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

Doctoral Program in Mathematical Sciences

Catalogue of the courses 2022-2023

Updated May 2nd, 2023

INTRODUCTION

This Catalogue contains the list of courses offered to the Graduate Students in Mathematical Sciences for the year 2022-2023.

The courses in this Catalogue are of three types.

1. Courses offered by the Graduate School (= Courses of the Doctoral Program)
2. Courses offered by one of its curricula.
3. Other courses of the following types:
   a) selected courses offered by the Master in Mathematics;
   b) selected courses offered by the PhD school in Information Engineering;
   c) selected courses offered by other PhD schools or other Institutions;
   d) reading courses.

(This offer includes courses taught by internationally recognized external researchers. Since these courses might not be offered again in the near future, we emphasize the importance for all graduate students to attend them.)

Taking a course from the Catalogue gives an automatic acquisition of credits, while crediting of courses not included in the Catalogue (such as courses offered by the Scuola Galileiana di Studi Superiori, Summer or Winter schools, Series of lectures devoted to young researchers, courses offered by other PhD Schools) is possible, but it is subject to the approval of the Executive Board. Moreover, at most one course of this type may be credited.

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

- pass the exam of at least four courses from the catalogue, among which at least two must be taken from the list of "Courses of the Doctoral Program", while at most one can be taken among the list of "reading courses"
- participate in at least one activity among the "soft skills"
- attend at least two more courses

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 instructor 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.

<u>Courses for Master of Science in "Mathematics"</u>

Students have the possibility to attend some courses of the Master of Science in Mathematics and get credits. The recommendation that a student takes one of these courses must be made by the supervisor and the type of exam must be agreed between the instructor and the supervisor.

Courses attended in other Institutions and not included in the catalogue. Students activities within Summer or Winter schools, series of lectures devoted to young researchers, courses offered by the Scuola Galileiana di Studi Superiori, by other PhD Schools or by PhD Programs of other Universities may also be credited, according to whether an exam is passed or not; the student must apply to the Coordinator and crediting is subject to approval by the supervisor and the Executive board. We recall that at most one course not included in the Catalogue may be credited.

Seminars

a) All students, during the three years of the program, must attend the **Colloquia of the Department** and participate regularly in the Graduate Seminar ("**Seminario Dottorato**"), whithin which they are also required to deliver a talk and write an abstract.
b) Students are also strongly 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 organization reasons, 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 2022 or later, and as soon as possible for courses that take place until December 2021.
In order to **register,** follow the procedure described in the preceding section.
Possible **cancellation** to courses must also be notified.

List of Courses

Courses of the Doctoral Program

1. Prof. Renzo Cavalieri
   Hurwitz theory, classical and tropical **DP-1**
2. Prof. Stefano De Marchi
   An introduction to multivariate approximation **DP-4**
3. Prof. Luis C. Garcia Naranjo
   Lie Groups and Symmetry **DP-5**
4. Prof. Giulio Giusteri
   Special Functions and Applications **DP-6**
5. Prof. Franco Rampazzo,
   Set separation and necessary conditions for minima **DP-7**

Courses of the "Mathematics" area

1. Dott. Federico Bambozzi
   Derived Geometry **M-1**
2. Dott.ssa Anna Barbieri,
   Bridgeland stability conditions in algebraic geometry and representation theory **M-3**
3. Prof. Jean-Paul Gauthier
   Stabilization with incomplete information **M-5**
4. Dott. Alessandro Goffi
   Qualitative and quantitative properties for elliptic equations **M-6**
5. Prof. Sergiy Plaksa
   Singular integral operators and boundary value problems for analytic functions **M-8**

Reading Courses

1. Prof.ssa Giovanna Carnovale, Prof. Francesco Esposito
   Representations of p-adic Groups **RC-1**
2. Proff. Rosanna Laking, Jorge Vitória
   Reading course: Torsion pairs in abelian categories **RC-3**

Courses of the "Computational Mathematics" area

1. Prof.ssa Beatrice Acciaio
   Stochastic optimal transport and applications in mathematical finance **MC-1**
2. Prof. Claude Brezinski
   Study the past if you would divine the future (Confucius) **MC-2**
3. Prof.ssa Alessandra Buratto
   Introduction to differential games **MC-3**
4. Prof.ssa Christa Cuchiero, Prof.ssa Sara Svaluto-Ferro
   Signatures in finance: life, death, and miracles **MC-4**
5. Prof. Giorgio Ferrari
   Theory and Applications of Singular Stochastic Control **MC-6**
6. Prof.ssa Maryam Mohammadi
   Meshless Approximation: Theory and Applications **MC-7**
7. Prof. Andrea Roncoroni
   Interface of Finance, Operations and Risk Management **MC-8**
8. Prof. Piergiacomo Sabino
   Monte Carlo Methods in Python with Financial Applications **MC-10**
9. Prof. Tiziano Vargiolu
   The Mathematics of Energy Markets **MC-12**

Soft Skills

1. Maths information: retrieving, managing, evaluating, publishing **SS-1**
2. Advanced LaTeX **SS-2**
3. Introduction to the use of ”Mathematica” in Mathematics and Science **SS-3**
4. Designing and delivering an effective talk **SS-4**
5. A critical introduction to bibliometric indices and to their use and abuse in evaluations **SS-5**
6. Attending mandatory courses organised by the Unipd CA (for Tutor Junior or UNIPhD fellows) **SS-6**
7. Active participation in events organized by the Department devoted to the popularization of mathematics, like Science4all, Kidsuniversity and others. **SS-7**

