Doctoral Program in Mathematical Sciences
Department of Mathematics "Tullio Levi-Civita"
University of Padova

Doctoral Program in Mathematical Sciences

Catalogue of the courses 2021-2022

Updated Septembre 8th, 2021

INTRODUCTION

This Catalogue contains the list of courses offered to the Graduate Students in Mathematical Sciences for the year 2020-2021.
The courses in this Catalogue are of two types.

1. Courses offered by the Graduate School. This offer includes courses taught by internationally recognized external researchers. Since these courses might be not offered again in the near future, we emphasize the importance for all graduate students to follow them.
2. Some courses selected from those offered by the Graduate School in Information Engineering of the University of Padova, by the Master in Mathematics, and by other institutions, that we consider of potential interest for the students in Mathematics.

We underline the importance for all students to follow courses, with the goal of **broadening their culture in Mathematics**, as well as developing their knowledge in their own area of interest.

REQUIREMENTS FOR GRADUATE STUDENTS

Within the **first two years of enrollment (a half of these requirements must be fulfilled within the first year)** all students are required to follow and **pass the exam** of

- **at least 2 among the courses called "Courses of the Doctoral Program"** in this catalogue;
- other courses for a total commitment **of at least 56 additional hours**;
- at least one activity on soft skills.

Students are warmly encouraged to take more courses than the minimum required by these rules, and to commit themselves to follow regularly these courses. At the end of each course the teacher will inform the Coordinator and the Secretary on the activities of the course and of the registered students.

Students **must register** to all courses of the Graduate School that they want to attend, independently of their intention to take the exam or not. We recommend to register as early as possible: the Graduate School may cancel a course if the number of registered students is too low. If necessary, the registration to a Course may be canceled.

Courses for Master of Science in "Mathematics"
Students have the possibility to attend some courses of the Master of Science in Mathematics and get credits for the mandatory 56 hours.
The recommendation of these courses must be made by the Supervisor and the amount of credits is decided by the Executive Board.

Courses attended in other Institutions. Students are allowed to attend Ph.D. courses offered by PhD Programs of other Universities or in Summer Schools, or other series of lectures devoted to young researchers and with a suitable form of final exam. Acquisition of credits will be subject to approval of the Executive Board.

Seminars
All students must attend the **Colloquia of the Department** and participate in the Graduate Seminar ("**Seminario Dottorato**"). They are also encouraged to attend the seminars of their research group.

HOW TO REGISTER AND UNREGISTER TO COURSES

The registration to a Course must be done online.
Students can access the **online registration form** on the website of the Doctoral Course http://dottorato.math.unipd.it/ (select the link Courses Registration), or directly at the address http://dottorato.math.unipd.it/registration/.
In order to register, fill the registration form with all required data, and validate with the command "Register". The system will send a confirmation email message to the address indicated in the registration form; please save this message, as it will be needed in case of cancellation.

Registration to a course implies the commitment to follow the course.

Requests of **cancellation** to a course must be submitted in a timely manner, and **at least one month before the course** (except for courses that begin in October and November) using the link indicated in the confirmation email message.

REQUIREMENTS FOR PARTICIPANTS NOT ENROLLED IN THE GRADUATE SCHOOL OF MATHEMATICS

The courses in this catalogue, although part of activities of the Graduate School in Mathematics, are open to all students, graduate students, researchers of this and other Universities.
For reasons of organization, external participants are required to **communicate their intention** (loretta.dallacosta@unipd.it) to take a course at least two months before its starting date if the course is scheduled in January 2021 or later, and as soon as possible for courses that take place until December 2020.
In order to **register,** follow the procedure described in the preceding paragraph.
Possible **cancellation** to courses must also be notified.

Courses of the Doctoral Program

Courses of the “Mathematics” area

11. Prof. Franz-Viktor Kuhlmann
    The Theory of the Defect and its Application to the Problem of Local Uniformization **M-14**
12. Prof. Marco Mazzucchelli
    Introduction to Floer Homology **M-15**
13. Proff. Ernesto C. Mistretta, Stefano Urbinati
    Positivity of Divisors and Vector Bundles in Algebraic Geometry **M-17**
14. Prof. Vincenzo Vespri
    Campanato Spaces and their Application to Regularity of Solutions to PDEs **M-18**
15. Prof. Richad Vinter
    Dynamic Optimization **M-19**

Courses of the "Computational Mathematics" area

1. Prof. Turgay Bayraktar
   Pluri-Potential Theory and Zeros of Random Polynomials **MC-1**
2. Prof. Immanuel Bomze
   Conic, especially copositive optimization **MC-2**
3. Prof. Alessandra Buratto
   Introduction to differential games **MC-3**
4. Prof. Oleg Davydov
   Mesh1ess Finite Difference Methods **MC-4**
5. Prof. Massimo Fornasier
   Consensus based optimization on manifolds **MC-5**
6. Prof. Archil Gulisashvili
   Asymptotic analysis of stochastic volatility models POSTPONED TO THE NEXT YEAR
7. Prof. Antoine Jacquier
   A smooth tour around rough models in finance (From data to stochastics to machine learning) POSTPONED TO THE NEXT YEAR
8. Prof. Sergei Levendorskii
   Fourier-Laplace Transform and Wiener-Hopf Factorization in Finance, Economics and Insurance **MC-8**

Courses offered within the Masters's Degree in Mathematics

1. Offered Courses **MD-1**

Soft Skills

Courses in collaboration with the Doctoral School on "Information Engineering"

Courses of the Doctoral Program

Numerical Methods in Probability

Proff. Giorgia Callegaro, Marco Formentin, Tiziano Vargiolu[1]

[1] University of Padova
Department of Mathematics
Emails: formen@math.unipd.it, gcallega@math.unipd.it, vargiolu@math.unipd.it

Timetable: 24 hrs. All lectures in Torre Archimede, Room 1AB/45.
Lectures from Monday, November 9, h. 14.30–16.30, every Monday and Tuesday

Course requirements: A previous knowledge of basic probability theory is required. Knowledge of Itô stochastic calculus could help for the advanced parts of the course, but during the course the basic concepts will be introduced for the understanding of the presented numerical methods.

Examination and grading: Seminar.

SSD: MAT/06 Probability and Mathematical Statistics

Course contents:

The course will present the most used numerical methods used in probability for the computation of quantities like $\mathbb{E}[f(X)]$, where f is a deterministic function and X is a random variable of known or unknown distribution, in growing complexity. With increasing difficulty, we will pass from the basic case when X is a given random variable with known distribution, to the case when X is a discrete time Markov chain, and finally to the case when X is a diffusion process. These latter objects will be gently introduced for those not acquainted to them. During the course, we will discuss the effectiveness of the various methods, depending on the dimension of the state space and of the complexity of the problem.

Monte-Carlo methods (10h): (Prof. Tiziano Vargiolu)

1. The basic idea: Monte Carlo estimators for the mean and for the error. Variance reduction techniques: control variates, antithetic variates, stratification, importance sampling
2. Definition and examples of Markov chains and of transition kernels.
3. Monte Carlo methods for Markov chains.
4. Introduction to Brownian motion, stochastic calculus and diffusion processes. A result of weak convergence for diffusion processes.
5. Monte Carlo methods for diffusion processes.

Tree methods (2h): (Prof. Tiziano Vargiolu)

1. Tree methods for diffusion processes.

Quantization techniques (6h): (Prof. Giorgia Callegaro)

1. Introduction to quantization: when, why and how? Examples of discretization of a random variable.
2. Quantization of a stochastic process: recursive marginal quantization.

3. Functional quantization: discretizing a Gaussian process.

Rare-event simulation (6h): (Prof. Marco Formentin)

1. Rare event simulation design.
2. Importance sampling and large deviation theory.
3. Importance sampling technique for Markov chains.
4. Rare events in multiplicative Markov models.

Lie Groups and Symmetry

Francesco Fassó[1]

[1] Dipartimento di Matematica, Universitá di Padova
Email: fasso@math.unipd.it

Timetable: 24 hrs. First lecture on Oct 13, 2020, 11:00 (dates already fixed, see calendar), Torre Archimede, Room 1BC/45.

Course requirements: (very) basic knowledge in differential geometry. The course is addressed to all students.

Examination and grading: oral examination on the topics covered during the course

SSD: MAT/

Aim: The course aims at providing an introduction to the theory of Lie groups and their actions, which is a topic of broad interest but almost completely absent from the courses of our Laurea Magistrale. After covering the fundamentals of the subject, the course will provide some examples of use of Lie groups in the study of ODE with symmetry.

Course contents:
Synopsis: Lie groups and their differential—and group—structure (left and right trivializations, Lie algebra of a Lie group, exponential map, maximal tori, (co)adjoint action, structure of compact Lie groups). The classical matrix groups and their properties. Differentiable actions of Lie groups on manifolds, quotient spaces (for proper actions), invariant vector fields. Reduction of invariant vector fields. Applications to ODEs with symmetry (reduction and reconstruction; integrability).

References

1. A. Baker, Matrix groups. An introduction to Lie group theory. (Springer, 2002)
2. J. Lee, Introduction to Smooth manifolds. 2nd edition. (Springer, 2013)
3. T. Bröcker and T. tom Dieck, Representations of compact Lie groups. (Springer 1985)
4. R. Cushman, J.J. Duistermaat and J. Śnyaticki, Geometry of Nonholonomically Constrained Systems. (World Scientific, 2010).

Mathematical and Numerical Modelling of the Human Cardiovascular System.

Prof. Alfio Quarteroni[1], Prof. Luca Dedé[2], Prof. Christian Vergara[3]

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[2] *Politecnico di Milano, Italia*
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[3] *Politecnico di Milano, Italia*
Email: christian.vergara@polimi.it

Timetable: 24 hrs. First lecture on February 8, 2021, 09:15. The course will be held online at: https://unipd.zoom.us/j/89301619168?pwd=ZlJnOGlGSy8vWFMrOEIwSVRLL095Zz09 or Meeting ID: 893 0161 9168 Passcode: 544118

Timetable and topics:

Prof. Alfio Quarteroni
- Feb 8, 2021 – 09:15-12:15 - Introduction: why mathematical modeling, example of clinical applications, basis of physiology
- Feb 8, 2021 – 14:15-16:15 - Introduction to computational fluid-dynamics and solid mechanics

Prof. Christian Vergara
- Feb 9, 2021 - 09.15-13.15 Fluid-structure interaction: models and numerics I
- Feb 9, 2021 - 14.15-16.15 Fluid-structure interaction: models and numerics II + Geometric Multiscale approach for the cardiovascular system I
- Feb 10, 2021 - 09.15-13.15 Geometric Multiscale approach for the cardiovascular system II + Modeling the cardiac valve dynamics

Prof. Luca Dedé
- Feb 10, 2021 - 14.15-16.15 Intro cardiaco
- Feb 10, 2021 - 16.15-17.15 Electrical activity of the heart: models and numerics (part 1)
- Feb 11, 2021 - 09.15-11.15 Electrical activity of the heart: models and numerics (part 2)
- Feb 11, 2021 - 11.15-13.15 + 14:15-15:15 Electro-mechanical activity: models and numerics
- Feb 11, 2021 - 15.15-17.15 Numerical solution of cardiac fluid-dynamics and heart integration

Course requirements:

Examination and grading:

SSD:

Aim: This course aims at introducing the foundations of mathematical and numerical models of the human cardiovascular system. We address the modeling of both the vascular circulation and the cardiac function. Regarding the vascular circulation, the focus is on the modeling of the arterial and venous systems blood dynamics, the wall mechanics and their interaction. As for the cardiac function, the modeling of the main core functionalities like electro-physiology, active and passive mechanics, blood dynamics and valve dynamics will be considered, together with their coupling. This yields a coupled system of time-dependent, nonlinear partial differential equations of multiscale nature. The choice of accurate and stable numerical methods will be discussed, together with the proposition of efficient algebraic solvers for large-scale computation. Several applications of clinical relevance will be presented.

