MAP-i: Doctoral Programme in Informatics
2014-2015 Edition

"Advanced Methods of Modelling and Simulation"

A Course Unit Proposal
By
Rosaldo Rossetti (LIACC-DEI/FEUP) and Artur Pereira (IEETA- DETI/U. Aveiro)

Part I: Module Programme

1. Course Unit Characterisation

- **Course Title**: "Advanced Methods of Modelling and Simulation"
- **Proposers**:
  Rosaldo J. F. Rossetti, PhD – Assistant Professor, DEI/FEUP, Researcher, LIACC/UP
  Artur J. C. Pereira, PhD – Assistant Professor, DETI/UA, Researcher, IEETA/UA
- **Course**: MAP-I – Doctoral Programme in Informatics (Minho, Aveiro, Porto)
- **Credits (ECTS):** 5
- **Lecturing Hours:** 21 hours
- **Expected Effort:** 135 hours
- **Lecturing Language:** English
- **Term:** either 1st or 2nd Term
- **UC Group:** The present proposal can be considered within the "Technologies" Option (**UCT**).

2. Subject, Justification and Motivation

The Corse Unit on **Advanced Methods of Modelling and Simulation** is basically motivated by the natural challenges pushing the development of such an interesting and stimulating topic. Computational modelling and simulation are important subjects in any engineering methodology, especially in domains whose characteristics and relationships are rather stochastic and complex. Given its key relevance, not only to Computer Science but to engineering in general and other application domains, the ACM Reference Curriculum on Computer Science explicitly include "Modelling and Simulation" as a topic on computing methodologies. Thus, many Computer Science, Informatics and Computer Engineering programmes of major Universities all over the world include computer modelling and simulation in their curricula, both in undergraduate as well as in post-graduate programmes, such as the "Introduction to Modeling and Simulation" module at MIT. At FEUP, a course with the same content and programme has been offered to students attending the Doctoral Programme in Informatics Engineering (ProDEI), which is currently in its fourth edition, with an increasing number of prospective students registering for the course each academic year. This course has also attracted the interest from students attending other doctoral programmes. For instance, for the next academic year, the course has been officially included in the Doctoral Programme in Industrial Engineering and Management curriculum, at FEUP, and is being considered to be included as well in the Doctoral Programme in Engineering and Public Police, also at FEUP. Most importantly is to mention that this course unit was offered as part of the MAP-i Programme in the current academic year (2011-2012), and its first edition in this programme counted on six students officially registered in the course.

The potential applications of computer modelling and simulation have actually transposed the boundaries of engineering and now are recognised as an imperative tool for analysis and decision support in a vast range of different knowledge areas, from social sciences, medicine, health care and biology, to economics, financial

markets and naturally all fields in engineering. On the other hand, modelling and simulation is also an interesting and motivating field of study on its own right. The combination of traditional techniques of systems analysis with new trends involving more intelligent approaches of modelling and simulation, data analysis and on-line decision-making processes has demonstrated to be an important asset in any engineering task. An important issue to address, however, still remains to be bridging the gap between theory and practice. While on the one hand increase in computational power has allowed more detailed models to be specified and built and larger simulation experiments to be carried out, testing, validating and calibrating complex models represent a great challenge for both the scientific community and practitioners. Keeping a straight and close relation between model and reality seems to be the way to build better simulation models, which must rely on smarter and reliable mechanisms supporting the whole simulation lifecycle, from domain analysis and model specification to testing, validating and calibrating simulation experiments. Therefore, an open and wide spectrum of issues and problems remain to be investigated and motivate many researchers from the scientific community to carry out their research work on the specific field of modelling and simulation.

On the other hand, many practitioners as well as researchers from different communities have realised the importance of modelling and simulation as an important decision support tool. For instance, contemporary communication networks and telecommunication systems are a field where computational simulation has gained a prominent hole, as well as robotics and intelligent transportation systems. Indeed, such systems have quickly grown in complexity and size, both in terms of services now provided and number of users benefiting from such services. As from two decades ago or so, the field of modelling and simulation of communication systems has grown and matured in many ways, and the use of simulation as a day-to-day tool is now even more common practice. These tools now are highly indispensable for anyone developing and managing any kind of infrastructure and services, designing or analysing complex systems in general, or simply considering the application of modelling and simulation to the analysis of engineering problems.

The main aim of this course is to build an understandable framework to study new trends in modelling and simulation, especially those related to the development of intelligent techniques supporting the whole simulation model lifecycle in a wide range of applications. Model conceptualisation will benefit from realistic abstractions allowing behavioural models to be easily built keeping important details in a more microscopic fashion, whereas the concept of hardware/software-in-the-loop-simulation together with agent-based simulation techniques will allow on-line model testing, calibration and validation. Theory and practice will be approached from a more integrated perspective, through examples and students will be motivated to apply these novel modelling and simulation methodologies to different application domains.

On the same way ProDEI students have become interested in this course, we are sure this proposal will equally motivate many students attending the MAP-i Programme, either as they use modelling and simulatin as research and decision support tool or as they carry out research on improving knowledge and advancing technological aspects of modelling and simulation methodologies.

