.11 Digital Processing I

Contact Hours: 75
Prerequisites: As decided by the instructor/s

Syllabus

1. Discrete Time Signals: Sequences; representation of signals on orthogonal basis; Sampling and Reconstruction of signals;

3. **Design of FIR Digital filters:** Window method, Park-McClellan’s method.

4. **Design of IIR Digital Filters:** Butterworth, Chebyshev and Elliptic Approximations; Lowpass, Bandpass, Bandstop and High pass filters.

5. Effect of finite register length in FIR filter design.


7. Introduction to multirate signal processing. Application of DSP to Speech and Radar signal processing.

Syllabus contributed by Anjali Kshirsagar

**M.4.12 Digital Processing II**

**Contact Hours:** 75

**Prerequisites:** As decided by the instructor/s

**Syllabus**

1. Steps in Digital Image Processing, Components of an Image Processing system, Applications. Human Eye and Image Formation; Sampling and Quantization, Basic Relationship among pixels- neighbour, connectivity, regions, boundaries, distance measures.

2. Spatial Domain-Gray Level transformations, Histogram, Arithmetic/Logical Operations, Spatial filtering, Smoothing and Sharpening Spatial Filters; Frequency Domain-2-D Fourier transform, Smoothing and Sharpening Frequency Domain Filtering; Convolution and Correlation Theorems;

3. Inverse filtering, Wiener filtering; Wavelets- Discrete and Continuous Wavelet Transform, Wavelet Transform in 2-D;

4. Redundancies- Coding, Interpixel, Psycho visual; Fidelity, Source and Channel Encoding, Elements of Information Theory: Loss Less and Lossy Compression; Run length coding, Differential encoding, DCT, Vector quantization, entropy coding, LZW coding; Image Compression Standards-JPEG, JPEG 2000, MPEG; Video compression;

5. Discontinuities, Edge Linking and boundary detection, Thresholding, Region Based Segmentation, Watersheds;

6. Introduction to morphological operations; binary morphology- erosion, dilation, opening and closing operations, applications; basic gray-scale morphology operations; Feature extraction; Classification; Object recognition;

Syllabus contributed by Anjali Kshirsagar

**M.4.13 Simulation of Control Theory I**

**Contact Hours:** 75

**Prerequisites:** As decided by the instructor/s

**Syllabus**

1. Problem formulation; Mathematical model; Physical constraints; Performance measure Optimal control problem. Form of optimal control. Performance measures for optimal control problem. Selection a performance measure.


4. Variational approach to optimal control problems; Necessary conditions for optimal control Linear regulator problems. Linear tracking problems. Pontryagin’s minimum principle and state inequality constraints.


Suggested Texts and References


M.4.14 Simulation of Control Theory II

Contact Hours: 75

Prerequisites: As decided by the instructor/s

Syllabus


2. Linear dynamic system Identification: Overview, excitation signals, general model structure, time series models, models with output feedback, models without output feedback. Convergence and consistency.


6. Advanced control: Pole placement control, minimum variance control, generalized predictive control.

Suggested Texts and References

Syllabus contributed by Anjali Kshirsagar
M.5  The Project (Internship/Industrial Training)

M.5.1  Project

Contact Hours: 375  Prerequisites: Passing grade in at least 30CR worth of course work of Year 1

Syllabus

- Please refer to Sec. 4.7.9 for a discussion on the project.

Suggested Texts and References

- No Texts. Resource hunt and reading work as recommended by the project advisor.

Syllabus contributed by Mihir Arjunwadkar