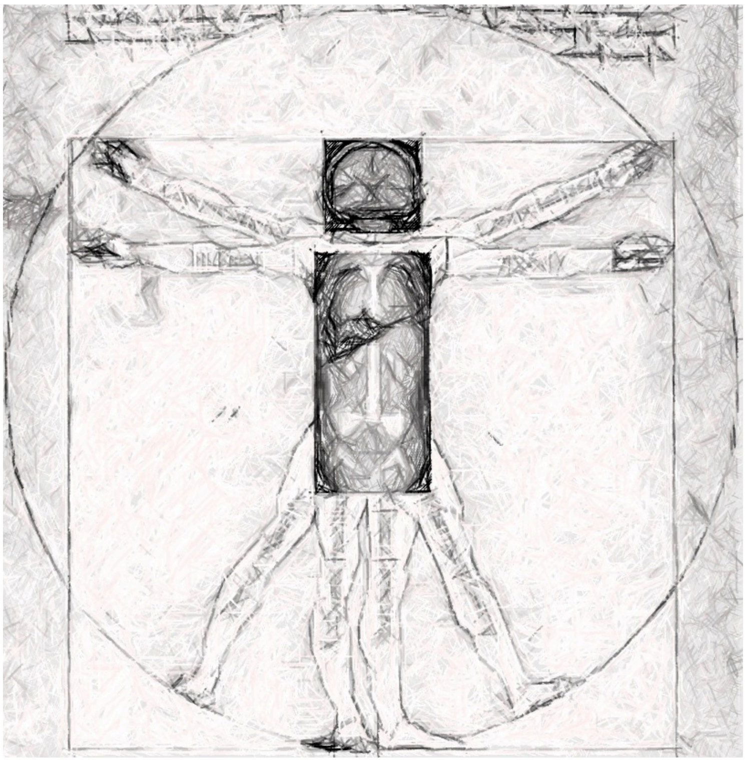
UNIVERSITAT POMPEU FABRA

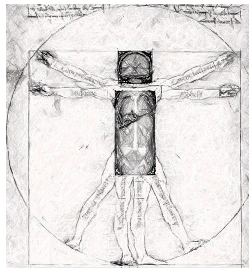


Teaching plan
Modelling of Organs and Systems (MOS)

Teaching guidelines
Activity program

Academic year: 2013-2014 **Trimestre:** 2nd
Name of course: Modelling of Organs and Systems
Course code: 22135
Degree: Bachelor's degree in Biomedical Engineering
Number of ECTS credits: 5
Hours of student work: 125
Language in which the course is taught: English

Teachers: Òscar Cámara (coordination, lectures), Mario Ceresa (labs), Daniel Romero (labs)



1. Course descriptors

- **Academic year:** 2013-2014
- **Year:** 3rd
- **Term:** 2nd trimester
- **Course name:** Modelling of Organs and Systems (MOS)
- **Course code:** 22135
- **Course type:** Mandatory
- **Degree:** Bachelor's degree in Biomedical Engineering
- **Number of ECTS credits:** 5
- **Hours of student work:** 125
- **Department:** *Departament de Tecnologies de la Informació i les Comunicacions*
- **Coordination:** *Òscar Cámara*
- **Teachers:** *Òscar Cámara (lectures, oscar.camara@upf.edu), Mario Ceresa (labs, mario.ceresa@upf.edu), Daniel Romero (labs, daniel.romero@upf.edu), seminar speakers (Gustavo Deco, James Sharpe, Mariano Vázquez, Paula Rudenick, Jérôme Noailly)*
- **Groups:** *1 group for lectures, 1 group for seminars, 2 groups of labs*
- **Language in which the course is taught:** English

2. Course presentation

"Modelling of Organs and Systems" is a mandatory subject of the 3rd year of the Biomedical Engineering Bachelor's degree at the Universitat Pompeu Fabra (UPF), taking place during the 2nd trimester, from January to March. The duration of the subject corresponds to 5 ECTS credits.

The main goal of the course is to **cover the most relevant computational steps in a patient-specific multi-scale modelling workflow**, going from three-dimensional patient-specific structural and functional information to personalized biophysical simulations that can help on better understanding the complexity of human systems. This information has a multi-scale nature across wide ranges of length (including genes, proteins, cells, tissues and organs) and time scales (from microseconds to human lifetime), as illustrated in Figure 1.