Course contents:

1. Introduction: why mathematical modeling, example of clinical applications, basis of physiology
2. Introduction to computational fluid-dynamics and solid mechanics.
3. Fluid-structure interaction: models and numerics
4. Geometric Multiscale approach for the cardiovascular system
5. Electrical activity of the heart: models and numerics
6. Electro-mechanical activity: models and numerics
7. Modeling the cardiac valve dynamics
8. Numerical solution of cardiac fluid-dynamics and heart integration

Bibliography

- A. Quarteroni, L. Dedé, A. Manzoni and C. Vergara, *Mathematical Modelling of the Human Cardiovascular System*. Data, Numerical Approximation, Clinical Applications. Cambridge University Press, 2019
- A. Quarteroni, *Numerical Models of Differential Problems*, Springer Series MSandA, 3rd edition, Springer Series MSandA, Vol 16, 2017 (xvii+681p.)

An Introduction to Optimal Control Theory

(Analysis, Geometry, and Applications)

Franco Rampazzo[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Universitá di Padova*
Email: rampazzo@math.unipd.it

Timetable: 24 hrs. First lecture on March 2, 2021, 09:00 (dates already fixed, see calendar), Torre Archimede, Room 1BC/50.

Course requirements: Basic mathematical analysis, Lebesgue measure theory. Other prerequisites –for instance, fixed point theorems, absolutely continuous maps, differential manifolds– will be recalled during the course.

Examination and grading: The final exams will consists of a standard oral questioning about either the the main parts of the program or a shortened version of program together with the contents of a pre-assigned research paper.

SSD: MAT/05

Aim: Presenting crucial results in Optimal Control Theory of ODEs, with a special attention to (the existence and to) necessary conditions for minima. (These results are strictly connected with basic topics in Calculus of Variations, Differential Geometry, Classical and Relativistic Mechanics, as well as with other applications, from epidemiology to economics, from aeronautics to space-navigation.)

It will be shown how the simple idea of 'set separation', including the corresponding separability criterions for (suitable) approximating cones, lie behind obtaining Maximum Priciples for minima, from elementary optimization problems up to nonlinear optimal control problems.

Time permitting, connections with characteristics theory for Hamilton-Jacobi equations will be treated, as well as issues from Differential Geometric Controllability. The course is ideally intended for students in Mathematical Analysis, Differential Geometry or Mechanics. However, because of the strong applicative potential of the addressed issues, also people from mathematically supported disciplines, such as Engineering, Physics, Epidemiology, and Economics might be interested in this course.

Course contents:

1. Brower fixed point theorem and a parameterized version of Banach-Caccioppoli fixed point theoreom. A directional 'open mapping' theorem with low regularity. Set separation and cone separability
2. Review of ODE's with vector fields measurable in time: local and global existence, uniqueness, continuity and differentiability with respect to initial conditions.
3. An abstract constrained minimum problem.
4. The Pontryagin Maximum Principle (PMP) with end-point constraints, with applications.
5. Controllability of control systems, at the first or higher order (Lie brackets).
6. If time permits: basic elements of Hamilton-Jacobi PDE's.

An Introduction to moduli spaces

Prof. Orsola Tommasi[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Universitá di Padova*
Email: tommasi@math.unipd.it

Timetable: hrs. 24. First lecture on December 2, 2020, 11:00 (dates already fixed, see calendar), Torre Archimede, Room 1BC/50.

Course requirements: Basic notions of geometry, as provided by a Mathematics degree. This course is open to any PhD student. Depending on the students' background, I will include a review of useful notions from geometry and topology.

Examination and grading:

SSD: MAT/02

Aim:

Course contents:

A moduli space is a space parametrizing all possible objects of a certain fixed type. A classical example is the following: let us fix a compact oriented surface $\sum$. Then the space of all possible complex structures on $\sum$ is the moduli space $\mathcal{M}$ of genus g Riemann surfaces, where g is the topological genus of $\sum$. By construction, the points of $\mathcal{M}_g$ correspond to the isomorphism classes of Riemann surfaces of genus g. This kind of construction generalizes to many other classification problems. In good cases, moduli spaces will turn out to be complex manifolds or varieties. However, in most cases the moduli space will not be truly a manifold, but rather a mild generalization of it, called an *orbifold*. Although the construction of moduli spaces originates in algebraic geometry, moduli spaces themselves are of interest also in other areas of mathematics, such as other areas of geometry, topology, group theory, analysis and mathematical physics. In this course, I would like to present the basic ideas and formalism underlying the concept of moduli space, along with some main examples of interdisciplinary interest. Besides the moduli space of Riemann surfaces, interesting examples with applications in different fields include:

- mirror symmetry, a construction from theoretical physics that predicts that there exist pairs of topological spaces $(X; X^*)$ such that the moduli space of complex structures on X is isomorphic to the moduli space of symplectic structures on X^*, and vice versa;
- modular curves in number theory, which are moduli spaces parametrizing elliptic curves with additional structures.

References: (tentative list)

- Kock, Joachim; Vainsencher, Israel. An invitation to quantum cohomology. Kontsevich's formula for rational plane curves. Progress in Mathematics, 249. Birkhäuser Boston, Inc., Boston, MA, 2007. xiv+159 pp.

- Newstead, P. E. Introduction to moduli problems and orbit spaces. Tata Institute of Fundamental Research Lectures on Mathematics and Physics, 51. Tata Institute of Fundamental Research, Bombay; by the Narosa Publishing House, New Delhi, 1978. vi+183 pp.
- Cox, David A.; Katz, Sheldon. Mirror symmetry and algebraic geometry. Mathematical Surveys and Monographs, 68. American Mathematical Society, Providence, RI, 1999. xxii+469 pp.
- Harris, Joe; Morrison, Ian. Moduli of curves. Graduate Texts in Mathematics, 187. Springer-Verlag, New York, 1998. xiv+366 pp.

Courses of the “Mathematics” area

Sub-Riemannian Geometry

Prof. Andrei Agrachev[1], Prof. Davide Barilari[2]

[1]Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste
Email: agrachev@sissa.it

[2]Dipartimento di Matematica "Tullio Levi-Civita", Universitá di Padova
Email:barilari@math.unipd.it

Timetable: 16 hrs. First lecture on April 13, 2021, 14:30. The course will be held online from prof. Andrei Agrachev with the follow calendar:
Tue April 13, 20, 27 at 14:30; Wed April 14, 21, 28 at 12:30 and Thu April 15, 22 at 11:30.
Link Zoom to the course: **This is a recurring meeting Meet anytime:**
https://unipd.zoom.us/j/81394988324 - Meeting ID: 813 9498 8324

Starting from March 17, 12:30, Torre Archimede, **at the same link Zoom**, a previous part of the course, addressed to students of Scuola Galileiana, but warmly recommended also to PhD Students, will be helded by prof. Davide Barilari according to the follow calendar:
Tue March 23, 30 at 14:30; Wed March 17, 24, 31, April 7 at 12:30 and Thu April 8 at 11:30.

Course requirements: basic differential geometry

Examination and grading:

SSD: MAT/05

Aim: Sub-Riemannian geometry is the geometry of a world with nonholonomic constraints. In such a world, one can move, send and receive information only in certain admissible directions but eventually one can reach every position from any other. In the last two decades sub-Riemannian geometry has emerged as an independent research domain impacting on several areas of pure and applied mathematics, with applications to many areas such as quantum control, image reconstructions, robotics and PDEs.

The fist part of the course is mainly an introduction to the subject towards theory and examples coming from applications such as mechanics. The second part focuses on more advanced questions, providing students to recent progress in the field and open questions.

Course contents:
Part 1
Vector fields, flow and Lie brackets. Frobenius and Chow-Rashevskii theorem. Applications to rolling spheres and isoperimetric problems.
Sub-Riemannian distance. Metric completeness. Pontryagin extremals : Symplectic geometry and Hamiltonian formalism. Normal and abnormal extremals. Examples in dimension 3.
Part 2
The second part will focus on different questions around abnormal extremal and length-minimizers, with discussions on recent advances and open questions.

References:
A Comprehensive Introduction to Sub-Riemannian Geometry, Cambridge Studies in Advanced Mathematics, Cambridge University Press, 2019

Introduction to Hyperbolic Conservation Laws

Prof. Fabio Ancona[1], Prof. Massimiliano Daniele Rosini[2]

[1] *Dipartimento di Matematica, Universit'¡ Padova*
Email: ancona@math.unipd.it

[2] *Dipartimento di Matematica e Informatica, Universitá di Ferrara*
Email: massimilianodaniele.rosini@unife.it

Timetable: 16 hrs. First lecture on May 3, 2021, 09:00 (dates already fixed, see calendar), Torre Archimede. The course will be held online at:
Zoom recurring meeting: https://unipd.zoom.us/j/98274705354 - Meeting ID: 982 7470 5354

Course requirements: very basic notions of ODE and PDE theory

Examination and grading: seminar

SSD: MAT/05 - Mathematical Analysis

Aim: the course aims at providing an introduction to:
- fundamental features of the theory of hyperbolic conservation laws in one space variable;
- topics in recent research on traffic flow models and networks for this class of first order non-linear PDEs.

The course shall be of particular interest for students in Mathematical Analysis, Mathematical Physics, Numerical Analysis, especially if interested in fluid dynamics models.

Course contents:
Part 1
Introduction to the general theory of entropy weak solutions of conservation laws. Discontinuous distributional solutions. Riemann problem. Wave front-tracking algorithm.
Part 2
Conservation laws with discontinuous flux and with point constraints. Analysis of traffic flow models via vanishing viscosity and many particle approximations (micro-macro limit).

References:

- A. Bressan, Hyperbolic Systems of Conservation Laws, The One-Dimensional Cauchy Problem, Oxford.
- C.M.Dafermos, Hyperbolic Conservation Laws in Continuum Physics, Fourth, ed. Springer Verlag.
- M. Garavello, K. Han, and B, Piccoli, Models for vehicular traffic on networks, AIMS, 2016.
- Massimiliano D. Rosini, Macroscopic Models for Vehicular Flows and Crowd Dynamics: Theory and Applications, Springer, 2013.