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

Please check regularly the website of the Doctoral Course in Information Engineering at the URL https://phd.dei.unipd.it/course-catalogues/

Calendar of activities on

`https://calendar.google.com/calendar/u/0/embed?src=fvsl9bgkbnhhkqp5mmqpiurn6c@group.calendar.google.com&ctz=Europe/Rome`

Courses of the Doctoral Program

Hurwitz theory, classical and tropical

Prof. Renzo Cavalieri[1]

[1] Department of Mathematics, Colorado State University, USA
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Timetable: 24 hrs. First lecture on October 11, 2022 14:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements:

Examination and grading:

SSD: MAT/03

Aim: The goal of the course is to explore the interactions of tropical and logarithmic geometry with Hurwitz theory, concerned with the enumeration of maps of Riemann surfaces.

The main question in Hurwitz theory dates all the way back to the late 1800s: how many maps of Riemann Surfaces does one have when fixing all the available discrete invariants? Over the last century, this question has experienced a wealth of translations (to topology, combinatorics, group theory, representation theory...) and found itself contributing to the most disparate areas of mathematics (integrable systems, mathematical physics, string theory...).

This course focuses on how Hurwitz theory interlaces with the geometry of moduli spaces of curves. The basic connection is that Hurwitz numbers are naturally interpreted as the degrees of appropriate branch morphisms among moduli spaces of covers and moduli spaces of target curves. After appropriately compactifying the moduli spaces, such degree is accessed through intersection theory. Tropical and logarithmic geometry allow for a combinatorial approach to such intersection theoretic questions. In recent year, this dictionary has provided fruitful applications that have improved our understanding of both the algebraic structre of Hurwitz number as well as the tautological intersection theory of moduli spaces of curves.

Course contents: The course will be structured in four modules, each of approximately six hours.

Classical Hurwitz Theory: basic notions on Riemann Surfaces, and the representation theory of symmetric groups; the Hurwitz problem, counting maps of Riemann Surfaces, or monodromy representations; the simisimplicity of the class algebra and the Burnside character formulas.

Tropical Hurwitz Theory: basic notions in tropical geometry, and connection to degenerations of curves. The definition of tropical Hurwitz numbers, and the connection with monodromy representations. The piecewise polynomiality structure of double Hurwitz numbers and their wall-crossing formulas.

Hurwitz Numbers from Moduli Spaces: basic notions on moduli spaces of curves and maps. Tautological morphisms. Hurwitz number as a degree of appropriate branch morphisms. The

ELSV formula for simple Hurwitz numbers.

Web of Connections: a very quick primer to toric varieties and a dirty introduction to logarithmic geometry as a generalization of toric geometry. Degeneration formulas, and connections between tropical and classical Hurwitz numbers through degeneration formulas. Hurwitz numbers as intersection cycles on moduli spaces of curves.

References:

The first part of the course will follow the textbook [CM16]. For the remaining part, the lecture notes [CMR21] will be made available to participants. Material will be drawn from several research articles, including, but not restricted to [ELSV01, GJV03, CJM10, CJM11, BBM11, CM14, CMR16].

BBM11 Benoit Bertrand, Erwan Brugallé, and Grigory Mikhalkin. Tropical open Hurwitz numbers. Rend. Semin. Mat. Univ. Padova, 125:157–171, 2011.

BC17 V. Blankers and R. Cavalieri. Intersections of ω classes in Mg,n, 2017. Preprint: arXiv: 1705.10955.

BC18 V. Blankers and R. Cavalieri. Witten's conjecture and recursions for κ classes, 2018. Preprint: arXiv:1810.11443.

BC19 V. Blankers and R. Cavalieri. Wall-crossings for hassett descendant potentials, 2019. Preprint: arXiv:1907.06277.

BSSZ15 Alexandr Buryak, Sergey Shadrin, Loek Spitz, and Dimitri Zvonkine. Integrals of Ψ-classes over double ramification cycles. American Journal of Mathematics, 137(3):699–737, 2015.

CJM10 Renzo Cavalieri, Paul Johnson, and Hannah Markwig. Tropical Hurwitz numbers. J. Algebraic Combin., 32(2):241–265, 2010.

CJM11 Renzo Cavalieri, Paul Johnson, and Hannah Markwig. Wall crossings for double Hurwitz numbers. Adv. Math., 228(4):1894–1937, 2011.

CM14 Renzo Cavalieri and Steffen Marcus. A geometric perspective on the polynomiality of double Hurwitz numbers. Canad. Math. Bull., 2014.

CM16 Renzo Cavalieri and Eric Miles. Riemann surfaces and algebraic curves, volume 87 of London Mathematical Society Student Texts. Cambridge University Press, Cambridge, 2016. A first course in Hurwitz theory.

CMR16 Renzo Cavalieri, Hannah Markwig, and Dhruv Ranganathan. Tropicalizing the space of admissible covers. Math. Ann., 364(3- 4):1275–1313, 2016.