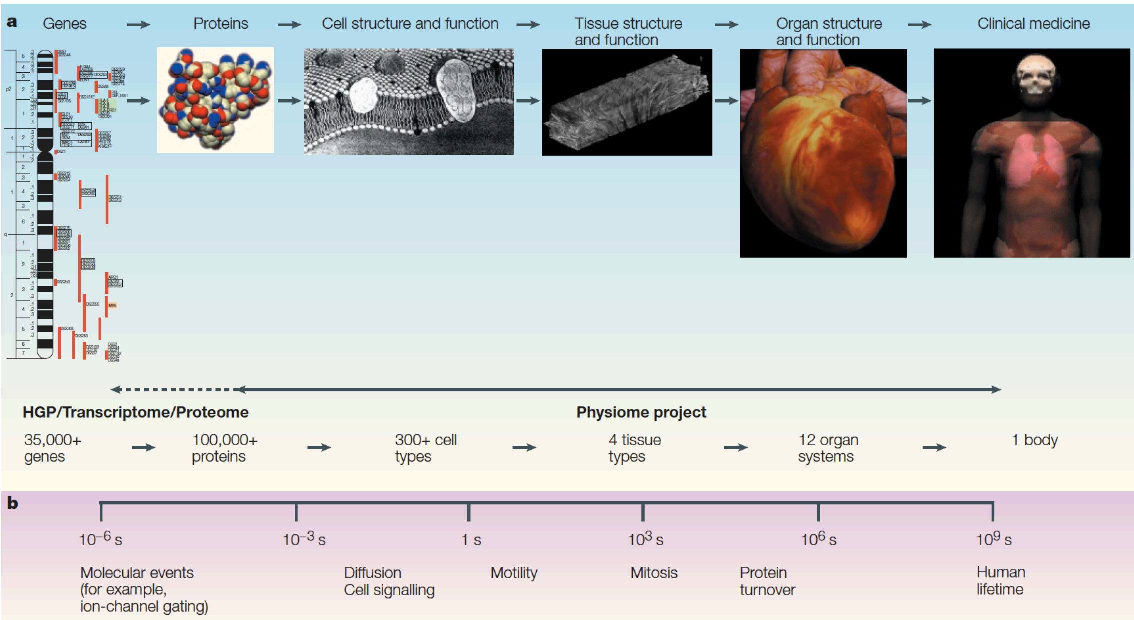
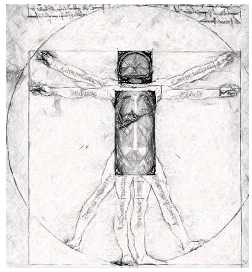


Figure 1: Multi-scale nature of human Systems in the Physiome project. From Hunter et al., Nature Review 2003.

Multi-scale modelling of biological systems requires the development of mathematical and engineering tools that can describe in a realistic way the structure and function of the different components of the system and integrated them into a common reference at reasonable computational times. Some of these tools include images and signal processing algorithms, meshing, numerical techniques for solving ordinary and partial differential (ODE, PDE) systems of equations, high-performance computing and validation/verification tools, among others. In this course the most common of these techniques available nowadays will be presented in lecture sessions. Application to particular human body systems will be the focus of seminars and lab sessions.

Keywords: Principles of mathematical modelling; multi-scale biophysical modelling; finite-element methods; meshing; parameter estimation; verification and validation; high-performance computing



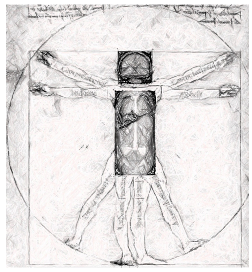
3. Prerequisites

The course of Modelling of Organs and Systems is focused on advanced computational methods applied on physiological systems. Therefore, it requires good knowledge on different concepts seen in several previous courses in the Biomedical Engineering degree. Some of these include:

- **Mathematical background**
  - solving systems of ODE/PDE equations with numerical techniques such as Finite-Element methods
  - courses related: Computational Techniques in Biomedicine (1st year), Mathematical Biomodelling II (2nd year)
- **Software tools and coding**
  - being used to learn open-source and commercial software and coding tools (e.g. Matlab) on computational techniques
  - courses related: Computational Techniques in Biomedicine (1st year), Mathematical Biomodelling II (2nd year)
- **Human physiology**
  - good knowledge of physiology of the human body
  - courses related: Systems Physiology I and II (2nd year), Pathophysiology (3rd year)

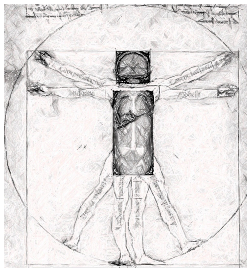
In addition, knowledge about data processing for personalizing simulations with patient-specific data would be preferable (course related: Signal and Systems Theory, 2nd year; Biosignals and Biosystems, 2nd year; Analysis of Biomedical Images, 3rd year).