Mathematics and Music: algebraic, categorical and computational methods in the maths/music research (Part 1)

Moreno Andreatta[1], Emmanuel Amiot[2], Greta Lanzarotto[3]

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[2] *Laboratoire de Mathématiques, Physique, et Informatique, Université de Perpignan, France*
Email: manu.amiot@free.fr

[3] *PhD student, University of Milano Bicocca - Université de Strasbourg*
Email: g.lanzarotto@campus.unimib.it

Timetable: 18 hrs., from May 3 to May 14. Moreno Andreatta: 3-4-5-6 May 15:30 - 17:30. Emmanuel Amiot: 7-10-11 May from 15:30 - 17:30. Greta Lanzarotto 12-13 May from 15:30 - 17:30. The course will be held online at:
https://unipd.zoom.us/j/84271750221?pwd=L0Jib1VBMVRzVCtUUjVVcE8xR1VkZz09
Meeting ID: 842 7175 0221 - Passcode: MathMusic

Course requirements: Basics of Algebra and Geometry.

Examination and grading:

SSD: MAT/02, MAT/03.

Aim: Despite a long historical relationship between mathematics and music, the interest of mathematicians for Music Theory is a recent phenomenon. The aim of this doctoral course on mathematics and music is to give a structural multidisciplinary approach into computational musicology making use of advanced mathematical tools. It is based on the interplay between different mathematical disciplines: algebra, topology and category theory. New results and perspectives are possible on important challenges such as revealing through suitable mathematical tools musical properties, studying the computational aspects of musical processes, preparing the automatic classification of musical styles.

Course contents: The first part of the course provides an introduction of the most active research axes in contemporary 'mathemusical' research by focusing on the SMIR project, a multidisciplinary research project based at IRMA (Institut de Recherche Mathématique Avancée) and carried on in collaboration with the Music Representation Team at IRCAM (Paris) and many researchers belonging to the international Society of Mathematics and Computation in Music (SMCM). After a survey on a panoply of research topics, special emphasis will be given to the topological representation and algebraic formalisation of different harmonic music spaces (the Generalized Tonnetze). Discrete Fourier Transform on algebraic structures will be used in order to provide computational tools for the study of chords, scales, rhythms and other musical parameters. The course will also include a special focus on tiling problems music composition and their link with Fuglede Spectral Conjecture (still open in dimension 1 and 2).

References:

- Emmanuel Amiot, *Music Through Fourier Space: Discrete Fourier Transform in Music Theory,* Springer, 2016.
- Moreno Andreatta, “From music to mathematics and backwards: introducing algebra, topology and category theory into computational musicology”, in M. Emmer and M. Abate (eds.), *Imagine Math 6 - Mathematics and Culture, XXth Anniversary*, Springer, 2018, pp. 77-88. Available at:
- Luis Bigo, Moreno Andreatta, “Topological Structures in Computer-Aided Music Analysis”, in D. Meredith (ed.), *Computational Musicology*, Springer, 2015, p. 57-80. Available at:
- Jordan B. L. Smith, Elaine Chew and G. Assayag (eds), *Mathemusical Conversations. Mathematics and Computation in Music Performance and Composition*. Lecture Notes Series, Institute for Mathematical Sciences, National University of Singapore: Volume 32, 2016.

Mathematics and Music: algebraic, categorical and computational methods in the maths/music research (Part 2)

Franck Jedrzejewski[1], Thomas Noll[2], Alexandre Popoff[3]

[1] *CEA and Collège international de philosophie, France*
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[2] *ESMuC, Spain and TU-Berlin, Germany*
Email: thomas.mamuth@gmail.com

[3] *Independent researcher, France*
Email: al.popoff@free.fr

Timetable: 18 hrs. (17 May 2021 - 27 May 2021).
Franck Jedrzejewski: 17-18-19 May 15:30 - 17:30 (the course will be held online, see below the link Zoom).
Thomas Noll: 20-21-24 May 15:30 - 17:30 (the course will be held in presence in Room 2AB40 and also online, see below the link Zoom).
Alexandre Popoff: 25-26-27 May 15:30 - 17:30 (the course will be held online, see below the link Zoom).

https://unipd.zoom.us/j/84271750221?pwd=L0Jib1VBMVRzVCtUUjVVcE8xR1VkZz09
Meeting ID: 842 7175 0221 - Passcode: MathMusic

Course requirements:

Examination and grading:

SSD: MAT/02, MAT/03.

Aim: Despite a long historical relationship between mathematics and music, the interest of mathematicians for Music Theory is a recent phenomenon. The aim of this doctoral course on mathematics and music is to give a structural multidisciplinary approach into computational musicology making use of advanced mathematical tools. It is based on the interplay between different mathematical disciplines: algebra, topology and category theory. New results and perspectives are possible on important challenges such as revealing through suitable mathematical tools musical properties, studying the computational aspects of musical processes, preparing the automatic classification of musical styles.

Course contents: The second part of the course focuses on three specific topics in mathemusical research: homometry and neo-riemannian musical theories; Word theory and its application to scales, modes, chords and rhythms; Categorical formalization of transformational theory. This second part of the course shows some non-trivial intersections between different domains in mathematics (algebra, combinatorics, category theory) that are applied to music-theoretical and analytical situations dealing with the formalisation and representation of musical structures and processes.

References:

- Franck Jedrzejewski, *Hétérotopies musicales. Modèles mathématiques de la musique,* Paris, Hermann, 2019.
- Franck Jedrzejewski, *Mathematical Theory of Music*, Éditions Delatour/IRCAM, 2006
- Srečko Brlek, Marc Chemillier and Christophe Reutenauer, "Music and Combinatorics on Words". Special Issue of the *Journal of Mathematics and Music*, Vol. 12, Issue 3, 2018. Available at:
- David Clampitt and Thomas Noll, "Modes, the Height-Width Duality, and Handschin?s Tone Character", *Music Theory Online*, Vol. 17, Issue 1. Available online at:
- Alexandre Popoff, Moreno Andreatta, Andrée Ehresmann, "Relational PK-Nets for Transformational Music Analysis", *Journal of Mathematics and Music*, Vol. 12, Issue 1, 2018, p. 35-55.
- Alexandre Popoff, Moreno Andreatta, Andrée Ehresmann, "Groupoids and Wreath Products of Musical Transformations: A Categorical Approach from poly-Klumpenhouwer Networks", in M. Montiel et al. (eds), Proceedings of the Mathematics and Computation in Music Conference 2019, Springer, pp. 33-45. Available at:

Nichols algebras

Giovanna Carnovale[1], Lleonard Rubio y Degrassi[2], Francesco Esposito[3]

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Email: lleonard@math.unipd.it

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Email: esposito@math.unipd.it

Timetable: 16 hours. First lecture on November 4, 2020, 10:00, Torre Archimede, Room 1BC/45 (eventual). The course will be held online at:
https://unipd.zoom.us/j/86466409649?pwd=VU9MQkNqWXQ3Mmo2aTJUUGZNdTB4dz09
Meeting ID: 864 6640 9649, Passcode: 606905

Course requirements:

Examination and grading: oral

SSD: MAT/02, MAT/03

Aim: The course intends to give a basic introduction to Nichols algebras, focusing on the different constructions available and on the classification problem.

Course contents:

Nichols (shuffle) algebras are a family of algebras including many important examples, such as the symmetric and exterior algebras, and the positive part of quantised enveloping algebras of semisimple Lie algebras. Their presentation by generators and relations can be given in different terms: representation of the braid group, derivations, bilinear forms. A geometric interpretation in terms of perverse sheaves on symmetric products of the complex line has been recently introduced by Kapranov and Schechtman, opening a new bridge between algebra, topology and algebraic geometry. They have also been used by Ellenberg, Tran, and Westerland in their proof of the upper bound of Malle's conjecture on the distribution of finite extensions of $\mathbb{F}_q(t)$ with specified Galois group.

Each Nichols algebra depends in fact only on a braiding on a vector space, i.e., on a solution of the braid equation, or, equivalently, of the Quantum Yang-Baxter equation. When the braiding is diagonal, finite-dimensional Nichols algebras have been classified by the work of Andruskiewitsch-Schenider, Heckenberger, Angiono, whereas the classification problem is still open in the non-diagonal case.

1. Hopf algebras, bialgebras and coalgebras and duality
2. The braid groups, Coxeter groups and reduced expressions
3. Braided vector spaces and braided monoidal (tensor) categories
4. Nichols algebras. First definition and main examples (symmetric algebra, exterior algebra, quantized nilpotent subalgefbras)

5. How to detect Nichols algebras. Equivalent definitions: derivations, properties of the ideal of definition, the bilinear form and Poincaré duality
6. PBW-type bases, the root system and the Weyl groupoid in the diagonal case
7. The classification problem of finite-dimensional Nichols algebras: the diagonal and non-diagonal case and the rack approach.
8. Kapranov-Schechtman's interpretation in terms of perverse sheaves on symmetric products of the complex line.

Bibliografy:

- N. Andruskiewitsch and H.-J. Schneider, Pointed Hopf algebras, New Directions in Hopf Algebras, MSRI Publications, vol. 43, Cambridge University Press, 2002.
- I. Heckenberger: Nichols Algebras (Lecture Notes), 2008 http://www.mi.uni-koeln.de/ iheckenb/na.pdf
- M. Kapranov. V. Schechtman, Shuffle algebras and perverse sheaves, https://arxiv.org/abs/1904.09325
- L. Vendramin, Nichols Algebras (Lecture Notes) http://mate.dm.uba.ar/ lvendram/lectures/rauischholzhau

Further reading

- J. S. Ellenberg, T. T. Tran, C. Westerland. Fox-Neuwirth-Fuks cells, quantum shuffle algebras and Malle's conjecture for functional fields. arXiv:1701.04541.
- E. Meir, Geometric perspective on Nichols algebras, https://arxiv.org/abs/1907.11490

Regularity theory for parabolic equations

Dr. Marco A. Cirant[1], Dr. Alessandro Goffi[2]

[1] Dipartimento di Matematica "T.Levi-Civita"
Email: cirant@math.unipd.it
[2] Dipartimento di Matematica "T.Levi-Civita"
Email: alessandro.goffi@math.unipd.it

Timetable: 16 hrs. First lecture on February 22, 2021, 11:00 (dates already fixed, see calendar), Torre Archimede, Room 1BC/45.

Course requirements: Basic knowledge of linear parabolic PDEs, Sobolev and Hölder spaces, Functional Analysis.

Examination and grading: The exam will be oral and tailored on the basis of the students' interests.

SSD: MAT/05

Aim: Introduce some classical and modern methods to study the regularity of solutions to linear and semi-linear parabolic partial differential equations.

Course contents:

- Recall of basic properties of L^p, Sobolev and Hölder spaces. Introduction of basic concepts in real interpolation and semigroup theory.
- A glimpse of regularity for abstract linear parabolic equations; space-time Schauder's estimates.
- Regularity properties of linear transport-diffusion equations.
- Regularity properties of semi-linear parabolic problems with super-linear first order terms: the nonlinear adjoint method.
- Applications to systems of parabolic PDEs arising in the theory of Mean Field Games.

