Erasmus Mundus

BioHealth Computing

European Master

COMPUTATIONAL MATHEMATICS

2012-3

UFR IMMAG, UJF-Grenoble

Advanced Lectures on Computational Mathematics
Applied Mathematics, UFR IM2AG
Joseph Fourier University, Grenoble
(Joint program with the University of Barcelona)
http://www.biohealth-computing.eu

Computational Mathematics at UJF Grenoble

1 Organization of the year

For the admission procedure and the detailed organization, see the BioHealth Computing EM web site http://www.biohealth-computing.eu

1.1 First semester – 30ECTS

- Integration period in Archamps - two weeks in august-sept - (6ECTS)
- Advanced lectures on Computational Mathematics at UJF-Grenoble (or at University of Barcelona) - Sept. to Feb. - (24 ECTS ; 3ECTS=18h of lecture at UJF)

1.2 Second semester – 30 ECTS

- Master thesis from February to July at University of Barcelona, department of mathematics - joint master project UB and UJF (or at UJF Grenoble if the Advanced courses were at UB), (30ECTS)
- Summer school in Archamps, August-September: presentation of the master thesis participation to an international workshop (additional 3ECTS out of the master).

2 List of lectures at UJF-Grenoble

Numerics and Partial Differential Equations (N)

2.1 (N) Mathematical methods for wave propagation: application to inverse problems and medical imaging

3 ECTS, E. Bonnetier and F. Triki

This course studies the propagation of electromagnetic waves, described in harmonic regime by the Maxwell equations, and, in some particular case, by the Helmholtz equation. We first present mathematical tools for such equations, then inverse problems like impedance tomography and magnetic resonance imaging.

2.2 (N) Inverse methods and data assimilation

3 ECTS, M. Nodet and E. Blayo

Forecasting the weather, identifying the optimal shape of an aircraft wing, medical imagery, and more generally determining the value of some unknown parameters in a system given a mathematical model and/or observations, is an inverse problem. Methods for addressing such problems are described in this course. These methods are based either on optimal control theory or on statistical estimation theory.

2.3 (N) Numerical methods for hyperbolic equations

3 ECTS, L. Debreu and G.H. Cottet

This course will cover the design and numerical analysis of finite-volume methods for conservation laws. It will first cover the essential properties of the underlying mathematical models (conservation, entropy conditions, maximum principle...). It will then describe the classical schemes (upwind, Lax-Wendroff...) and the techniques to derive TVD and high order methods. The properties of the methods will be illustrated in applications in fluids mechanics and geophysics.

2.4 (N) Coupling methods

3 ECTS, E. Blayo

This course presents numerical methods for solving systems of PDEs in the context of coupled or multiscale phenomena. These tools are based mostly on Schwarz methods for domain decomposition, and on variational techniques.

2.5 (N) Optimal Transport, level-set: applications to biophysics

3 ECTS, E.Maître

This lecture will link level-set modeling of biomechanical systems (e.g. immersed elastic membranes mechanics) with optimal transportation theory. Interpolation algorithms based on physical knowledge of images content will be studied. Theoretical as well as practical implementation aspects will be considered.

Statistics (S)

2.6 (S) Computational statistics in biology and medicine

3ECTS, (C 18H), Lecturers: O. François and JB Durand/G Bouchard

Corresponding to the french UE (Ensimag): « Algorithmes et statistique »

Computational statistics concerns the application of algorithmic techniques to problems in statistics and in the analysis of large data sets. At the interface between computer science and statistics, this field addresses a large number of applications in biology and medicine. This course will give an overview of methodological and practical approaches in computational statistics with applications to epidemiology, genetics or medical signal analysis.

2.7 (S) Time Series Analysis

3ECTS, A. Latour

This course attempts to provide a comprehensive introduction to time series analysis. It gives an account of linear time series models and their application to the modeling and forecasting of data collected sequentially in time. A time series is a sequence of random variables Xt, the index t in Z being referred to as "time". Typically the observations are dependent and one aim is to predict the "future" given observations X1, . . . , Xn in the "past". Although the basic statistical concepts apply (such as likelihood, mean square errors, etc.) the dependence must be taken into account. In the spirit of Brockwell and Davis (1991), the approach is based on elementary Hilbert space methods.

2.8 (S) Point processes, reliability and survival analysis

3ECTS, O Gaudoin

Random point processes are used for modeling the occurrence of recurrent events in time. Their study has multiple applications in the areas of health, industry, demography, actuarial science, etc... The objective of this course is to present the essentials of stochastic modeling and statistical inference for such processes. The preferred fields of application will be reliability and survival analysis.

2.9 (S) Kernel methods in machine learning

3ECTS 18h, Teacher: Zaid Harchaoui (zaid.harchaoui@gmail.com)

Objectives: To provide an introduction to kernel methods in Statistics for machine learning.