Finally, this course will ask for intensive team-work and good communication and writing skills, in particular for lab sessions where groups of 3-4 students will prepare one common project that will be presented in a session during the last week of the trimestre.



4. Competences the course aims to teach or to train

Transversal competences	Specific competences
Instrumental **INS2.** Organization and planning ability **INS3**. Ability for applying knowledge in practice **INS7**. Oral and written communication in English in academic or professional environments. **Interpersonal** **INT1**. Teamwork **INT3**. Leadership skills, coordination and initiative **Systemic** **SIS1**. Ability for applying flexibly and creatively the acquired knowledge to new scenarios. **SIS5**. Motivation for innovation	**Professional specific competences** **B1.** Ability for solving mathematical problems that may appear in engineering. Aptitude for applying knowledge on: linear algebra; geometry; differential geometry; differential and integral calculus; differential equations; numerical methods; numerical algorithms; and statistics. **B2.** Ability to use and program computers. Ability to use diverse operating systems, databases and computer programs intended for engineering. **B6.** Knowledge on linear systems, circuit theory, electronic circuits, electronic and photonic devices, materials technology. **B10.** Ability to understand the principles and to implement computational methods for the resolution of biophysical models with continuous or discrete formulations (e.g. finite-element methods, etc) **Fundamental learning specific competences** **IB3.** To understand the main physiopathological mechanisms and to computationally model the diverse organ and systems of the human body, with emphasis on the cardiovascular system, the nervous system and the locomotor system **IB4.** To apply computational models of human physiology and its personalization through clinical information for planning of minimally-invasive interventions **BM4.** Description and analysis of structure and function of human organs and systems, and their more relevant alterations **BM10.** Analyze and relate the biological fundamentals of structure and function of human beings, and of molecular and cellular basis of diseases



5. Contents

The theoretical content of this course will cover the more methodological aspects fo the whole modelling pipeline, leaving the application side to the seminars and lab sessions.

Lectures

Module 1. Modelling of organs and systems in biomedicine
Principles of mathematical modelling. Multi-scale modelling workflow. Physiome project. Examples of biophysical modelling

Module 2. Mesh generation
Patient-specific meshes. Geometry concepts. Marching Cubes. Structured and unstructured meshing algorithms. Remeshing. Quality measures. Mesh-less methods.

Module 3. Numerical techniques
Finite differences. Boundary Element Method. Non-linear Finite Element Methods. Boundary conditions. Computational Fluid Dynamics.

Module 4. System identification and parameter estimation
Model specification. Variational vs sequential methods.

Module 5. Verification and validation
VVUQ (Verification, Validation, Uncertainty, Quantification). Convergence and stability. Mesh resolution independence, sources of errors. Phantoms. Experimental models. Tissue experiments.

Module 6. Software tools and high-performance computing
Open source vs commercial. Repositories and standards. Parallelization in High Performance Computing (HPC). Computational times, real-time applications.

Seminars

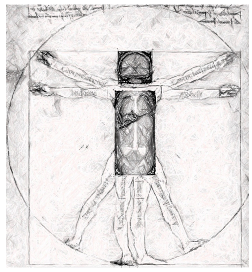
Seminar 1. Human Brain Connectome
Prof. Gustavo Deco, Universitat Pompeu Fabra.

Seminar 2. Musculo-skeletal modelling
Dr. Jérôme Noailly, Institute for Bioengineering of Catalonia.

Seminar 3. Organ regeneration
Prof. James Sharpe, Centre de Regulació Genòmica.

Seminar 4. Cardiovascular modelling
Dr. Mariano Vázquez, Barcelona Supercomputing Centre.

Seminar 5. Computational Fluid Dynamics
Paula Rudenick, Hospital Universitari Vall d'Hebron.



5. Methodology

There are three types of sessions in this course: lectures, seminars and labs.