Bibliografy:

1. A. Lunardi. *Interpolation theory*, volume 16 of *Appunti. Scuola Normale Superiore di Pisa (Nuova Serie)*. Edizioni della Normale, Pisa, 2018. Third edition.
2. V.I. Bogachev, N.V. Krylov, M. Röckner, and S.V. Shaposhnikov. *Fokker-Planck-Kolmogorov equations*, volume 207 of *Mathematical Surveys and Monographs*. American Mathematical Society, Providence, R.I., 2015.
3. R. Dautray and J.-L. Lions. *Mathematical analysis and numerical methods for science and technology. Vol. 5*. Springer-Verlag, Berlin, 1992. Evolution Problems.

Introduction to Dispersive Equations

Prof. Piero D'Ancona[1]

[1] Dipartimento di Matematica, Universitá La Sapienza, Roma
Email: dancona@mat.uniroma1.it

Timetable: 16 hrs. see webpage https://dottorato.math.unipd.it/calendar/202104 the lectures will be held online on zoom, at the following link
https://unipd.zoom.us/j/83227085508? pwd=Vlo2dlBaNFgvaDRMOHVvbzNRNEVIQT09
Start: April 7th, 2021

Course requirements: Sobolev spaces, Fourier transform, a good understanding of basic Functional and Real Analysis

Examination and grading: TBA

SSD: MAT/05

Aim: the course will provide an introduction to the theory of the Nonlinear Schrodinger equation (NLS) as a model of the class of nonlinear dispersive equations.

Course contents:

1. The linear flows: classical representations vs the approach from spectral theory.
2. Dispersive properties of the flows: pointwise decay, Strichartz estimates, smoothing estimates.
3. Nonlinear perturbations: what is a solution? Defocusing vs focusing NLS. The L2 theory. The H1 theory. Global existence and blow up results.
4. Scattering for NLS: classical and modern results.
5. Other dispersive models: nonlinear waves, Klein-Gordon, Dirac and KdV equations.

Maximal subgroups of the symmetric group

Dott. Martino Garonzi[1]

[1] *Departamento de Matemíca, University of Brasilia, Brazil*
Email: mgaronzi@gmail.com

Timetable: 16 hours. November 10-12-17-19-24-26, December 1-2, 2020, 14:30, online.

Course requirements:

Examination and grading: Seminar talk

SSD: MAT/02

Aim:

Course contents:

In this course I will talk about maximal subgroups of the symmetric group, specifically the various types of maximal subgroups: intransitive, imprimitive, and primitive. I will work out several basic examples. Concerning primitive groups, I will talk about their important role in group theory and their connection with simple groups, characteristically simple groups, multiple transitivity, Jordan groups and the O'Nan-scott theorem, affine groups, almost-simple groups, product actions and diagonal actions. I will give applications in terms of recent research papers.

Bibliografy:

1. Cameron, Peter J.; Permutation groups. London Mathematical Society Student Texts, 45. Cambridge University Press, Cambridge, 1999.
2. Dixon, John D.; Mortimer, Brian; Permutation groups. Graduate Texts in Mathematics, 163. Springer-Verlag, New York, 1996.
3. M. Isaacs, Finite Group Theory. Graduate Studies in Mathematics, 92. American Mathematical Society. Providence, RI, 2008.
4. Liebeck, Martin W.; Praeger, Cheryl E.; Saxl, Jan; On the O'Nan-Scott theorem for finite primitive permutation groups. J. Austral. Math. Soc. Ser. A 44 (1988), no. 3, 389-396.
5. J. S. Rose, A course on group theory, Cambridge University Press, 1978.
6. Schneider, C; Praeger, C; Permutation Groups and Cartesian Decompositions, London Mathematical Society Lecture Notes, 2018.

Spaces and operators in complex analysis

Prof. Alexey Karapetyants[1]

[1] Institute for Mathematics, Mechanic and Computer Sciences, Southern Federal University, Russia
Email: karapetyants@gmail.com

Timetable: 12 hrs. First lecture on ..., ... , Torre Archimede, Room 2BC/30.

Course requirements:

Examination and grading:

SSD: MAT/05

Aim: The function theory of holomorphic spaces has experienced several breakthroughs during the last five-ten years. Some new spaces of nonstandard growth were introduced and studied. This was possible during to the mixture of the methods of real and complex harmonic analysis involved in the study of such spaces and operators. However, the basics are still going back to the classical Bergman type and even Hardy spaces. Therefore, studying classical approach along with new trends will open a good perspective for the further development of the subject.

Course contents:

1. Classical spaces of holomorphic functions: Hardy, Bergman, Besov, Holder spaces.
2. Basic properties of the mentioned spaces: duality, interpolation, atomic decomposition.
3. Holomorphic spaces of nonstandard growth: variable exponent, Orlicz, Morrey, generalized Holder spaces.
4. Operators and transforms on these classical and new spaces: Bergman projection, more general operators, including potentials and operators of fractional integroodifferentiation, Berezin transform, composition operators, Toeplitz operators.
5. Recent advances: new classes of integral operator in complex analysis of Hausdorf, Hardy and Bergman type, some applications.

Rational points on varieties

Remke Kloosterman

Dipartimento di Matematica 'Tullio Levi-Civita"
Email: klooster@math.unipd.it

Timetable: 16 hrs. First lecture on March 5, 2021, 10:00, (date already fixed, see Calendar) Torre Archimede, Room 1BC/50.

Course requirements: Basic knowledge of algebraic geometry (definition of an algebraic variety; morphisms between algebraic varieties; interaction between algebra and geometry; genus of an algebraic curve/Riemann surface) and algebraic number theory (some knowledge on ring of integers of a number field; completion of a number field).

Examination and grading: Seminar talk.

SSD: MAT/02 and MAT/03

Aim: An introduction to the study of rational points on varieties, in particular on curves, abelian varieties and Del Pezzo surfaces.

Course contents:

1. Revisiting field theory (C_r fields; Galois theory)
2. Introduction to varieties over arbitrary fields
3. Weil conjectures for algebraic curves over finite fields
4. Properties of morphisms
5. Algebraic groups and group cohomology
6. Selmer groups and Tate-Shafarevich groups and rational points on elliptic curves and abelian varieties.
7. Brauer-Manin obstruction and rational points on Del Pezzo surfaces

Bibliografy: Bjorn Poonen, Rational points on Varieties, American Mathematical Society, 2017.

The theory of the defect and its application to the problem of local uniformization

Prof. Franz-Viktor Kuhlmann[1]

[1] Department of Mathematics, University of Szczecin, Poland
Email: fvk@math.usask.ca

Timetable: 16 hrs. First lecture on February 19, 2021, 15:00 (dates already fixed, see calendar), the course will be held online at:
https://unipd.zoom.us/j/84197177413?pwd=QXRyKzRpbk43RUg5TWREbnhieHdvQT09
Meeting Zoom: ID 841 9717 7413 Passcode: 294477

Some introductory lessons to the course will be held by prof. Giulio Peruginelli starting from February 15, 2021, 09:00.

Course requirements: Basic knowledge of field theory, ordered groups, basic valuation theory

Examination and grading: Students will be evaluated by presentations they will give in the seminar that will follow the course.

SSD: MAT/02, MAT/03

Aim: To introduce graduate students to some deep open research problems in valuation theory, providing known partial results and their proofs.

Course contents:

- Meeting 1: Finite extensions of valued fields and their invariants - the fundamental inequality - the defect - the Lemma of Ostrowski - examples of defect extensions.
- Meeting 2: Ramification theory of normal extensions of valued fields - absolute ramification theory - tame and separably tame fields.
- Meeting 3: Valued function fields - the Abhyankar inequality and Abhyankar valuations - extensions of valuations to function fields - Zariski spaces of places I.
- Meeting 4: The Generalized Stability Theorem I.
- Meeting 5: The Generalized Stability Theorem II - local uniformization for Abhyankar places.
- Meeting 6: Henselian Rationality I.
- Meeting 7: Henselian rationality II - local uniformization by alteration.
- Meeting 8: Connection with other problems: decidability of the elementary theory of Laurent series fields over finite fields - valued function fields revisited - Zariski spaces of places II - open problems and new approaches.

Introduction to Floer Homology

Marco Mazzucchelli[1]

[1] *CNRS, École Normale Supérieure de Lyon, UMPA, France*
Email: marco.mazzucchelli@ens-lyon.fr

Timetable: 12 hrs. First lecture on 25 September, 2020; the course will be held online via Zoom (the link to the meeting will be communicated a few days before the start of the course)

Timetable of the lectures:
Friday Sept 25, 2020, 10:00 - 12:00
Monday Sept 28, 2020, 10:00 - 12:00
Tuesday Sept 29, 2020, 10:00 - 12:00
Wednesday Sept 30, 2020, 10:00 - 12:00
Thursday Oct 1st, 2020, 16:30 - 18:30
Friday Oct 2, 2020, 10:00 - 12:00

Course requirements: The students attending this course are required to know the basics of functional analysis (Banach and Hilbert spaces), differential geometry and topology (manifolds, vector fields, differential forms, vector bundles, Riemannian metrics, critical points of a smooth map), and some symplectic geometry (symplectic forms, Hamiltonian vector fields).

Examination and grading:

SSD: MAT/07

Aim:

Course contents (tentative):

- **Lecture 1:** Crash course in algebraic topology: singular homology and co-homology, De Rham cohomology.
- **Lecture 2:** The Morse homology theorem.
- **Lecture 3:** Variational principle for Hamiltonian periodic orbits, action spectrum, the Conley-Zehnder index.
- **Lecture 4:** Construction of the Floer homology groups for aspherical manifolds I.
- **Lecture 5:** Construction of the Floer homology groups for aspherical manifolds II, proof of the Arnold conjecture on the fixed points of generic Hamiltonian diffeomorphisms.
- **Lecture 6:** Bott's iteration formula for the Conley-Zehnder index, proof of the Conley conjecture on the periodic points of generic Hamiltonian diffeomorphisms of aspherical manifolds. Bonus arguments: Floer homology for monotone manifolds, products in Floer homology, spectral invariants, symplectic homology, etc.

Refereces:

- M. Audin, M. Damian, Morse theory and Floer homology, Universitext. Springer, London; EDP Sciences, Les Ulis, 2014. xiv+596 pp. ISBN: 978-1-4471-5495-2; 978-1-4471-5496-9; 978-2-7598-0704-8.
- A. Banyaga, D. Hurtubise, Lectures on Morse Homology, Lectures on Morse homology. Kluwer Texts in the Mathematical Sciences, 29. Kluwer Academic Publishers Group, Dordrecht, 2004. x+324 pp. ISBN: 1-4020-2695-1.
- D. Salamon, Lectures on Floer homology, Symplectic geometry and topology (Park City, UT, 1997), 143-229, IAS/Park City Math. Ser., 7, Amer. Math. Soc., Providence, RI, 1999.
- D. Salamon, E. Zehnder, Morse theory for periodic solutions of Hamiltonian systems and the Maslov index, Comm. Pure Appl. Math., 45 (1992), 1303-1360
- M. Schwarz, Morse homology, Progress in Mathematics, 111. Birkhauser Verlag, Basel, 1993. x+235 pp. ISBN: 3-7643-2904-1

Positivity of Divisors and Vector Bundles in Algebraic Geometry

Ernesto C. Mistretta[1], Stefano Urbinati[2]

[1] *Dipartimento di Matematica*
Università di Padova Email: ernesto.mistretta@unipd.it

[2] *Dipartimento di Matematica e Informatica*
Università di Udine Email: urbinati.st@gmail.com

Timetable: 16 hrs. First lecture on April 8, 2021, 11:00 date already fixed, see Calendar) Torre Archimede, Room 1BC/50.