CMR21 Renzo Cavalieri, Hannah Markwig, and Dhruv Ranganathan. Tropical and logarithmic methods in enumerative geometry. Oberwolfach Seminar, 2021.

ELSV01 T. Ekedahl, S. Lando, M. Shapiro, and A. Vainshtein. Hurwitz numbers and intersections on moduli spaces of curves. Invent. Math., 146(2):297–327, 2001.

FP00 Carel Faber and Rahul Pandharipande. Hodge integrals and Gromov-Witten theory. Invent. Math., 139(1):173–199, 2000.

GJV03 Ian Goulden, David M. Jackson, and Ravi Vakil. Towards the geometry of double Hurwitz numbers. Preprint: math.AG/0309440v1, 2003.

HM98 Joseph Harris and Ian Morrison. Moduli of Curves. Springer, 1998.

Kap93 Mikhail Kapranov. Chow quotients of Grassmannians. I. In IM Gelfand Seminar, volume 16, pages 29–110, 1993.

KV07 Joachim Kock and Israel Vainsencher. An invitation to quantum cohomology, volume 249 of Progress in Mathematics. Birkhäuser Boston Inc., Boston, MA, 2007. Kontsevich's formula for rational plane curves.

Vak08 R. Vakil. The moduli space of curves and Gromov–Witten theory.In Enumerative invariants in algebraic geometry and string theory, pages 143–198. Springer, 2008.

An introduction to multivariate approximation theory and applications

Prof. Stefano De Marchi[1]

[1] Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova
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Timetable: 24 hrs. First lecture on December 5th, 2022, 10:30 (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: students should have acquired the classical notions of functional analysis and numerical analysis from the corresponding courses for the degree and master in mathematics and/or applied mathematics and/or mathematical engineering.

Examination and grading: final oral test or a seminar to deepen some of the topics introduced.

SSD: MAT/08

Aim: the course will give an overview of the approximation of functions and data in several variables. More recent approximation methods are also introduced and discussed.

Course contents:
Course contents: The course will consists of three Parts (P1-P3) of about 8h each.

- P1 Polynomial spaces, projections, Lebesgue constant, best approximation, modulus of continuity,optimal and near-primal interpolation points on compacts or surfaces.
- P2 Padua points: construction and their properties. Applications of Padua points (for instance cubature, imaging). Admissible meshes. Computational aspects.
- P3 Kernel-based approximation: positive definite kernels and Reproducing Kernel Hilbert Spaces (RKHS). Optimality of RKHS methods. Stability issues. Scattered-data fitting and application to machine learning.

Bibliography:

- E.W. Cheney,W. A. Light: " A course on approximation theory", American Mathematical Soc., 2009.
- G. E. Fasshauer and M. McCourt: "Kernel-based Approximation Methods Using Matlab", World Scientific, 2015.
- Lecture notes of the teacher on "Multivariate Polynomial Approximation" and "Lectures on Radial Basis Functions" (updated)

Lie Groups and Symmetry

Prof. Luis C. García-Naranjo[1]

[1] Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova
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Timetable: 24 hrs. First lecture on November 9th, 2022, 13:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

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/07

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).

Special Functions and Applications

Prof. Giulio G. Giusteri[1]

[1] Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova
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Timetable: 24 hrs. First lecture on October 17th, 2022, 10:30, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Basic notions of analysis and algebra, ordinary differential equations and partial differential equations.

Examination and grading: Oral examination on the program and on a student's project.

SSD: MAT/07

Aim: To present various families of special functions, their emergence and usefulness in applied mathematics contexts.

Course contents:

- Recap of basic facts in complex analysis: holomorphic functions, Laurent series, contour integrals, Cauchy theorem. Euler's Gamma function.
- The Probability Integral function: from error estimates to heat conduction and vibrations.
- Laplace and Helmholtz equations, separation of variables. Legendre, Hermite, and Laguerre polynomials. Curvilinear coordinates.
- Cylindrical coordinates and Bessel functions: electrostatic field and the bi-harmonic Stokes problem.
- Polar coordinates and spherical harmonics: Schrödinger equation and the orbitals of the hydrogen atom.
- Further applications (or functions) can be selected based on the audience (possible topics in fluid mechanics, potential theory, stochastic analysis, numerical solution of PDEs).

References:

1. N. N. Lebedev, Special Functions and Their Applications, Prentice–Hall, 1965.
2. G. Arfken, Mathematical Methods for Physicists, 3rd ed., Academic Press, 1985.
3. I. S. Gradshteyn, I. M. Ryzhik, Table of Integrals, Series, and Products, 7th ed., Elsevier, 2007.

Set separation and necessary conditions for minima (with applications, in particular, to Optimal Control Theory)

Prof. Franco Rampazzo[1]

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

Timetable: 24 hrs. First lecture on March 3rd, 2023 14:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Basic Calculus, Basic Lebesgue measure theory. (Other prerequisites – for instance fixed point theorems, absolutely continuous maps, – will be recalled during the course).

Examination and grading: An oral exam based on lectures contents and/or a scientific article preventively chosen.

