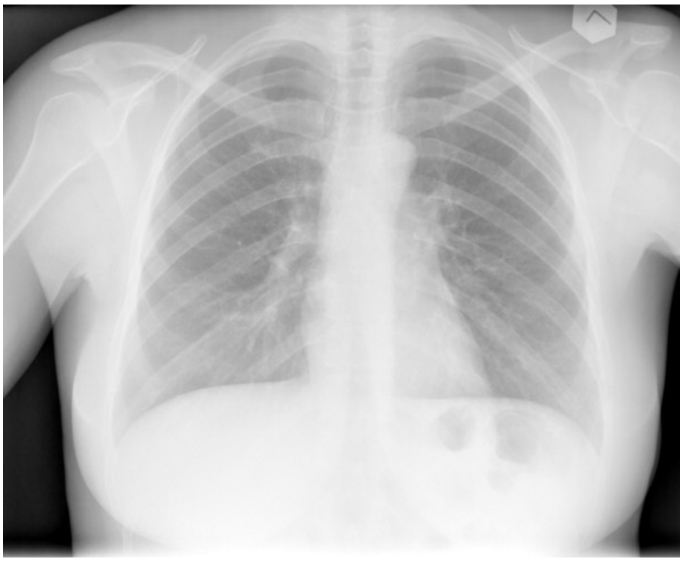
NEW !

Master in Mathematics with Specialization in:

Modelling and Simulation for Biomedical Applications (in English)

Department of Mathematics
University of Trento, Italy
Academic year 2012-2013



SUMMARY: The specialization of *Modelling and Simulation for Biomedical Applications* deals with topics in applicable mathematics, such as theoretical mechanics, partial differential equations, numerical methods and scientific computing, along with practical applications to biology, imaging and medicine. This specialization is highly interdisciplinary and involves physicists, biologists, engineers, mathematicians and medical doctors, providing the student with highly transferable mathematical skills, thus widening employment opportunities.

BACKGROUND

In most modern societies people now live longer than in the past. This in itself generates new problems to societies. Families have to care for the elderly and national health services have to assist patients under increasing financial costs as well as increasing financial constraints. Societies must find new ways of facing the problem, in which disciplines others than medicine enter the scene. Medical care is no longer an exclusively medical problem. Modern technology, interdisciplinary research and training of high-level scientists have become essential complementary aspects.

Key aspects of this two year Master Course in Mathematics are (i) mathematical modelling (ii) numerical simulation, (iii) scientific computing (iv) solid and fluid mechanics, (v) physiology and (vi) medical problems. To illustrate the core idea of *modelling and simulation* let us consider one example: the flow of blood in the body. The physics of blood flow may be seen as part of the general subject of fluid dynamics, a broad branch of physics that is present in many areas of research, including pure science, technological, industrial and environmental disciplines. Mathematical modelling and simulation in these areas has been a success story in science and technology in the last few decades, with the aerospace disciplines being a representative case. A virtual space vehicle is studied, designed and sent to the line production after being modelled and simulated on a computer. Then the real space vehicle is lunched. In this manner, expensive and often dangerous experiments are, in many ways, substituted by a good theoretical model and effective simulation tools. For an experiment that is impossible to realize, simulation is the only way forward. These staggering developments have not gone unnoticed to researchers working in cardiovascular mathematics, a very active area that is beginning to make significant progress and where mathematicians play a key role. There are many other aspects of bio-medicine for which an analogous parallel with physical sciences can be made, regarding modelling and simulation. Some examples are: understanding tumour growth and optimizing therapies, interpreting results from biomedical imaging, to name but a few.

This two-year Master Course in Mathematics with specialization in "*Modelling and Simulation for Biomedical Applications*" is seen as an important contribution to university training of young scientists, who may in the future contribute to society in the many areas of health and related industries.