Course requirements: Basic algebraic geometry.

Examination and grading: Seminar.

SSD: MAT/03.

Aim: Have a view on the algebraic aspects of positivity, in the cases of divisors, line bundles and vector bundles.

Course contents:

- Introduction. Divisors on projective varieties: Weil divisors, Picard divisors, Cartier divisors. Global sections.
- Divisor groups, numerical equivalence, duality. Equivalence on smooth varieties. Real divisors.
- Divisor cones. Properties of cones of divisors, criterions.
- Base loci of line bundles. Asymptotic properties.
- Time permitting: parenthesis on Okunkov bodies; examples; birational properties.
- Vector bundles and their base loci. Projective bundles, Grassmannian varieties. Globally generated vector bundles.
- Asymptotic base loci for vector bundles, positivity for vector bundles, algebraic properties and analytic properties.
- Varieties with positive tangent / cotangent bundle, some characterizations.

Bibliografy: Robert Lazarsfeld, Positivity in Algebraic Geometry I ans II, Springer.

Campanato Spaces and their Applications to Regularity of Solutions to PDEs

Prof. Vincenzo Vespri[1]

[1] Dipartimento di Matematica e Informatica "Ulisse Dini", Università degli Studi di Firenze
Email: vincenzo.vespri@unifi.it

Timetable: 8 hrs. First lecture on May 26, 2021, 13:30 (dates already fixed, see calendar), Torre Archimede, Room 1BC/45. The course will be held also online. Link Zoom to the event: https://unipd.zoom.us/j/86942695772?pwd=NVFKekhDNnFKVWJVOUhOcG5YSGczQT09
Meeting ID: 869 4269 5772 Passcode: 317937

Course requirements: standard undergraduate background in Mathematical Analysis

Examination and grading: oral exam

SSD: MAT/05

Course contents:

In his seminal papers published in 1963 Sergio Campanato introduced the spaces that nowadays are named after him. These spaces play an important role in regularity theory and harmonic analysis. The classical regularity approach was based on the singular integrals theory approach introduced by A.P. Calderón and A. Zygmund who proved in particular regularity in L^p for solutions to elliptic or parabolic equations, see [**?**]. J. Nash [**?**] used this approach to solve the XIX Hilbert problem and proved Hölder regularity for solutions to elliptic and parabolic equations with L^∞ coefficients. One year before, E. De Giorgi [**?**] proved the same result using a functional space approach. S. Campanato proved that De Giorgi's approach works also in the case of equations with mildly regular coefficients (i.e., continuous or Hölder continuous coefficients) recovering the Calderon-Zygmund results, see [**?**, **?**].

The focus of this PhD class is on Campanato's approach. The lecture course will be organized as follows. Lectures I and II: definition of Campanato spaces, their embedding in the space of Hölder continuous functions, preliminary lemmata; Lectures III and IV: estimates in L^p for solutions to elliptic operators; Lectures V and VI: estimates in Hölder classes for solutions to elliptic operators; Lectures VII and VIII: proof of De Giorgi regularity result.

Bibliografy:

1. A.P. Calderon, A. Zygmund, *On singular integrals.* American Journal of Mathematics, The Johns Hopkins University Press, 78 (2) (1956), 289–309.
2. S. Campanato, G. Stampacchia, *Sulle maggiorazioni in L^p nella teoria delle equazioni ellittiche.* (in Italian) Bollettino dell'Unione Matematica Italiana, Serie 3, Vol. 20 (1965), n.3, p. 393-399. Bologna, Zanichelli, 1965.
3. S. Campanato, *Sistemi ellittici in forma divergenza: regolarità all'interno.* (in Italian) Pisa, Scuola Normale Superiore editors, 1980.
4. E. De Giorgi, *Sulla differenziabilità e l'analiticità delle estremali degli integrali multipli regolari.* (in Italian) Mem. Accad. Sci. Torino Cl. Sci. Fis. Mat. Nat., (3) 3 (1957),

Dynamic Optimization

Richard Vinter[1]

[1] *Department of Electrical and Electronic Engineering, Faculty of Engineering, Imperial College, London*
Email: r.vinter@imperial.ac.uk

Timetable: 12 hrs. First lecture on September 13, 2021, 10:00 (dates already fixed see calendar),Torre Archimede, Room 1BC50 and online at
Zoom Meeting
https://unipd.zoom.us/j/86729567873?pwd=S3dqS2U1Y1hkSWFpTE9rbEpCWUFGZz09
Meeting ID: 867 2956 7873 - Passcode: Vinter21

Course requirements: There are no pre-requisites, but if the students have done an earlier course in control, they will find my lectures easier to understand.

Examination and grading: Oral examination

SSD: MAT/05

Aim: Dynamic optimization concerns optimization problems, in which we seek to minimize a functional over arcs that satisfy some kind of dynamic constraint. When this constraint takes the form of a controlled differential equation, such problems are known as optimal control problems. In Dynamic Optimization, the 'dynamic constraint' is allowed a broader interpretation, and is formulated as, say, a differential inclusion. Earlier applications of the theory were principally in aerospace (selection of flight trajectories in space missions) and chemical engineering. But now the field is recognised as having far wider application, in econometrics, resource economics, robotics and control of driverless vehicles, to name just a few areas. Dynamic optimization dates back, as a unified field of study, to the early 1950's, when two breakthroughs occured. One was the Maximum Principle, a set to necessary conditions for a control function to be optimal. The other was dynamic programming, which reduces the search for optimal controls to the solution of the Hamilton Jacobi equation (HJE). Early developments in the field relied on classical analysis and, even today, introductory courses on Optimal Control given based on traditional calculus. But, more recently, advances in the field have increasingly depended on new techniques of nonlinear analysis, which are referred to, collectively, as nonsmooth analysis. Nonsmooth analysis aims to give meaning to the 'derivative' of functions that are not differentiable in the classical sense and to tangent vectors to sets with nonsmooth boundaries. First order necessary conditions and Hamilton Jacobi theory continue to have a prominent role in the latest developments, but now interpreted in deeper and more insightful ways.

We begin the course by identifying deficiencies in the early theory and explaining why new analytical tools were needed to move the theory forward. We then introduce these tools (the main constructs of nonsmooth analysis and an accompanying calculus) and use them to derive optimality conditions (both first order necessary conditions and conditions related to the (HJE) equation). Our goal is to bring participants in the course 'up to speed', so that they can follow the latest literature, understand the underlying motivation and make future contributions.

Course contents:

Part I (Preliminaries) Dynamic Optimization (significance and illustrative examples)

Nonsmooth Analysis:

- Basic constructs (subdifferentials, normal cones, etc.)
- Subdifferential calculus
- The generalized mean value inequality
- Nonsmooth multiplier rules in Nonlinear Programming

Additional analytic techniques:

- Variational principles
- Compactness of trajectories
- Quadratic inf convolution
- Exact penalisation

Part II (First Order Necessary Conditions)

The maximum principle

The nonsmooth maximum principle

Necessary conditions for differential inclusion problems:

- The Generalized Euler Inclusion The Hamiltonian Inclusion
- Refinements to allow for pathwise state constraints.

Part III (Dynamic Programming)

Invariance:

- Weak invariance theorems
- Strong invariance theorems

Generalized solutions to the HJ equations

Links with viscosity solution concepts

Characterisation of the value function as generalized solution of (HJE)

Refinements to allow for pathwise state constraints

Part IV (Miscellaneous Topics)

Regularity of minimizers

Non-standard optimal control problems:

- discontinuous state trajectory problems
- problems involving time delay
- open problems and future directions.

Bibliografy:

I will provide a handout and will deliver slides for my lectures. I will aim to make my handout self-contained and there are no course texts. (The course will be based on a revision of by 2000 book 'Optimal Control', which I am currently working on.)

Courses of the “Computational Mathematics” area

Pluri-Potential Theory and Zeros of Random Polynomials

Prof. Turgay Bayraktar[1]

[1] *Faculty of Engineering and Natural Sciences, Sabanci University ISTANBUL, TURKEY*
Email tbayraktar@sabanciuniv.edu

Timetable: 16 hrs. POSTPONED TO THE NEXT YEAR

Course requirements:

Examination and grading:

SSD:

Course contents:

The purpose of this mini-course is to introduce basic notions of complex potential theory in order to study statistics and asymptotic distribution of zeros of random polynomials. In the first part, we will cover central objects of interest of the modern weighted pluripotential theory in several complex variables, such as the pluricomplex Green functions, regular sets, equilibrium measures, Bernstein-Markov measures and Bergman functions. In the second part, we will focus on statistics of zeros of random polynomials and polynomial mappings.

Bibliografy:

[Bay16] T. Bayraktar. Equidistribution of zeros of random holomorphic sections. Indiana Univ. Math. J., 65(5):1759–1793, 2016.

[Bay17] T. Bayraktar. Asymptotic normality of linear statistics of zeros of random polynomials. Proc. Amer. Math. Soc., 145(7):2917–2929, 2017.

[Bay20] T. Bayraktar. Mass equidistribution for random polynomials. Potential Anal., 53 (2020), no. 4, 1403-1421.

[BCHM18] T. Bayraktar, D. Coman, H. Herrmann, and G. Marinescu. A survey on zeros of random holomorphic sections. Dolomites Res. Notes Approx., 11(4):1–19, 2018.

[BCM] T. Bayraktar, D. Coman, and G. Marinescu. Universality results for zeros of random holomorphic sections. Trans. Amer. Math. Soc., 373(6): 3765-3791, 2020.

[Bl05] T. Bloom. Random polynomials and Green functions. Int. Math. Res. Not., (28):1689–1708, 2005.

[Bl] T. Bloom and N. Levenberg. Random Polynomials and Pluripotential-Theoretic Extremal Functions. Potential Anal., 42(2):311–334, 2015.

[SZ99] B. Shiffman and S. Zelditch. Distribution of zeros of random and quantum chaotic sections of positive line bundles. Comm. Math. Phys., 200(3):661–683, 1999.

[SZ08] B. Shiffman and S. Zelditch. Number variance of random zeros on complex manifolds. Geom.Funct. Anal., 18(4):1422–1475, 2008.

Conic, especially copositive optimization

Prof. Immanuel Bomze[1]

[1] Dept. Applied Mathematics and Statistics, University of Vienna
Email: immanuel.bomze@univie.ac.at

Timetable: 8 hrs. At https://elearning.unipd.it/math/course/index.php?categoryid=47 enrolled people can find useful information to follow the classes.