SSD: MAT/05

Aim: This course, which does not require any particular prerequisite, aims primarily to frame the general notion of constrained minimum (in finite and infinite dimension) within the elementary concept of separation of sets: roughly speaking, a point is of local minimum if it locally separates the set of profitable states from the set of reachable states. Most of classical and more recent minimum problems can be seen under this perspective.
Through open mappings arguments (which will give us the occasion to see some notions of generalized differentiation and of approximating cone), necessary conditions for set separation can be translated into necessary conditions for minima: after immediately recognizing some of the more standard results in Calculus, we will apply the set-separation approach to Optimal controls of ODE's (so, in particular, to Calculus of Variations).
Time permitting, some connections with Differential Geometric Controllability or Hamilton-Jacobi equations will be treated as well.

Course contents:

1. Brower fixed point theorem and a parameterized version of Banach 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.

Courses of the “Mathematics” area

Derived Geometry

Dott. Federico Bambozzi[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova*
Email: federico.bambozzi@unipd.it

Timetable: 16 hrs. First lecture on May 2nd, 2023, 14:30, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: A basic knowledge of category theory and commutative algebra. The knowledge of the basics of algebraic topology and algebraic geometry is helpful but not necessary as the required material from these subject will be recalled in the course, mainly as key examples.

Examination and grading: Oral presentation of an argument related to the topics presented during the lectures.

SSD: MAT/02, MAT/03

Aim: The notion of derived geometry is a natural extension of the classical notion of geometry. This extension can be phrased in the abstract categorical language of geometry relative to a closed symmetric monoidal category. When this is done it soon becomes clear that not only algebraic geometry has a derived extension but also analytic geometry, differential geometry and more. In the course we will recall the categorical language needed to define the closed symmetric monoidal categories that are well-suited for defining derived geometries. If time permits it will be explained how derived geometry can interpreted as a specific example of an Algebraic Theory in the sense of Lawvere. Then, some basic constructions will be discussed: derived schemes, derived stacks, cotangent complex, loop space. If time permits a geometric version of the Hochschild-Kostant-Rosenberg in this context will be discussed. The focus will be on presenting abstract notions via a good amount of key examples.

Course contents:

- Localization of categories, model categories and 1-categories.
- Monoidal categories and monoidal 1-categories.
- HAG and DAG contexts.
- Derived schemes and derived stacks.
- The cotangent complex and derived de Rham cohmology.
- The tangent space and the loop space.

Optional topics:

- Derived Geometry as an algebraic theory.
- The Hochschild-Kostant-Rosenberg Theorem.
- Ind-coherent sheaves.

- Derived enhancement of moduli spaces.
- Tensor triangulated geometry.

Bibliography:

- Lurie, Jacob. "Higher algebra." (2017).
- Lurie, Jacob. "Higher topos theory." Princeton University Press, 2009.
- Töen, Bertrand, and Gabriele Vezzosi. "Homotopical algebraic geometry I: Topos theory." Advances in mathematics 193.2 (2005): 257-372.
- Töen, Bertrand, and Gabriele Vezzosi. "Homotopical Algebraic Geometry II: Geometric Stacks and Applications: Geometric Stacks and Applications." Vol. 2. American Mathematical Soc., 2008.
- Töen, Bertrand. "Derived algebraic geometry." EMS Surveys in Mathematical Sciences 1.2 (2014): 153-240.
- Gaitsgory, Dennis, and Nick Rozenblyum. "A study in derived algebraic geometry: Volume I: correspondences and duality." Vol. 221. American Mathematical Society, 2019.
- Kelly, Jack, Kobi Kremnizer, and Devarshi Mukherjee. "Analytic Hochschild-Kostant-Rosenberg Theorem." arXiv preprint arXiv:2111.03502 (2021).

Bridgeland stability conditions in algebraic geometry and representation theory

Dott.ssa Anna Barbieri[1]

[1] *Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova*
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Timetable: 16 hrs. First lecture on January 31, 2023, 15:30, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Familiarity with notions of categories, manifolds, vector bundles, possibly sheaves; basis of algebra.

Examination and grading: Seminar

SSD: MAT/02, MAT/03

Aim: Bridgeland stability for triangulated categories has become a very active research theme, with applications in algebraic and birational geometry, representation theory, mirror symmetry, and mathematical physics. The aim of the course is to give an introduction to the notion of Bridgeland stability condition and the stability manifold associated to a category. We will see examples of stability for geometric and algebraic categories. Time permitting, we will review other notions of stability (Gieseker and slope stability) for abelian categories and the problem of constructing moduli spaces, and recent research directions in the field of stability conditions in algebra and geometry. The course is oriented towards students in geometry and algebra and can be considered complementary to a previous course by Mistretta-Fiorot which, however, is not a prerequisite.

Laura Pertusi, from the University of Milano, will deliver a seminar on stability conditions in purely geometric context, during the period of the course.

Course contents:

- review of categories, sheaves, cohomology, the derived category.
- triangulated categories, bounded t-structures, examples.
- Bridgeland stability conditions for triangulated categories.
- the stability manifold and main properties.
- stability manifold for relevant categories: curves, (K3 surfaces), quiver categories.
- optional: modern research directions.