3. Goals of the Course Unit

The main objectives for the course on **Advanced Methods of Modelling and Simulation** are:

- To present in a rather practical way basic concepts of computational modelling and simulation in the context of different areas of application;
- To review the main mathematical tools, statistical and quantitative methods in general, indispensable for simulation experiments, namely to deal with raw data and to analyse experimental results;
- To comprehensively present all phases within the simulation project lifecycle, from domain analysis and model specification to testing, calibration, validation and application of results;
- To present and discuss the adequacy of different types of models, as well as different simulation approaches and techniques to various application domains, emphasising on how each approach fits a wide range of application domains;
- To introduce and extensively discuss the state of the art and recent advances in intelligent simulation technologies so as to identify major tendencies, challenges and areas of interest that potentially foster

further advances and research projects, especially those resulting in a PhD degree in the specific field of interest of students attending the course.

4. Learning Outcomes

After successfully completing the **Advanced Methods of Modelling and Simulation** course programme, a student must be able to:

- Identify problems that can be tackled through simulation, build simulation models, design and carry out a whole simulation project;
- Use modelling and simulation frameworks, tools and environments;
- Gather, analyse and apply simulation results to practical problems, with emphasis on sound data analysis and inference;
- Include modelling and simulation techniques within the scientific methodology in different knowledge domains and research fields, especially those involved in students' main research area of interest;
- Demonstrate acquaintance and understanding of major areas in intelligent modelling and simulation;
- Project, extend and customise simulation frameworks and environments for general and specific purposes;
- Report and deploy simulation results appropriately, according to different perspectives of applications, ranging from systems characterisation to forecasting, training or as a decision support system.

5. Detailed Programme

The course syllabus will include the following major subjects, as listed below:

1. First Part – Review and presentation of basic concepts:
    a. Simulation as a tool in engineering;
    b. Modelling (realism vs. abstraction) and types of models (normative vs. behavioural);
    c. Raw data collection and preparation;
    d. Review of statistical and quantitative methods, and random numbers algorithms;
    e. Modelling of complex systems and stochastic processes;
2. Second Part – simulation projects:
    a. Basic simulation techniques: continuous, discrete and stochastic;
    b. The simulation project lifecycle: system analysis and modelling, collection and preparation of raw data, scenario design, test, calibration and validation of models, result analysis and implementation;
    c. Simulation languages, tools and environments;
3. Third Part – advanced topics in modelling and simulation:
    a. Object-oriented simulation;
    b. Distributed simulation;
    c. Visual modelling and simulation;
    d. Realistic simulation;
    e. Simulation environnements vs. environnent simulation;
4. Fourth Part – advanced topics in intelligent modelling and simulation:
    a. Basics of intelligent simulation;
    b. Agent-based modelling and simulation: agent simulations vs. simulation agents;
    c. Learning, adaptation and evolution in simulation models;
    d. Optimisation techniques in simulation;
5. Fifth Part – advanced application of computational modelling and simulation:
    a. General purpose modelling and simulation;
    b. Domain specific modelling and simulation techniques;
6. Sixth Part – Development of a complete simulation project.

6. Lecturing Methods

Main teaching techniques will be focused on:

- Challenging students to higher level learning as is appropriate to a PhD programme of this type. Of course low level learning, i.e., comprehending and remembering basic information and concepts is important. However, emphasis will be given to topics related to intelligent modelling and simulation, using such techniques to problem solving, decision-making, critical thinking/design, and creative thinking/design.
- Use active learning such as the use of modelling and simulation platforms and tools. Exposition will be made mostly with interaction in theoretical classes. Some learning will of course be passive, i.e., listening and reading. Nonetheless, high level learning requires active learning and thus the use of appropriate material/platforms/simulators will also be an important technique to be used in the course. Students will research on general purpose platforms as well as frameworks, both those of general purpose and those tailored to specific domains.
- Structured sequence of different learning activities (lectures, demonstrations, reading, analysis, writing, oral presentations, design, experimentation, among others). Learning activities structured in a sequence such that they enable opening classes and assignments about basic principles to lay the foundations for complex and high level learning tasks in later, complex classes and assignments;
- Detailed feedback given to students about the quality of their research work and learning process. High level, active learning require, more than any type of learning, frequent and immediate feedback for students to know whether they are "doing it well and correctly!".

This high-level teaching methodology will enable students not only to increase their skills in researching on the basics of modelling and simulation but also on developing advanced studies on topics of intelligent modelling and simulation techniques and related fields, both in informatics and computer science, as well as other application domains that can benefit from modelling and simulation as powerful decision support tools. Some of the exercises involving modelling and simulation frameworks will be supported by documentation that will be produced specifically for this course.

7. Assessment System

This is primarily a research course, intended first to teach students the state of the art on diverse topics on intelligent modelling and simulation focusing on both general purpose simulation and domain specific applications. Bearing such an aim in mind, it is strongly desirable that students are able to do simple projects and write a paper of publishable quality in an international conference on one of the subjects covered in this course programme. There will be a significant amount of reading/analysis of quality research papers that will be handed out throughout the course. The evaluation of students will be based on:

- Analysis of a selected scientific paper about advanced techniques of intelligent modelling and simulation;
- Oral presentation of a selected new trend on intelligent modelling and simulation;
- Mid-term written examination, to consolidate theoretical and methodological aspects taught;
- Practical Project with demonstration, oral defence and production of a publishable scientific paper.