Calendar of the lectures
Tuesday October 27, 2020, 16:00
Wednesday October 28, 2020, 10:00-12:00
Thursday October 29, 2020, 10:00-12:00 and 15:00-17:00

Course requirements:

Examination and grading:

SSD: MAT/09

Aim:

Course contents: Quite many combinatorial and some important non-convex continuous optimization problems admit a conic representation, where the complexity of solving non-convex programs is shifted towards the complexity of sheer feasibility (i.e., membership of the cone which is assumed to be a proper convex one), while structural constraints and the objective are all linear. The resulting problem is therefore a convex one, and still equivalent to some NP-hard problems with inefficient local solutions despite the fact that in the conic formulation, all local solutions are global.

Using characterizations of copositivity, one arrives at various approximations. However, not all of these are tractable with current technology. In this course, we will address some approaches on which tractable SDP- or LP-approximations, and also branch-and-bound schemes, may be based.

This way, good tractable bounds can be achieved which serve as quality control for any primal-feasible algorithm. But which one should be employed? Complementing above (dual) approach, we will, mainly as one example, address a classical yet not widely known first-order approach for poly/posynomial optimization under simplex constraints, embedded in some general optimization principles for iterative primal methods.

Introduction to differential games

Prof. Alessandra Buratto[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Universitá di Padova*
Email:buratto@math.unipd.it

Timetable: 12 hrs. First lecture on February 18, 2020, 14:30 (dates already fixed, see calendar), the course will be held online.

Course requirements: Basic notions of Differential equations and Optimal control

Examination and grading: Homework assignments during classes + final presentation of a research paper selected from the literature on differential games

SSD: SECS-S/06

Aim: Differential games are very much motivated by applications where different agents interact exhibiting an inter-temporal aspect. Applications of differential games have proven to be a suitable methodology to study the behaviour of players (decision-makers) and to predict the outcome of such situations in many areas including engineering, economics, military, management science, biology and political science.
This course aims to provide the students with some basic concepts and results in the theory of differential games.

Course contents:

- Recall of basic concepts of game theory, equilibrium (Nash ...)
- Dynamic games: formalization of a differential game
- Simultaneous and competitive differential games (Nash Equilibrium)
- Hierarchic differential games (Stackelberg equilibrium)
- Time consistency and perfectness

References:

- Basar T., and Olsder G.J., Dynamic Noncooperative Game Theory Classics in Applied Mathematics.. SIAM 2 Ed., 1999.
- Bressan, A. "Noncooperative differential games." Milan Journal of Mathematics 79.2 (2011) 357-427.
- Dockner, E.J. et al., Differential Games in Economics and Management Science, Cambridge University Press, 2000.
- Haurie, A., et al, Games and dynamic games. Vol.1 World Scientific Publishing Company, 2012.
- Jehle, G. A. and Reny P.J., Advanced Microeconomic Theory (Third). Essex: Pearson Education Limited, 2011.

Meshless Finite Difference Methods

Prof. Oleg Davydov[1]

[1] *Mathematisches Institut, Universität Giessen (Germania)*
Email: Oleg.Davydov@math.uni-giessen.de

Timetable: 16 hrs. First lecture on October ..., 2020, ..:.. Torre Archimede, Room 2BC/30.

Course requirements:

Examination and grading:

SSD:

Aim:

Course contents:

1. Introduction into positive definite functions and reproducing kernel Hilbert spaces. (2h)
2. Numerical differentiation with polynomials and kernels I-II. (4h)
3. Meshless finite difference methods: Introduction and error bounds I-II. (4h)
4. Meshless finite difference methods: Computational aspects I-III. (6h)

Consensus based optimization on manifolds

Massimo Fornasier[1]

[1] Technische Universität München, Fakultät für Mathematik,
München, Germany
Email: massimo.fornasierematma.tum.de

Timetable: 12 hrs. First lecture on March 1st, 2021, 13:00 (dates already fixed, see calendar), the course will be held online at Zoom Meeting https://tum-conf.zoom.us/j/8330201692, Meeting ID: 833 020 1692, Passcode: 3141592

Course requirements:

Examination and grading:

SSD: MAT/06

Aim:

Course contents:

We introduce new stochastic multi-particle models for global optimization of nonconvex functions on manifolds. These models belong to the class of Consensus-Based Optimization methods. In fact, particles move over the manifold driven by a drift towards an instantaneous consensus point, computed as a combination of the particle locations weighted by the cost function according to Laplace's principle.
The consensus point represents an approximation to a global minimizer. The dynamics is further perturbed by a random vector field to favor exploration, whose variance is a function of the distance of the particles to the consensus point. In particular, as soon as the consensus is reached, then the stochastic component vanishes. In the first part of the course, we study the well-posedness of the model on global compact manifolds without boundary and we derive rigorously its mean-field approximation for large particle limit.

In the second part of the course we address the proof of convergence of numerical schemes to global minimizers provided conditions of well-preparation of the initial datum. The proof combines previous results of mean-field limit with a novel asymptotic analysis, and classical convergence results of numerical methods for SDE.
We present several numerical experiments, which show that the proposed algorithm scales well with the dimension and is extremely versatile. To quantify the performances of the new approach, we show that the algorithm is able to perform essentially as good as ad hoc state of the art methods in challenging problems in signal processing and machine learning, namely the phase retrieval problem and the robust subspace detection.

References:

- José A Carrillo, Young-Pil Choi, Claudia Totzeck, and Oliver Tse. An analytical framework for consensus-based global optimization method. Mathematical Models and Methods in Applied Sciences,28(06):1037–1066, 2018
- Massimo Fornasier, Hui Huang, Lorenzo Pareschi, and Philippe Sünnen. Consensus-based optimization on the sphere I: Well-posedness and mean-field limit. arXiv:2001.11994, 2020

- Massimo Fornasier, Hui Huang, Lorenzo Pareschi, and Philippe Sünnen. Consensus-based optimization on the sphere II: Convergence to Global Minimizers and Machine Learning. arXiv:2001.11988, 2020
- René Pinnau, Claudia Totzeck, Oliver Tse, and Stephan Martin. A consensus-based model for global optimization and its mean-field limit. Mathematical Models and Methods in Applied Sciences,27(01):183–204, 2017

A smooth tour around rough models in finance (From data to stochastics to machine learning)

Prof. Antoine Jacquier[1]

[1] *Imperial College, Londra*
Email: a.jacquier@imperial.ac.uk

Timetable: 16 hrs. POSTPONED TO THE NEXT YEAR

Course requirements: Probability and Stochastic Calculus

Examination and grading: oral examination on the topics covered during the course

SSD: MAT/06, SECS-S/06

Aim: Aim: the course aims at introducing the recent theory on rough volatility models, namely stochastic volatility models in finance driven by the fractional Brownian motion. This class of models will naturally arise by looking at market data and at the end of the course the PhD student will have full control of advanced tools in stochastic calculus which are crucial in modern finance.

Course contents:

A quick glance at time series in market data (Equities, Currencies, Commodities, Rates...) leaves no doubt that volatility is not deterministic over time, but stochastic. However, the classical Markovian setup, upon which a whole area of mathematical finance was built, was recently torn apart when Gatheral-Jaisson-Rosenbaum showed that the instantaneous volatility is not so well behaved and instead features memory and more erratic path behaviour. Rough volatility was born. This new paradigm does not come for free, though, and new tools and further analyses are needed in order to put forward the benefits of this new approach. The goal of this course is to explain how Rough Volatility naturally comes out of the data, and to study the new techniques required to use it as a tool for financial modelling. We shall endeavour to strike a balance between theoretical tools and practical examples, and between existing results and open problems. The contents shall span, with more or less emphasis on each topic, the following:

1. Estimating roughness from data. Constructing a rough volatility model.
2. Constructing a model consistent between the historical and the pricing measure: joint calibration of SPX and VIX options.
3. Pricing options in rough volatility models: from Hybrid Monte Carlo to Deep learning

The first item is anchored in fairly classical Statistics and Probability, while the second deals with Stochastic analysis. The last item draws upon recent literature connecting Path-dependent PDEs, Backward SDEs and Deep Learning technology. Prior knowledge in all areas is not required, but good Probability/Stochastic analysis background is essential.

Fourier-Laplace transform and Wiener-Hopf factorization in Finance, Economics and Insurance

Prof. Sergei Levendorskii[1]

[1] Calico Science Consulting. Austin, TX
Email: levendorskii@gmail.com

Timetable: 12 hrs. First lecture on October, 19, 2020, 16:30. The course will be held online via Zoom (the link to the meeting will be communicated a few days before the start of the course)

Course requirements: Probability and Stochastic Calculus

Examination and grading: oral examination on the topics covered during the course

SSD: MAT/06, SECS-S/06

Aim: The course aims at introducing recent fast and robust pricing techniques for exotic derivatives (such as Bermudan and American) in general Lévy models.

Course contents:

The Fourier-Laplace transform and Wiener-Hopf factorization are ubiquitous in Mathematics, Physics, Engineering, Probability, Statistics, Insurance and Finance. Recently, several difficult problems in Game Theory and Economics were solved using the Wiener-Hopf factorization techniques. From the analytical viewpoint, problems considered in the course can be reduced to a sequence of calculations, each involving either the Fourier (or inverse Fourier) transform of a given function, or the convolution of two given functions. In turn, each of these operations can be performed numerically with high efficiency using the standard fast Fourier and Hilbert transforms and fast convolution. We introduce new more efficient versions of the fast Fourier and Hilbert transforms. The second general topic of the course is the new general methodology for efficient evaluation of integrals with integrands analytic in regions around the lines of integration, examples being numerical Fourier-Laplace inversion, calculation of the Wiener-Hopf factors and high transcendental functions. We introduce three families of conformal deformations of the contour of integration in the Fourier inversion formula and the corresponding changes of variables, which lead to much faster and more accurate calculations. The third general topic of the course is the EPV (expected present value operators) method. The strength of the EPV method stems from the interaction of the probabilistic and analytical techniques. In the standard analytical approach to solution of boundary problems, the operators are interpreted as the expectation operators. This allows one to relatively easily evaluate complicated expectations and solve optimal stopping problems with non-standard payoffs. All topics in the course and additional topics will be covered in S. Boyarchenko, M. Boyarchenko, N. Boyarchenko, and S. Levendorskij. Spectral Methods in Finance, Economics and Insurance. Springer, New York, 2020, the monograph in preparation for Springer due to be finished in this Fall. The full lists of references for the lectures and a more detailed contents' list will be given during the first lecture.

- Lecture 1. Lévy models
- Lecture 2. Evaluation of probability distributions and pricing European options in Lévy models
- Lecture 3. Simplified trapezoid rule, Fast Fourier Transform and its variations
- Lecture 4. Conformal acceleration techniques
- Lecture 5. Barrier options with discrete monitoring and Bermudan options. Calculations in the state space
- Lecture 6. Barrier options with discrete monitoring and Bermudan options. Calculations in the dual space
- Lecture 7. Wiener-Hopf factorization
- Lecture 8. Contingent claims with continuous monitoring, boundary value problems and Wiener-Hopf factorization
- Lecture 9. Options with continuous monitoring, cont-d
- Lecture 10. Affine models
- Lecture 11. American options with infinite time horizon
- Lecture 12. American options with finite time horizon

Courses offered within the Master's Degree in Mathematics

The Master Degree (Laurea Magistrale) in Mathematics of this Department offers many courses on a wide range of topics, in Italian or in English. The PhD students are encouraged to follow the parts of such courses they think are useful to complete their basic knowledge in Mathematics. In some cases this activity can receive credits from the Doctoral school, upon recommendation of the supervisor of the student. Since the courses at the Master level are usually less intense than those devoted to graduate students, the number of hours given as credits by our Doctorate will be less than the total duration of the course. Some examples of courses that receive such credits, unless the student already has the material in his background, are the following.