Bibliography:

- Bridgeland, Tom. "Stability conditions on triangulated categories." Annals of Mathematics (2007): 317-345.
- Bayer, Arend. "A tour to stability conditions on derived categories." notes (2011)

- Huybrechts, Daniel. ”Introduction to stability conditions”, Moduli spaces 411 (2014):179-229.
- Gelfand, Sergei I., and Yuri I. Manin. Methods of homological algebra. Springer, 2002.
- Ringel, Keller, Keller-Yang research papers

Stabilization with incomplete information

Prof. Jean-Paul Gauthier[1]

[1] *University of Toulon*
Email: gauthier@univ-tln.fr

Timetable: 16 hrs. First lecture on May 8th, 2023, 11:00 (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Basic knowledge of Ordinary Differential Equations

Examination and grading: Oral examination

SSD: MAT/05

Aim: In the context of control theory, the course provides the basis of observability for nonlinear systems and its application to problems of stabilization.

Course contents:

1. Preliminaries
   - Stability theory, direct and inverse Lyapunov's theorems
   - Center manifold theory
   - Transversality theorems
2. Nonlinear observability
   - Observability results (generic and singular cases)
   - Nonlinear observers, including deterministic Kalman filter
3. Stabilization with incomplete information
   - Strongly observable situation
   - singular situation.

Bibliography:

[1] Gauthier, JP, Kupka I ., Deterministic Observation Theory and applications, Cambridge Univesity press, 2011.

[2] Teel A, Praly L, Global stabilizability and observability imply semi-global stabilizability by output feedback, Systems and Control letters, 1994.

[3] L. Brivadis, J.P. Gauthier, L. Sacchelli, Output feedback stabilization of nonuniformly observable systems, to appear in Proceedings of the Steklov mathematical Institute, 2022

[4] L. Brivadis, L. Sacchelli, V. Andrieu, J.P. Gauthier, U. Serres, From local to global asymptotic stabilizability for weakly contractive control systems, Automatica, 2021

[5]Lucas Brivadis, Jean-Paul Gauthier, Ludovic Sacchelli, Ulysse Serres, Avoiding observability singularities in output feedback bilinear systems, SIAM Journal on Optimization and Control 2021.

Qualitative and quantitative properties for elliptic equations

Alessandro Goffi[1]

[1] *Università degli Studi di Padova, Dipartimento di Matematica*
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Timetable: 16 hrs. First lecture on September 26, 2022, 11:00 (date already fixed, see the Calendar of activities at https://dottorato.math.unipd.it/calendar) Torre Archimede, Room 2BC30.

Course requirements: Basic knowledge of linear elliptic PDEs, Sobolev and Hölder spaces.

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 qualitative and quantitative properties for elliptic problems, such as Liouville and regularity theorems.

Course contents:

- Basic concepts in the theory of partial differential equations (PDEs): quick review on the classification of linear and nonlinear equations, various notions of solutions and useful function spaces;
- Review of some basic tools for harmonic, sub- and superharmonic functions. Mean-value properties, strong and weak maximum principles, Harnack inequalities, Caccioppoli inequalities, Bernstein-type gradient bounds and some consequences: Hölder regularity, Liouville-type theorems under various a priori conditions on the solution (L^∞, L^p, finite Dirichlet energy, one-side bounds). Characterization of harmonic functions through touching functions: the notion of viscosity solution;
- Nonlinear equations (mostly driven by the Laplacian):
  - PDEs with gradient dependent terms:
    - Hölder/Lipschitz regularity for semi-solutions/solutions via integral/maximum principle methods;
    - Liouville properties for elliptic equations and inequalities via maximum principle and integral methods respectively.
  - PDEs with zero-th order nonlinearities:
    - Liouville properties for solutions using integral approaches and for semi-solutions via maximum principle methods .
  - If time permits, some discussions and extensions to problems driven by p-Laplacian, mean-curvature, fully nonlinear second order operators.

Bibliography:

1. L. Ambrosio, A. Carlotto and A. Massaccesi, Lectures on Elliptic Partial Differential Equations, Edizioni della Normale, Pisa, 2018.
2. A. Bensoussan and J. Frehse, Regularity results for nonlinear elliptic systems and applications, volume 151 of Applied Mathematical Sciences, Springer-Verlag, Berlin, 2002.
3. S. Dipierro and E. Valdinoci, Elliptic partial differential equations from an elementary viewpoint, arXiv: 2101.07941, 2021.
4. D. Gilbarg and N.S. Trudinger, Elliptic partial differential equations of second order, Springer-Verlag, Berlin, 2001.
5. Q. Han and F. Lin, Elliptic partial differential equations, second edition, Courant Lecture Notes in Mathematics, American Mathematical Society, Providence, RI, 2011.
6. P. Quittner and P. Souplet, Superlinear parabolic problems. Blow-up, global existence and steady states, Second edition, Birkhäuser/Springer Cham, 2019.

Singular integral operators and boundary value problems for analytic functions

Prof. Sergiy Plaksa[1]

[1] *Institute of Mathematics of the National Academy of Sciences of Ukraine*
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Timetable: 12 hrs. First lecture on December 5th, 2022, 14:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: the training course is a continuation of the classical course of the analytic function theory in the complex plane

Examination and grading:

SSD: MAT/05

Aim:

Course contents:

Singular Cauchy integral on a rectifiable Jordan curve. Sufficient conditions for the existence of singular Cauchy integral. The Zygmund estimate for the singular Cauchy integral.

Cauchy type integral. Sokhotski–Plemelj formulas for limiting values of the Cauchy type integral.

Riemann boundary value problem. The solution of a jump problem. The solution of a homogeneous problem. The solution of an inhomogeneous problem.