Some of the oral presentations to be carried out by the students will be included in the "Readings in Modelling and Simulation" Seminar Series, at FEUP.

8. Main Bibliography

- Michel C. Jeruchim, Philip Balaban, K. Sam Shanmugan (2000) **Simulation of Communication Systems: Modeling, Methodology and Techniques.** Springer: Berlin. 924p.

- Brito, A.; Teixeira, J. (2001) Simulação por computador: fundamentos e implementação em C e C++. Publindústria: Porto.
- Law, A. (2007) Simulation Modeling and Analysis. McGraw-Hill: Boston, MA.
- Banks, J.; Carson, J.; Nelson, B. (2005) Discrete-event System Simulation. Prentice Hall: Upper Saddle River, NJ.
- Chung, C. (2003) Simulation Modeling Handbook: a practical approach. CRC Press: New York, NY.
- Papers published in proceedings of major conferences and journals in the field.

Part II: Lecturing Team

9. People involved

Two lecturers will be directly involved with this Course Unit, namely Rosaldo Rossetti, from FEUP, University of Porto, and Artur Pereira, from University of Aveiro. This way, two of the institutions involved in MAP-i are represented in this course proposal. A brief overview of their activities is presented below.

Rosaldo J. F. Rossetti received the B.Eng. (Hons, 5-year) degree in engineering from UFC, in 2005 and both the M.Sc. and Ph.D. degrees in computer science from II-UFRGS, Brazil, in 1998 and 2002, respectively. He carried out his doctoral research as a full-time Ph.D. research student with Leeds University's Institute for Transport Studies, Leeds, U.K., within the Network Modelling Group. In 2006 he was awarded the equivalent PhD Degree in Computer Science by Faculty of Sciences, University of Porto, Portugal. He is currently with the Department of Informatics Engineering, University of Porto, where he is also a senior research fellow at LIACC, within the Distributed Artificial Intelligence and Intelligent Simulation Group, based on FEUP campus. His areas of interest generally include complex systems analysis, systems optimization, and computer modelling and simulation theory, methods and applications. Currently, he is focusing on the application of DAI techniques to tackle engineering problems in general, and more specifically on using multi-agent systems as a modelling metaphor to address issues in Artificial Transportation Systems (ATS). Dr. Rossetti has been engaged as a member of technical committees and/or as a co-organizer of many scientific events concerned with empirical AI, modelling and simulation and intelligent transportation systems, and served as reviewer for journals such as the IEEE Transactions On Intelligent Transportation Systems, Transportation Research Part C, the Journal of the American Society of Civil Engineering, the Transactions of SCS International, and the Journal of Intelligent Transportation Systems: Technology, Planning, and Operations. **He was a member of the IEEE ITS Society's Board of Governors, for the term 2011-2013, and is currently Chair of the Society's Technical Activities Committee on ATS and Simulation. Dr. Rossetti is also an Associate Editor of IEEE Transactions on ITS, and the ITS Department Editor of IEEE Intelligent Systems. As of 2013, he is a member of the IEEE Smart Cities initiative, serving as the Editor-in-Chief of its eNewsletter. In 2016, Dr. Rossetti will serve as the General Chair for the IEEE ITS Conference, to be held in Rio de Janeiro, Brazil.** He is also an active member of ACM, APPIA, and AISTI.

Artur J. C. Pereira received the B.Eng (Hons, 5-year) degree in Engineering from University of Aveiro, in 1984, and the PhD degree in Electrical and Computers Engineering in 2003, from University of Aveiro. Dr. Pereira has been directly involved with the CAMBADA Project, which is the RoboCup middle-size league soccer team that has been awarded different prizes in that completion since the team started in 2003. He is also one of the creators of the Ciber-Rato Simulator, which is a state-of-the-art robotics simulator that is used in the Micro-Rato Robotics Competition. Besides his involvement with robotics simulation, Dr. Pereira is also directly involved in projects concerning multi-agent based modelling and simulation.

10. Course Unit Coordinator

For this proposal, the coordinator will be Dr. Rosaldo Rossetti. His contact details are listed below:

Dr. Rosaldo Rossetti
Faculty of Engineering, University of Porto
Department of Informatics Engineering
Rua Dr. Roberto Frias, S/N
4200-465, Porto

Tel: +351 22 508 1566
Fax: +351 22 557 4103
E-mail: rossetti@fe.up.pt

11. Short CV of Lecturers

Files containing the short CVs of each lecturer involved will be attached to the proposal. Further details can also be found on their personal Web sites, as listed below:

Dr. Rosaldo J. F. Rosetti
http://www.fe.up.pt/~rossetti

Dr. Artur J. C. Pereira
http://wiki.ieeta.pt/wiki/index.php/Artur_Pereira
http://www.ieeta.pt/~artur/