The design of the course rests heavily on the idea of developing *transferable skills.* That is, students will be equipped with mathematical modelling and simulations techniques (modelling, numerical methods, programming, statistics, development of collaborative research, etc.) than can be applied to a wide range of scientific, technological, industrial problems, not just to bio-medical problems. In this manner successful graduates will find a broad range of employment opportunities in industry, development and consultancy organizations or even research institutions. The most successful graduates may also want to consider continuing to PhD studies.

COURSES

Course Title	Year-semester	Lecturer	Credits
Theoretical biomechanics	Year 1-Semester 1	Prof. D Bigoni (Solid bio-mechanics) Prof. G Rosatti (Fluid bio-mechanics)	9
Partial differential equations in biology	Year 1-Semester 1	Prof. M Iannelli and Prof. A Valli	9
Integral transforms	Year 1-Semester 1	Prof. L. Tubaro	6
Statistical models	Year 1-Semester 1	Prof. A Pugliese	3
Physiology	Year 1-Semester 1	Prof. Y Bozzi	6
Scientific computing	Year 1-Semester 2	Prof. M Dumbser	6
Biomedical imaging	Year 1-Semester 2	Prof. R. Antolini	6
Mathematical aspects of bioelectromagnetism imaging	Year 1-Semester 2	Prof. A. Alonso	6
Mathematical biology	Year 1-Semester 2	Prof. M. Iannelli and Prof. A. Pugliese	9
Models and numerical methods for blood flow	Year 2-Semester 1	Prof. E F Toro	9
Physiological flow and transport in porous tissues	Year 2-Semester 2	Prof. A Bellin	6
Medical applications	Year 2-Semester 2	Part 1: Medical imaging Part 2: Haemodynamics Part 3:Waves in medicine	6
Elective course (*)	---		6
Thesis (**)	Year 2		30

(*) Chosen freely from any of the courses offered in mathematics, science or engineering in Trento.

(**) The thesis has typically a duration of six months and includes an internship at one of the collaborating institutions or research groups of the University of Trento. The thesis is report of supervised independent work on a project, often leading to a scientific publication.

SYLLABUSES

Theoretical biomechanics
Professor D. Bigoni
www.ing.unitn.it/~bigoni

This course is divided into (a) structural biomechanics and (b) solid biomechanics.

The aim is to show how forces influence shape and growth of biological systems and how to treat deformation and stress of biological tissues. Basic models to answer the following questions:

- what is the mechanics of DNA segments and of the cellular cytoskeleton,
- how animals move,
- how fracture develops in bones,
- how arteries deform under increasing blood pressure,
- how the cardiac muscle deforms and
- how brain tissue behaves under slow increasing deformation.

Theoretical biofluid-mechanics
Professor G. Rosatti

The main aim of the second part of the course is to provide the student with the mathematical tools for the mechanical description of bio-fluids. After a general approach valid for each type of viscous and turbulent fluid, the peculiarity of bio-fluids will be presented with particular reference to haemodynamics in large vessels. The systems of partial differential equations necessary to describe the flows in various conditions will be derived and solved analytically in some reference cases.
The course will be supplemented with some seminars held by Dr. Bonmassari, (director of the Cardiology Department of the Hospital of Trento), regarding some physiological, medical and pathological aspects of human haemodynamics.

PDEs in Biology
Professor M. Iannelli and Professor A. Valli
www.science.unitn.it/~iannelli
www.science.unitn.it/~valli

Starting from basic results about the classification of linear 2nd order PDEs and methods to find explicit solutions of simple equations, the course on the one hand will build a theoretical background for the equations of fluid mechanics; on the other hand it will study the class of reaction-diffusion equations, widely used in biology, analyzing phenomena like travelling-wave solutions, and mechanisms for pattern formation.

Integral transforms
Professor L. Tubaro
www.science.unitn.it/~tubaro

Aim: to introduce to the theory of Fourier and (to a limited extent) Laplace transform, and their applications especially in PDEs.