Prerequisites: The minimal prerequisites for this course are a mastering of basic Probability theory for discrete and continuous variables and of basic Statistics.

Schedule: to be precised.

Textbooks/references: to be precised

Imaging (I)

2.10 (I) Wavelets and applications

3ECTS, Valérie Perrier

Wavelets are basis functions widely used in a large variety of fields: signal and image processing, numerical schemes for partial differential equations, scientific visualization.

This course will present the construction and practical use of the wavelet transform, and their applications to image processing : Continuous wavelet transform, Fast Wavelet Transform (FWT), compression (JPEG2000 format), denoising, inverse problems.

The theory will be illustrated by several applications in medical imaging (segmentation, local tomography, ...).

2.11 (I) Medical Imaging: tomography and 3D reconstruction from 2D projections

3ECTS, L. Desbat

CT Scanners and nuclear imaging (SPECT and PET) have greatly improved medical diagnoses and surgical planning. Mathematics is necessary for these medical imaging systems to deliver images. We present mathematical problems arising from these medical imaging systems. We show how to reconstruct images from projections of the attenuation function in radiology or respectively of the activity in nuclear imaging. We present recent advances in 2D and 3D reconstruction problems.

This presentation covers 2D tomography including the reconstruction of Region Of Interest from non-complete data (very short scan trajectories, truncated projections), 3D tomography from Orlov and Tuy conditions to Kolsher filter and Katsevich reconstruction formula, and dynamic tomography.

In the introduction we present briefly the physical interactions between photons and matter. We derive the mathematical problem formulation of a function reconstruction from its projections. We introduce the Radon transform and the x-ray transform, their basic properties, in particular the Fourier slice theorem. In 2D tomography, we demonstrate the Filtered Back Projection inversion formula and its application to fan-beam geometries. We then concentrate on recent advances in ROI reconstruction from incomplete projections. In 3D reconstruction, we derive inversion conditions and formulas for the parallel geometry and the Cone Beam Geometry. We develop recent advances based on the Katsevich formula. We then introduce dynamics problems, i.e. reconstruction from dynamic objects. We consider the problem reconstructing a 2D dynamic object from its projections and show extensions to 3D dynamic reconstruction.

2.12 (I) Advanced Imaging

3ECTS, Sylvain Meignen

In this course, we will first focus on linear methods for image denoising. In this regard, we will investigate some properties of the heat equation and of the Wiener filter. We will then introduce nonlinear partial equations such as the Perona-Malick model for noise removal, and some other similar models. A last part of the course will be devoted to edge detection for which we will consider the Canny approach and, more precisely, we will deal in details with active contours and level sets methods.

Transverse (T)

2.13 (T) Efficient methods in optimization

3ECTS, Anatoli Juditsky (anatoli.iouditski@imag.fr)
http://www-ljk.imag.fr/membres/Anatoli.Iouditski/cours/convex/cours.pdf

Optimization problems arise naturally in many application fields. Whatever people do, at some point they get a craving for organizing things in a best possible way. This intention, converted in a mathematical form, appears to be an optimization problem of certain type (think of, say, Optimal Diet Problem). Unfortunately, the next step, consisting of finding a solution to the mathematical model is less trivial. At the first glance, everything looks very simple: many commercial optimization packages are easily available and any user can get a ``solution'' to his model just by clicking on an icon at the desktop of his PC.

One of the goals of this course is to show that, despite to their attraction, the general optimization problems very often break the expectations of a naive user. In order to apply these formulations successfully, it is necessary to be aware of some theory, which tells us what we can and what we cannot do with optimization problems. The elements of this theory can be found in each lecture of the course. It describes some of most efficient optimization techniques available today.

2.14 (T) Dynamical Systems, bifurcations and applications

6ECTS, Antoine Girard

This course introduces fundamental notions for the study of nonlinear dynamical systems with an emphasis on instabilities and bifurcation phenomena. We will present general methods for the local analysis of nonlinear models (Lyapunov-Schmidt reduction, center manifold, normal forms). We will also consider hybrid dynamical systems that result from the interaction of discrete and continuous processes.

2.15 (T) Advanced Scientific Computing

3ECTS Prof. Ch Prud'homme, M.Ismail (UJF)
Corresponding to the french UE “Calcul scientifique avancé”
http://ljk.imag.fr/M2MA/Cours/calc_sci2.html
http://course-scicomp.www.ljkforge.imag.fr/doku.php?id=scientific_computing_2

3 List of lectures at University of Barcelona (UB)

- Dynamical systems (6ECTS)
- Optimization and Control (6ECTS)
- Simulation methods (6ECTS)
- Stochastic Calculus (6ECTS)

See http://www.mat.ub.es/pop/masters/programes.htm

The first semester takes place from September to January. Each EM student choose three courses out of the five proposed.

The second semester takes place at UJF Grenoble with a joint (UB-UJF) master thesis project.