Lectures

There will be 8 sessions of 2 hours each for lectures on theoretical aspects. They will be quite conventional with slide materials for each session covering the six modules presented above. Theoretical aspects of modelling will be complemented with examples on state-of-the-art biophysical models applied to different human systems. Associate professor Oscar Camara will be in charge of these lectures as well as being the coordinator of the course.

Seminars

There will be 5 sessions of 2 hours each for seminars given by worldwide reputed researchers on different fields of human physiological modelling. These seminars will be open to the whole UPF community due to the high quality of the speakers. MOS students will be required to present a short report on 3 of the 5 seminars, chosen at will (more details in the Assessment section).

Labs

The lab sessions (7 sessions with 1h or 2h, in total 8 hours per group, since the class will be divided in two groups) are designed to be the support of the modelling project that need to be done in groups of 3-4 students during the whole trimester. The main objective of the modelling project is to apply the theoretical concepts acquired in lectures of the MOS course and previous courses of the degree to implement the full pipeline of the modelling of a given human body system. There will be 8 proposed different simple modelling projects that the teams could choose, all of them using open-source (and Matlab) tools for the different steps of the modelling pipeline. A first phase of the modelling project will consist in implementing or using a simple existing model while during the second phase, teams will need to develop and advanced version of the model including some methodological or application novelties.

Eventually there will be the possibility of teams to choose to model a different human organ/system bearing in mind that assistance and feedback from teachers will be more limited.

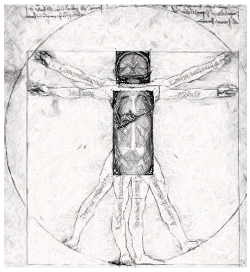
Student teams will be asked to work on the modelling project mainly outside in-person classes with the assistance and feedback of teachers, having lab sessions as check-points to present intermediate results, questions, bottle-necks and re-orient objectives and strategies. It is assumed then that within each team there is a laptop available where open-source tools can be run and they are brought to each lab session. In case no laptop is available, one can be booked from the library.

There will be a theory session in the last week of the trimester where every team will present (10 minutes) the modelling project to the rest of students and teachers. During the trimester, teams will prepare a report in the form of a scientific paper summarizing the modelling project and including different sections such as bibliography, design of the methodology, experiments, validation dataset, discussion and conclusions, among others. Some deliverables with intermediate results will be due in weeks 4, 6 and 8 (see more details in Assessment section). An approximate planning of lab sessions is included in Table 1.

Dr. Marco Ceresa and Daniel Romero will coordinate lab sessions and provide feedback to the different teams.

Week	Duration (h)	Description
1	1	Course and Models presentation
3	2	Model and bibliography presentation
4	-	Intro part of the paper is due. **Deliverable**
5	2	Model implementation presentation
6	-	Methods part of the paper is due. **Deliverable**
7	2	Presentation of advanced model proposal
8	-	Results part of the paper is due. **Deliverable**
9	1	Refinement of results towards the final presentation
10	2	Presentation of modelling project. **Deliverable**

Table 1: Organization of lab sessions



6. Assessment

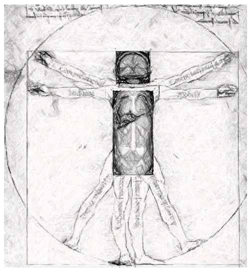
The assessment of the MOS course is designed assuming continuous learning and work from the students and feedback from teachers during the whole trimester, especially in labs sessions which represent a higher than usual weight in the total assessment. The assessment of the course, how grades will be computed, minimum requirements and which parts can be retaken (at July call) are summarized in Table 2.

	ELEMENTS	WEIGHT	CAN BE RETAKEN
Theory quiz	▪ Multiple choice quiz on lecture sessions (minimum grade >=5)	30%	Yes
Written reports of seminars	▪ Three individual reports (of 3 pages each) about three out of the five seminar sessions ▪ (average grade >=5)	20%	Yes
Modelling project	▪ Intermediate sections of the paper and presentations (3 presentations and 3 deliverables, each accounts for 2.5%)	15%	No
	▪ 10 minutes presentation of modelling project in week 10 ▪ 0.5 additional point to best modelling project chosen by students	10%	No
	▪ Final report (paper) ▪ 0.5 additional point to best report chosen by teachers ▪ (minimum grade >=5)	25%	Yes

Table 2: Assessment of MOS course

Theoretical concepts seen in lectures will be evaluated at the end of the trimester during the exam period in the form of a multiple choice quiz, which represents 30% of the final grades. Students will need a minimum mark of 5.0 in order to be able to pass the course. If failed, this quiz could be re-taken during the July exam period.