Topology 2

Prof. Andrea D'Agnolo
Università di Padova, Dipartimento di Matematica
Email: dagnolo@math.unipd.it

Period: 1st semester

Contents and other information:

https://didattica.unipd.it/off/2020/LM/SC/SC1172/001PD/SCQ0094298/N0

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Differential Equations

Prof. Martino Bardi
Università di Padova, Dipartimento di Matematica
Email: bardi@math.unipd.it

Period: 2nd semester

Contents and other information:

https://didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0093962/N0

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Homology and Cohomology

Prof. Bruno Chiarellotto
Università di Padova, Dipartimento di Matematica
Email: chiarbru@math.unipd.it

Period: 2nd semester

Contents and other information:

https://didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094081/N0

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Calculus of Variations

Prof. Luca Martinazzi

Università di Padova, Dipartimento di Matematica
Email: luca.martinazzi@math.unipd.it

Period: 2nd semester

Contents and other information:

https://didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0093999/N0

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Hamiltonian Mechanics

Prof. Paolo Rossi

Università di Padova, Dipartimento di Matematica
Email: paolo.rossi@math.unipd.it

Period: 2nd semester

Contents and other information:

https://didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094081/N0

Soft Skills

Doctoral Program in Mathematical Sciences

a.a. 2020/2021

SOFT SKILLS

Maths information: retrieving, managing, evaluating, publishing

Abstract: This course deals with the bibliographic databases and the resources provided by the University of Padova; citation databases and metrics for research evaluation; open access publishing and the submission of PhD theses and research data in UniPd institutional repositories.

Language: The Course will be held in Italian or in English according to the participants

Timetable: 5 hrs – February 16, 2021, 09:30 (2:30 hrs), February 19, 2021, 09:30 (2:30 hrs), the Course will be held online

16 and 19 February 2021, 9:30 – 12:00

information literacy

On-line workshop (Zoom) for PhD Students and Researchers

16/02/2021

- Citation databases and bibliographic databases
- Researcher metrics
- The new tool: Galileo Discovery
- Mathscinet and Zentralblatt (for PhD Students in Mathematics)

19/02/2021

- Scholarly communication
- Open Science at the University of Padova: Open Access, Open Data
- Institutional repositories

Trainers: Domenico Castellani, Federica Nalesso, Marina Zannoni

To enroll: http://www.cab.unipd.it/Corsi-SBA-Iscrizione > (Area Scienze)

For further information:

Biblioteca biologico-medica Vallisneri:
email biblioteca.vallisneri@unipd.it; tel. 049 827 6360

Biblioteca di Matematica:
email biblio@math.unipd.it; tel. 049 827 1251

SISTEMA BIBLIOTECARIO DI ATENEO

Entrepreneurship and Technology-based Startups

Course Area: Transversal Skills

Credits: 5 (20 hours)

Instructors: Prof. Moreno Muffatto, Ing. Francesco Ferrati, Dip.to di Ingegneria Industriale, Università di Padova

e-mail: moreno.muffatto@unipd.it, francesco.ferrati@unipd.it

Topics:

From the idea to the market

- Entrepreneurship attitudes
- What is a startup
- From a research project to an entrepreneurial project
- Market dimension, customers profiles and value proposition
- Development of the product/service concept

Intellectual Property Rights

- Types of IPR (patent, copyright, trademark)
- The structure of a patent application (description, claims, etc)
- Getting a patent: the patenting process (step by step)
- When to file a patent application: priority date, Patent Cooperation Treaty (PCT)
- Where to protect an invention
- Different IPR strategies

The team and the early decisions

- The creation of the founders' team
- Types and characteristics of founders' teams
- Founders' decisions and their consequences
- Frequent mistakes and suggestions deriving from experience

The economic and financial aspects of a startup

- The fundamental economic and financial operations of a technology-based startup
- The structures of the financial statements
- Income Statement, Balance Sheet, Cash Flow
- Evaluation of the value of the company
- Sources and cost of capital

Funding a startup

• Different sources of funds: Angel Investors and Venture Capital

• Investment companies and funds: how they work

• How and what investors evaluate

• The investment agreements between investors and startups

• New ventures' funding options

References:

• Noam Wasserman (2013) The Founder's Dilemmas: Anticipating and Avoiding the Pitfalls That Can Sink a Startup, Princeton University Press.

• Thomas R. Ittelson (2009), Financial Statements: A Step-by-Step Guide to Understanding and Creating Financial Reports, Career Press.

• Hall, J., & Hofer, C. W. (1993). Venture capitalists' decision criteria in new venture evaluation. Journal of Business Venturing, 8(1), 25-42.

Schedule and room: see on https://phd.dei.unipd.it/course-catalogues/

Enrollment:
To attend the course registration is compulsory by using the Moodle platform of the PhD Course in Industrial Engineering (in order to enter the Moodle platform click on "dettagli" of the course at the page http://www.cdii.dii.unipd.it/corsi). Once you are registered, if you cannot attend the course, please inform the lecturer.

Examination and grading: Attendance is required for at least 70% of the lecture hours (i.e. 14 hours). Final evaluation will be based on the discussion of a case study of a technology-based startup.

Reading Courses

Courses in collaboration with the Doctoral School on “Information Engineering”

for complete Catalogue and class schedule see on

https://phd.dei.unipd.it/course-catalogues/

Introduction to Reinforcement Learning

Dr. Juan José Alcaraz Espín[1]

[1] Technical University of Cartagena, Spain
email: juan.alcaraz@upct.es

Timetable: see on https://phd.dei.unipd.it/course-catalogues/

Important note: course to be confirmed based on the result of the Visiting Scientist Call

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Basics of linear algebra, probability theory, Python scripting

Examination and grading: The grading will be based on the students' solutions to the proposed assignments.

SSD: Information Engineering

Aim: The course will provide an introduction to the field of reinforcement learning, covering its mathematical foundations and the description of the most relevant algorithms. The main concepts and techniques will be illustrated with Python code and application examples in telecommunications and other related areas. The students will acquire hands-on experience with the proposed assignments in which they will have to implement Python code for solving several challenges and exercises. The course will start with the basic concepts of learning in sequential decision problems, formalized in the multi-armed bandit (MAB) problem and its variants. Then, the Markov decision processes (MDPs), which generalize the MAB problem, will be introduced. The objective of reinforcement learning (RL) is to find approximate solutions to MDPs. The main RL approaches will be presented incrementally: 1) tabular methods, which are capable of addressing relatively small problems, 2) value function approximation, which allows scaling up previous algorithms to larger problems, and 3) policy gradient algorithms which follow a different scaling approach and can be used in combination with value function approximation (Actor-Critic methods).

Course contents:
Unit 1. Introduction to Reinforcement Learning
Unit 2. Multi-Armed Bandits: Stochastic Bandits, Boltzmann Exploration, UCB algorithms, Thompsom Sampling, Contextual Bandits.
Unit 3. Markov Decision Processes: Stochastic Shortest Path problems. Policy Iteration. Value Iteration. MDPs with discount.
Unit 4. Tabular Methods: Monte Carlo Method, Temporal Difference, Off-policy algorithms, Planning at decision time.
Unit 5. Value Function Approximation (VFA) Methods: Linear VFA, Monte Carlo with VFA, TD methods with VFA.
Unit 6. Policy Gradient Algorithms: Score functions, Policy Gradient Theorem, Monte Carlo Policy Gradient, Actor-Critic Policy Gradient.
Unit 7 (Optional) Evolutionary Algorithms

References:

1. Reinforcement Learning: An Introduction, Second Edition, Richard S. Sutton and Andrew G. Barto, MIT Press, Cambridge, MA, 2018.
2. Approximate Dynamic Programming: Solving the Curses of Dimensionality, Second Edition, Warren B. Powell, Wiley, 2011.
3. Dynamic Programming and Optimal Control Vol I and Vol II, 4th Edition, Dimitri P. Bertsekas, Athena Scientific, 2012.
4. Algorithms for Reinforcement Learning, Csaba Szepesvári, Morgan and Claypool, 2010.
5. Reinforcement Learning and Optimal Control, Dimitri P. Bertsekas, Athenea Scientific, 2019.
6. Markov Decision Processes: Discrete Stochastic Dynamic Programming, Martin L. Puterman, Wiley, 2006.

Causal Inference for Complex Networks

Prof. Reza Arghandeh[1]

[1] *Department of Electrical and Computer Engineering, Florida State University, USA*
E-mail: r.arghandeh@fsu.edu

Timetable: 16 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: familiarity with basic probability. Knowledge of network theory also helps, but it is not a requirement.

Examination and grading: a final project or a take-home exam.

SSD: INF/01 Information Engineering

Aim: One of the notable analytical challenges of our century is the intricate complexity of systems that shape our civilization ranging from electricity networks to computer networks to biological networks and social networks due to all interdependency and interconnectivity among them. It is near impossible to understand complex network systems behavior unless we go beyond the classic machine learning and network science and develop a casual insight into the machinery behind different networks. Nevertheless, the notable differences in forms, scopes, components, and nature of different networks, most networks follow common cause and effect principles. This course provides a selection of concepts from information theory and causality inference domains to analyze complex networks considering their inherent interdependencies. During the course, students will be familiar with use cases from electric grids, roadways, and social networks.

Course contents:

1. Motivating problems in complex networked systems. i) some analytical problems in smart grids. ii) some analytical problems in smart cities.
2. Elements of Graph Theory: i) overview of graphs. ii) path, connectivity, and weighted graphs. iii) metrics for graphs.
3. Causality Inference: i) causality language ii) theory of causation and intervention iii) state-of-the-art causality inference methods
4. Causality for Complex networks i) causality methods for large scale networks ii) example applications in smart grids

References:

1. J. Pearl, Causality, Cambridge University Press, 2009.
2. A. Barabasi, Network Science, Cambridge University Press , 2016.
3. F. Bullo, Lectures on Network Systems, CreateSpase, 2018. Class lectures and other material and research papers will be available online for download.

Bayesian Machine Learning

Giorgio Maria Di Nunzio[1]

[1] *Department of Information Engineering*
Email: dinunzio@dei.unipd.it

Timetable: 20 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Course requirements: Basics of Probability Theory. Basics of R Programming.

Examination and grading: Homework assignments and final project.

SSD: Information Engineering

Aim: The course will introduce fundamental topics in Bayesian reasoning and how they apply to machine learning problems. In this course, we will present pros and cons of Bayesian approaches and we will develop a graphical tool to analyse the assumptions of these approaches in classical machine learning problems such as classification and regression.