Singular integral equations with the Cauchy kernel on a rectifiable Jordan curve

Reading Courses

Reading course: Representations of p-adic Groups

Giovanna Carnovale[1], Francesco Esposito[2]

[1] *Dipartimento di Matematica, Università degli Studi di Padova*
Email: Carnoval@math.unipd.it

[2] *Dipartimento di Matematica, Università degli Studi di Padova*
Email: esposito@math.unipd.it

Timetable: 16 hrs. First lecture on November 3rd, 2022, 14.30 Torre Archimede, Room 2BC30, then on thursdays at 14.30 from november 17 on. A schedule of content, speaker, and related references will be discussed and settled during the first meeting. Interested students are invited to contact the teachers beforehand.

Course requirements: The prerequisites are reduced to the minimum; the concepts of local field, reductive group and their classification will be will be discussed in detail during the first lectures.

Examination and grading: Students are supposed to deliver lectures during the course and credits will be awarded on the grounds of active participation.

SSD: MAT02/03

Aim: A p-adic group is the group of F -points of a connected reductive group over a non-archimedean local field F. They are located at the croassroads of Group Theory, Geometry, Representation Theory, Harmonic Analysis and Number Theory, as it is apparent for instance in the Langlands program. This reading course aims at introducing the student to the basic concepts in the structure of p-adic groups and their admissible representations.

Course contents:

I. Local fields: Definition, examples, ring of integers, residue field, integration.
II. Reductive groups: Definition, examples, root systems and root data, classification over algebraically closed fields, forms.
III. Reductive groups over local fields: Examples, compact open subgroups, Bruhat-Tits buildings, classification.
IV. Representations of p-adic groups: Smooth and admissible representations, induction and restriction; classification.
V. Examples: GL_2, GL_n

Bibliography:

1. "Representations of p-adic groups" notes by Jessica Fintzen.
2. "Representations of p-adic groups" notes by Joseph Bernstein.

3. “Structure and representation theory of reductive p-adic groups” notes taken by Pak-Hin Lee.
4. “Introduction to the theory of admissible representations of p-adic reductive groups” notes by William Cassleman.
5. “Algebraic Number Theory” Cassels and Frohlich, Chapter 1 by Frohlich.
6. “Local fields” Jean Pierre Serre, Chapters 1-3.
7. “Reductive groups” Tonny Springer, Proceedings Symposia Pure Mathematics 33.
8. “Reductive groups over local fields” Jacques Tits, Proceedings Symposia Pure Mathematics 33.
9. “Représentations des groupes réductifs p-adiques” Guy Henniart, Séminaire Bourbaki 1990/1991.
10. “Automorphic forms and representations” Daniel Bump, Chapter 4.

Reading course:
Torsion pairs in abelian categories

Rosanna Laking[1], Jorge Vitória[2]

[1] *Dipartimento di Informatica - Settore di Matematica, Università degli Studi di Verona*
Email: rosanna.laking@univr.it

[2] *Dipartimento di Matematica, Università degli Studi di Padova*
Email: jorge.vitoria@unipd.it

Timetable: 24 hrs. First lecture on 25/11/2022, 16.00, alternating between Torre Archimede, Room TBA (Padova) or Ca'Vignal 2, Room TBA (Verona), with a zoom link for the participants outside the institution in which the lecture takes place. There will be regular meetings following the 25/11/2022: those dates will be discussed in the first meeting. A schedule of speakers, and related references will also be discussed during the first meeting. Interested participants are invited to contact the organisers beforehand.

Course requirements: Participants in this reading seminar should be familiar with some elementary aspects on rings, modules, categories and homological algebra. Complementary materials may be provided upon request to cover any specific topic for which participants feel they need further preparation.

Examination and grading: Participants are expected to attend the lectures in a participative way and to deliver at least one lecture covering part of the program.

SSD: MAT/02

Aim: A torsion pair in an abelian category is a decomposition of it into two parts: a torsion and a torsionfree part. It turns out that both the study of individual torsion pairs and the study of the whole collection of torsion pairs often provides us with useful information on the category. This is a recurring technique both in representation theory and in algebraic geometry (see also the course of Anna Barbieri in our PhD School).

In this reading course, structured through a series of seminars, we aim to provide participants with a wide range of techniques and examples concerning the study of torsion pairs in abelian categories. The course will focus both on categorical aspects as well as on two particular contexts where examples are well-understood: in the representations theory of finite-dimensional algebras and in the study of modules over commutative noetherian rings.

Course contents:

1. Grothendieck categories and finiteness properties. Torsion pairs in abelian categories and closure properties. Hereditary torsion pairs and categorical localisations.
2. Elements of approximation theory. Functorially finite torsion classes. Elements of support τ-tilting theory. τ-tilting finiteness.
3. Torsion pairs in length categories, lattice structure, brick labelling, completely join/meet irreducible torsion classes, semi-bricks, mono-bricks.

4. Definability and torsion pairs.
5. Classification of torsion pairs using geometric models for finite-dimensional algebras: type A, tube categories, cluster-tilted type A-tilde.
6. Torsion pairs for commutative noetherian rings: Matlis's correspondence, support and Gabriel's theorem.

If time allows we may discuss research directions and further recent developments, which may include silting/cosilting theory and torsion pairs in triangulated categories.