Statistical models
Professor A. Pugliese
www.science.unitn.it/~pugliese

A short introduction to the methods of statistics, especially linear models, in data analysis with the use of specialized software on test data.

Physiology
Professor Y Bozzi
https://sites.google.com/site/bozzilab/home

Scientific Computing
Professor M. Dumbser

Basic and advanced scientific programming skills for coding numerical algorithms using modern programming languages: Fortran 90, Fortran 2003 or C. Mixed-language programming.

Applications will involve linear algebra, ordinary and partial differential equations taken from science and engineering.

Basic parallelization strategies for modern multi-core CPU systems will be discussed and implemented in practice.

Computer laboratory sessions, practical programming issues, efficient code writing and debugging, scientific data visualization.

Desirable prerequisites: Elementary numerical analysis, ODEs, PDEs.

Biomedical Imaging
Professor R. Antolini

Introduction to mathematical, physical, and computational principles underlying modern medical imaging systems.

Fundamentals of X-ray radiography, X-ray computed tomography (CT), ultrasonic imaging, nuclear imaging, magnetic resonance imaging (MRI).

General concepts required for the above, such as linear systems theory, Fourier Transform and numerical optimization.

Basic concepts of biomedical image computing (visualization, segmentation, and analysis of image data).

Applications of medical imaging, such as image-guided intervention.

Mathematical aspects of bioelectromagnetism imaging
Professor Ana Alonso
www.science.unitn.it/~alonso

There are many biomedical imaging modalities that use different physical principles for signal generation and detection:

• electro- and magneto-encephalography,
• X-ray tomography,
• magnetic resonance imaging,
• impedance tomography.

This course provides the mathematical tools that are essential for the understanding of different imaging techniques with particular emphasis on those based on bio-magnetic properties:

• Maxwell equations,
• integral transforms,
• fundamental solutions and layer potentials,
• inverse problems and regularization techniques.

Models and numerical methods for blood flow
Professor E F Toro
www.ing.unitn.it/toro

Aim of the course: to contruct mathematical models and numerical methods for the computer simulation of blood flow in humans.

Contents of the course:

- Basics on theory and numerical methods for hyperbolic equations.
- Advanced methods for model hyperbolic problems.
- Governing equations for blood flow in medium to large vessels.
- Zero-D models. Numerical methods.
- One-dimensional models. Theoretical study of the models. Tube laws. Simplified models and analytical solutions. Numerical methods for 1D models.
- Methods for junctions (bifurcations).
- Simplified networks.
- Practical project and seminars.

Physiological flow and transport in porous tissues
Professor A. Bellin
www.ing.unitn.it/~bellin

This course deals with the mechanisms leading to transport of oxygen, nutrients, waste products and heat around the body rapidly.

- rapid convective transport in the main vessels,
- transport processes occurring between micro-vessels and the tissue.

Such exchange is crucial for carrying oxygen and nutrients to the cells and wash out metabolic waste, through the lymphatic system.

Modeling these processes may contribute to unveil the origin of a large class of diseases, including neurodegenerative diseases and better tailor treatments, for example through a better understanding of drug delivery.

Mathematical Biology
Professor M. Iannelli and Professor A. Pugliese
www.science.unitn.it/~iannelli
www.science.unitn.it/~pugliese

This course is an introduction to mathematical modelling in several areas of biology. Emphasis is on qualitative modelling, i.e. on building and analysing simple models that, over a reasonable range of parameter values, yield patterns in qualitative agreement with characteristic features of the biological phenomenon under study. In this way, it may be possible to understand which assumptions are essential to yield, for instance, convergence to a stable state, or oscillating patterns; a switch-like behaviour or the transmission of a single or repeated impulses, as some external input varies. Areas of biology examined will include ecology, epidemiology, and selected topics in cellular and molecular biology.

Further enquiries:

Professor A Pugliese: pugliese@science.unitn.it

Professor E F Toro: toro@ing.unitn.it