Course contents:

Introduction of classical machine learning problems.

1. Mathematical framework
2. Supervised and unsupervised learning

Bayesian decision theory

1. Two-category classification
2. Minimum-error-rate classification
3. Bayes decision theory
4. Decision surfaces

Estimation

1. Maximum Likelihood Estimation
2. Expectation Maximization
3. Maximum A Posteriori
4. Bayesian approach

Graphical models

1. Bayesian networks
2. Two-dimensional visualization

Evaluation

1. Measures of accuracy

References:

1. J. Kruschke, Doing Bayesian Data Analysis: A Tutorial Introduction With R and Bugs, Academic Press 2010
2. Christopher M. Bishop, Pattern Recognition and Machine Learning (Information Science and Statistics), Springer 2007
3. Richard O. Duda, Peter E. Hart, David G. Stork, Pattern Classification (2nd Edition), Wiley-Interscience, 2000
4. Yaser S. Abu-Mostafa, Malik Magdon-Ismail, Hsuan-Tien Lin, Learning from Data, AML-Book, 2012 (supporting material available at http://amlbook.com/support.html)
5. David J. C. MacKay, Information Theory, Inference and Learning Algorithms, Cambridge University Press, 2003 (freely available and supporting material at http://www.inference.phy.cam.ac.uk/mackay/
6. David Barber, Bayesian Reasoning and Machine Learning, Cambridge University Press, 2012 (freely available at http://web4.cs.ucl.ac.uk/staff/D.Barber/pmwiki/pmwiki.php?n=
7. Kevin P. Murphy, Machine Learning: A Probabilistic Perspective, MIT Press, 2012 (supporting material http://www.cs.ubc.ca/ murphyk/MLbook/)
8. Richard McElreath, Statistical Rethinking, CRC Presso, 2015 (supporting material https://xcelab.net/rm/statistical-rethinking/)

Statistical Methods

Prof. Lorenzo Finesso[1]

[1] CNR IEIIT Padova
email: lorenzo.finesso@unipd.it

Timetable: 24 hrs. see on https://phd.dei.unipd.it/course-catalogues/
Enrollment: Students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: familiarity with basic linear algebra and probability.

Examination and grading: Homework assignments

SSD: Information Engineering

Aim: The course will present a small selection of statistical techniques which are widespread in applications. The unifying power of the information theoretic point of view will be stressed.

Course contents:

- *Background material.* The noiseless source coding theorem will be quickly reviewed in order to introduce the notions of entropy and informational divergence (relative entropy or Kullback-Leibler distance) between positive measures.
- *Divergence minimization problems.* Three I-divergence minimization problems will be posed and, via examples, connected with basic methods of statistical inference: ML (maximum likelihood), ME (maximum entropy), and EM (expectation-maximization).
- *Multivariate analysis methods.* The three standard multivariate methods, PCA (Principal Component Analysis), Factor Analysis, and CCA (Canonical Correlations Analysis) will be reviewed and their connection with divergence minimization discussed. Applications of PCA to least squares (PCR principal component regression, PLS Partial least squares). Approximate matrix factorization and PCA, with a brief detour on the approximate Nonnegative Matrix Factorization (NMF) problem.
- *EM methods.* The Expectation-Maximization method will be introduced in the context of Maximum Likelihood (ML) estimation with partial observations (incomplete data) and interpreted as an alternating divergence minimization algorithm à la Csiszár Tusnády.
- *Applications to stochastic processes.* Introduction to HMM (Hidden Markov Models). Maximum likelihood estimation for HMM via the EM method. If time allows: derivation of the Burg spectral estimation method as solution of a Maximum Entropy problem.

References:
Lecture notes and a list of references will be posted on the course moodle site.

Computational Inverse Problems

Prof. Fabio Marcuzzi[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Universitá Padova*
e-mail: marcuzzi@math.unipd.it

Timetable: 20 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Course requirements:
- basic notions of linear algebra and, possibly, numerical linear algebra.
- the examples and homework will be in Python (the transition from Matlab to Python is effortless).

Examination and grading: Homework assignments and final test.

SSD: MAT/08

Aim: We study numerical methods that are of fundamental importance in computational inverse problems. Real application examples will be given for distributed parameter systems in continuum mechanics. Computer implementation performance issues will be considered as well.

Course contents:

- definition of inverse problems, basic examples and numerical difficulties.
- numerical methods for QR and SVD and their application to the square-root implementation in PCA, least-squares, model reduction and Kalman filtering; recursive least-squares; High Performance Computing (HPC) implementation of numerical linear algebra algorithms.
- regularization methods;
- underdetermined linear estimation problems and sparse recovery;
- numerical algorithms for nonlinear parameter estimation: nonlinear least-squares (Levenberg-Marquardt), back-propagation learning;
- underdetermined nonlinear estimation problems and deep learning;
- examples with distributed parameter systems in continuum mechanics: reconstruction of forcing terms and parameters estimation;

References:

1 F.Marcuzzi "Computational Inverse Problems", lecture notes (will be posted on the moodle page of the course)

2 G. Strang, "Linear Algebra and Learning From Data", Wellesley - Cambridge Press, 2019

3 L. Trefethen and J. Bau, "Numerical Linear Algebra", SIAM, 1997

Applied Functional Analysis and Machine Learning

Prof. Gianluigi Pillonetto[1]

[1] Department of Information Engineering, Univ. Padova
e-mail: giapi@dei.unipd.it

Timetable: 28 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: The classical theory of functions of real variable: limits and continuity, differentiation and Riemann integration, infinite series and uniform convergence. The arithmetic of complex numbers and the basic properties of the complex exponential function. Some elementary set theory. A bit of linear algebra.

Examination and grading: Homework assignments and final test.

SSD: Information Engineering

Aim: The course is intended to give a survey of the basic aspects of functional analysis, machine learning, regularization theory and inverse problems.

Course contents:

Review of some notions on metric spaces and Lebesgue integration: Metric spaces. Open sets, closed sets, neighborhoods. Convergence, Cauchy sequences, completeness. Completion of metric spaces. Review of the Lebesgue integration theory. Lebesgue spaces.

Banach and Hilbert spaces: Finite dimensional normed spaces and subspaces. Compactness and finite dimension. Bounded linear operators. Linear functionals. The finite dimensional case. Normed spaces of operators and the dual space. Weak topologies. Inner product spaces and Hilbert spaces. Orthogonal complements and direct sums. Orthonormal sets and sequences. Representation of functionals on Hilbert spaces.

Compact linear operators on normed spaces and their spectrum: Spectral properties of bounded linear operators. Compact linear operators on normed spaces. Spectral properties of compact linear operators. Spectral properties of bounded self-adjoint operators, positive operators, opera- tors defined by a kernel. Mercer Kernels and Mercer theorem.

Reproducing kernel Hilbert spaces, inverse problems and regularization theory: Representer theorem. Reproducing Kernel Hilbert Spaces (RKHS): definition and basic properties. Examples of RKHS. Function estimation problems in RKHS. Tikhonov regularization. Primal and dual formulation of loss functions. Regularization networks. Consistency/generalization and relationship with Vapnik's theory and the concept of V-gamma dimension. Support vector regression and classification.

References:

1. W. Rudin. Real and Complex Analysis, McGraw Hill, 2006
2. C.E. Rasmussen and C.K.I. Williams. Gaussian Processes for Machine Learning. The MIT Press, 2006
3. H. Brezis, Functional analysis, Sobolev spaces and partial differential equations, Springer 2010

Heuristics for Mathematical Optimization

Prof. Domenico Salvagnin[1]

[1] *Department of Information Engineering, Padova*
email: dominiqs@gmail.com - domenico.salvagnin@unipd.it

Timetable: 20 hrs. see https://phd.dei.unipd.it/course-catalogues/

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements:
- Moderate programming skills (on a language of choice)
- Basics in linear/integer programming.

Examination and grading: Final programming project.

SSD: Information Engineering

Aim: Make the students familiar with the most common mathematical heuristic approaches to solve mathematical/combinatorial optimization problems. This includes general strategies like local search, genetic algorithms and heuristics based on mathematical models.

Course contents:
- Mathematical optimization problems (intro).
- Heuristics vs exact methods for optimization (intro).
- General principle of heuristic design (diversification, intensification, randomization).
- Local search-based approaches.
- Genetic/population based approaches.
- The subMIP paradigm.
- Applications to selected combinatorial optimization problems: TSP, QAP, facility location, scheduling.

References:

1. Gendreau, Potvin "Handbook of Metaheuristics", 2010
2. Marti, Pardalos, Resende "Handbook of Heuristics", 2018

Control of Multivariable Systems: A Geometric Approach

Prof. Andrea Serrani[1]

[1] *The Ohio State University, USA*
e-mail: serrani.1@osu.edu

Timetable: 20 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Course requirements: A basic course in linear system theory and proficiency in linear algebra are required. Working knowledge in MATLAB/SIMULINK is needed for the design examples.

Examination and grading: Homework assignments and/or take-home final examination.

SSD: INF/01 Information Engineering

Aim: The goal of the course is to introduce the geometric theory of linear multivariable systems as a fundamental tool for the solution of relevant control problems, including disturbance rejection, non-interaction, fault detection and isolation, and tracking and regulation. Attention will be devoted to routines available in MATLAB for numerical implementation of the control algorithms presented in class. Design examples on a realistic model of an aerospace system will be introduced.

Course contents:

1. **Background:** Subspaces, maps, factor spaces, projections.
2. **Systems Theory:** Controllability, observability, compensator design.
3. **Disturbance Decoupling:** Controlled invariance, controllability subspaces. Duality: Conditioned invariance, unknown-input observers.
4. **Eigenvalue Assignment under Invariance Constraints:** Multivariable zeros. Zero dynamics.
5. **Non-interacting Control:** Synthesis via dynamic extension. Duality: Fault detection and isolation.
6. **Tracking and Regulation:** Right-inversion. The regulator problem.

References:

1. W.M. Wonham, “Linear Multivariable Control: A Geometric Approach,” Springer-Verlag; Supplementary notes.

Elements of Deep Learning

Prof. Gian Antonio Susto[1]

[1] *Department of Information Engineering, Univ. Padova*
e-mail: gianantonio.susto@dei.unipd.it

Timetable: 24 hrs. see on https://phd.dei.unipd.it/course-catalogues/

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Basics of Machine Learning and Python Programming.

Examination and grading: Final project.

SSD: Information Engineering

Aim: The course will serve as an introduction to Deep Learning (DL) for students who already have a basic knowledge of Machine Learning. The course will move from the fundamental architectures (e.g. CNN and RNN) to hot topics in Deep Learning research.

Course contents:

- Introduction to Deep Learning: context, historical perspective, differences with respect to classic Machine Learning.
- Feedforward Neural Networks (stochastic gradient descent and optimization).
- Convolutional Neural Networks.
- Neural Networks for Sequence Learning.
- Elements of Deep Natural Language Processing.
- Elements of Deep Reinforcement Learning.
- Unsupervised Learning: Generative Adversarial Neural Networks and Autoencoders.
- Laboratory sessions in Colab.
- Hot topics in current research.

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