Bibliography:

1. T.Adachi, O.Iyama, I.Reiten, *τ-tilting theory*, Comp. Math. **150**(3) (2014), 415–452.
2. L.Angeleri Hügel, *On the abundance of silting modules*, Surveys in representation theory of algebras, Contemp. Math. **716**, Amer. Math. Soc., Providence, RI (2018), 1-23.
3. K. Bauer, A. Buan, R. Marsh, *Torsion pairs and rigid objects in tubes*, Alg. Rep. Th. **17**(2) (2014), 565-591.
4. W. Crawley-Boevey, *Locally finitely presented additive categories*, Comm. Algebra **22**(5) (1994), 1641–1674.
5. P. Gabriel, *Des catégories abéliennes*, Bull. Soc. Math. France **90** (1962), p. 323-448.
6. B. Stenström, *Rings of quotients*, Springer, 1975.

Courses of the “Computational Mathematics” area

Stochastic optimal transport and applications in mathematical finance

Prof. Beatrice Acciaio, ETH Zurich[1]

[1] *Department of Mathematics, ETH Zurich*
Email: beatrice.acciaio@math.ethz.ch

Timetable: 12 hrs. First lecture on April 4th, 2023, 10:30 (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Probability and Stochastic Calculus (basic)

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

SSD: MAT/06, SECS-S/06

Aim: This course aims at introducing the required basis on optimal transport, to then focus on recent developments of stochastic transport with applications to mathematical finance. In particular we will discuss: weak transport, martingale transport and model-independent finance, causal and adapted transport and model uncertainty.

Course content: We will motivate the introduction of different kinds of optimal transport in order to deal with several problems in mathematical finance. Specifically, to price and hedge in a model-independent setting, to gauge the distance between financial models, to account for model uncertainty. We will see how results from classical transport theory modify to account for a generalization of the cost or the introduction of constraints. We will appreciate how tools from optimal transport find wide applications in mathematical finance and stochastic analysis. Special attention will be devoted to the constraint of causality, that takes into account the flow of information arriving in time, and turns out to be the suitable one in order to account for model uncertainty in stochastic optimization.

The organization of the course will be as follows:

- Classical optimal transport: recall of main concepts and results (existence, duality, cyclical-monotonicity).
- Weak optimal transport: introduction of the problem, expositions of main results, application to robust pricing in fixed-income markets, analysis of special cases: entropic transport, barycentric transport.
- Martingale optimal transport: introduction of the problem, expositions of main results, model-independent pricing and hedging, Skorokhod Embedding problem.
- Causal and adapted optimal transport: introduction of the problem, expositions of main results, stability in mathematical finance, applications to: filtration enlargement, equilibrium problems, quantification of arbitrage.

Study the past if you would divine the future (Confucius)

Claude Brezinski

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E-mail: Claude.Brezinski@univ-lille.fr.
http://math.univ-lille1.fr/˜brezinsk/

Timetable: 12 hrs. First lecture on April 5th, 2023, 10:00 (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: None

Examination and grading: Reading and analysis of an historical paper (only for PhD students that need credits).

SSD: MAT

Aim: This course is devoted to the study of the historical roots of some ideas and methods used in analysis, numerical analysis and applied mathematics. The themes addressed will also serve as an introduction to research topics.

Course contents:
The scientific context in which some specific methods used in analysis, numerical analysis and applied mathematics appeared will be described and the original works of the mathematicians involved will be studied. Since a mathematical discovery could not be separated from its social and cultural environments, the epoch of each of them will be evoked. Since the life of a mathematician also plays a role in her/his work, we will also present their biography.

The topics covered will be

- A panorama of numerical analysis during the 20th century: Runge-Kutta method, Remez algorithms, Monte-Carlo method, splines, the simplex algorithm, Romberg method, finite elements, QR-algorithm, fractals and chaos, A-stability, fast Fourier transform, singular value decomposition, wavelets, GMRES, etc. (3 hours).
- The method of Cholesky: its origin, Gauss decomposition, the methods of Banachiewicz and others, the discovery of the original manuscript, the family and the life of André Louis Cholesky (1 hour).
- The history of continued fractions: definition and properties, the antiquity and the first steps, the works of Bombelli, Cataldi, Euler, Lambert, Lagrange, Stieltjes and others will be reviewed (2 hours).
- Padé approximants: their history before Henri Padé, his life and his work, the transcendence of the numbers e and π by Hermite and Lindemann, their developments by Borel, Hilbert, and others (1 hour).

- Extrapolation methods from Archimedes to the present days: Snellius, Huygens, Richardson (an independent mind who is the father of fractals), Romberg, Aitken, Steffensen, Shanks, Wynn among others (2 hours).
- The Stein-Rosenberg theorem for relaxation methods: the theorem of Perron and Frobenius, the convergence of the methods of Jacobi and Gauss-Seidel, the lives of Perron, Frobenius, Stein and Rosenberg (1 hour).
- The history of projection methods for solving linear systems: their approaches by linear algebra and by orthogonal polynomials, Krylov subspaces, Lanczos method, the conjugate gradient algorithm, the implementation of the methods, and the lives and work of Lanczos, Hestenes, Stiefel and Fletcher (2 hours).