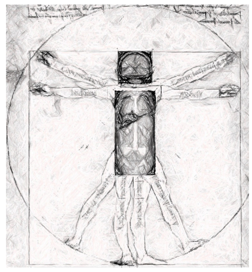
Students will be asked to prepare an individual 3-page report on three of the five invited talks that will take place in seminar sessions. These reports should include the most relevant points presented in the seminars related to the theoretical concepts seen in the MOS course and applications of the presented computational methods in biomedicine. The average mark of the three reports will account for 20% of the final grades and a minimum grade of 5.0 is required to pass the course. If failed, students will be asked to repeat one of the reports and submit a new one out of the two not considered the first time.



The modelling project is the main contributor to the final grades of the MOS course, accounting for 50% of it, illustrating the relevance of the practical and team-work in this course. The modelling project grade will be obtained from the assessment of the intermediate results (sections of the paper, 15%), the evaluation of the final presentation (10%) and the final report (scientific paper, 25%). Some criteria that will be considered for the evaluation of the scientific papers are: ability to assimilate concepts on the different steps in the pipeline; ability to be familiar with open-source software and coding tools for model implementation; ability for bibliographic searches; ability on designing experiments; ability to explain with scientific rigour and criticism their own work and properly relate to the state of the art; ability to foresee advances and new applications of the existing models.

Additionally, there will be an extra 0.5 points (within the 50% of the final grades) for the best presentation (voted by all teams during the final session) and an extra 0.5 points (within the 50% of the final grades) for the best scientific paper (voted by all teachers).

Very important: copies or plagiarism will not be tolerated at all. Immediate consequence at the slight suspicion will be the reporting to the Committee board of the ESUP and opening of an institutional file and consequently disciplinary actions.



7. Bibliography and didactic resources

Suitable books available as free electronic resources at the web site of the UPF library (http://www.upf.edu/bibtic/):

- J. Enderle, J.D. Bronzino. *Introduction to Biomedical Engineering*. Elsevier / Academic Press Series in Biomedical Engineering. 2011 (3rd ed.). ISBN: 9780123749796 (covers M1, M4, M5)
- J.P. Keener, J. Sneyd. *Mathematical Physiology, Volume 2: Systems Physiology*. Springer. 2009 (2nd ed.). ISBN: 9780387793870 (covers M1 and labs)
- J.J. Batzel, M. Bachar, F. Kappel. *Mathematical modelling and validation in physiology: applications to the cardiovascular and respiratory systems*. Springer. 2013 (1st ed.). ISBN: 9783642328817 (covers M4, M5)
- K. Velten. *Mathematical modelling simulation: introduction for scientists and engineers*. Wiley-VCH. 2009 (1st ed.). ISBN: 9783527407583 (covers M1, M3, M4)
- O.C. Zienkewicz, R.L. Taylor, J.Z. Zhu. *The Finite Element Method: Its basis and fundamentals*. Elsevier, Butterworth-Heinemann. 2005 (6th ed.). ISBN: 9780750663200. (covers M3)

Additional suitable books are:

- J.D. Bronzino. *The Biomedical engineering handbook, Volume I*. CRC Press. 2000 (2nd ed.). ISBN: 9780849304613. (covers M1, M4, M5).
- J. Fish, T. Belytschko. A First Course in Finite Elements. Wiley. 2007. ISBN: 9780470035801 (covers M3)
- M. Kutz. *Biomedical Engineering and Design Handbook, Volume 1: Biomedical Engineering Fundamentals*. McGraw-Hill Professional. 2009 (2nd ed.). ISBN: 9780071498388 (covers M1, M4)
- C.L. Dym. *Principles of Mathematical Modeling*. Elsevier Academic Press, 2004 (2nd ed.) ISBN: 9780122265518 (covers M1)
- J.F. Thompson, B.K. Soni, N.P. Weatherill. *Handbook of Grid Generation*. CRC Press. 1998 (1st ed.). ISBN: 0849326875. (covers M2)

Other didactic resources include the teaching material of lectures in the form of slides that will be available at the Moodle of the course. For the modelling project, there will be several open-source and commercial tools that could be used:

- Elmer: http://www.csc.fi/english/pages/elmer
- OpenSim: https://simtk.org/home/opensim
- Matlab