Claude Brezinski is Professor Emeritus at the University of Lille, France, where he had been the head of the *Laboratory of Numerical Analysis and Optimization* for 30 years. He is the founder and Editor-in-Chief of the journal *Numerical Algorithms*. He was the advisor of 60 Ph.D. thesis in France and in foreign countries. He is the authors of 22 books and 250 research papers. In 1988, he received the Special Prize of the Jury Seymour Cray for his work and, in 2002, he was elected as a foreign member of the Royal Academy of Sciences of Zaragoza, Spain.

Introduction to differential games

Prof.ssa Alessandra Buratto[1]

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

Timetable: 12 hrs. First lecture on February 21st, 2023, 11:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

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.1World Scientific Publishing Company, 2012.
- Jehle, G. A. and Reny P.J., Advanced Microeconomic Theory (Third). Essex: Pearson Education Limited, 2011.
- Long, Ngo Van, A Survey of Dynamic Games in Economics Surveys on Theories in Economics and Business Administration, Vol. 1, 2010.

Signatures in finance: life, death, and miracles

Prof.ssa Christa Cuchiero[1], Prof.ssa Sara Svaluto-Ferro[2]

[1] Department of Statistics and Operations Research University of Vienna
Email: christa.cuchiero@univie.ac.at

[2] Department of Economcis, University of Verona
Email: sara.svalutoferro@univr.it

Timetable: 12 hrs. Torre Archimede.

- 5.9: 10:00 - 11:30 Room 2BC30,
- 6.9: 10:00 - 11:30 Room 2BC30,
- 7.9: 10:00 - 11:30 Room 2BC30,
- 19.9: 10:00 - 11:30, 14:00-15:30 Meeting Room 702,
- 20.9: 10:00 - 11:30, 14:00-14:45 Meeting Room 702.
- 21.9: 10:00 - 11:30 Meeting Room 702

Course requirements: Probability and Stochastic Calculus (basic)

Examination and grading: seminar

SSD: MAT/06, SECS-S/06

Aim: This course aims at introducing the signature of a stochastic process, to then focus on recent development and application to Mathematical Finance, with a special emphasis on numerical aspects relative to its computation.

Course contents:
Signature methods represent a non-parametric way for extracting characteristic features from time series data which is essential in machine learning tasks. This explains why these techniques become more and more popular in Econometrics and Mathematical Finance. Indeed, signature based approaches allow for data-driven and thus more robust model selection mechanisms, while first principles like no arbitrage can still be easily guaranteed.

In this course we shall therefore focus on the use of signature as universal linear regression basis of continuous functionals of paths for financial applications. We first give an introduction to continuous rough paths and show how to embed continuous semimartingales into the rough path setting. Indeed our main focus lies on signature of semimartingales, one of the main modeling tools in finance. By relying on the Stone-Weierstrass theorem we show how to prove the universal approximation property of linear functions of the signature in appropriate topologies on path space. In view of calibration of financial models, we shall also point out in which situations the signature approximation can be tricky. To cover models with jumps we shall additionally introduce the notion of cadlag rough paths, Marcus signature and its universal approximation properties in appropriate Skorokhod topologies.

In the financial applications that we have in mind one key quantity that one needs to compute is the expected signature of some underlying process. Surprisingly this can be achieved for generic classes of jump diffusions (with possibly path dependent characteristics) via techniques from affine and polynomial processes. More precisely, we show how the signature process of these jump diffusions can be embedded in the framework of affine and polynomial processes. These classes of processes have been – due to their tractability – the dominating process class prior to the new era of highly over-parametrized dynamic models. Following this line we obtain that, in generic cases, the infinite dimensional Feynman Kac PIDE of the signature process can be reduced to an infinite dimensional ODE either of Riccati or linear type. This then allows to get power series expansions for the expected signature and its Fourier-Laplace transform.

In terms of financial applications, we shall treat two main topics: stochastic portfolio theory and signature based asset price models.

In the context of stochastic portfolio theory we introduce a novel class of portfolios which we call linear path-functional portfolios. These are portfolios which are determined by certain transformations of linear functions of a collections of feature maps that are non-anticipative path functionals of an underlying semimartingale. As main example for such feature maps we consider signature of the (ranked) market weights. Relying on the universal approximation theorem we show that every continuous (possibly path-dependent) portfolio function of the market weights can be uniformly approximated by signature portfolios. Besides these universality features, the main numerical advantage lies in the fact that several optimization tasks like maximizing expected logarithmic utility or mean-variance optimization within the class of linear path-functional portfolios reduces to a convex quadratic optimization problem, thus making it computationally highly tractable. We apply our method to real market data and show generic out-performance on out-of-sample data even under transaction costs.

In view of asset price models we consider a stochastic process whose dynamics are described by linear functions of the time extended signature of a primary underlying process, which can range from a (market-inferred) Brownian motion or a Lévy process to a general multidimensional semimartingale. The framework is universal in the sense that classical models can be approximated arbitrarily well and that the model's parameters can be learned from all sources of available data by simple methods. We provide conditions guaranteeing absence of arbitrage as well as tractable option pricing formulas for so-called sig-payoffs, exploiting the polynomial nature of generic primary processes. One of our main focus lies on calibration, where we consider both time-series and implied volatility surface data, generated from classical stochastic volatility models and also from S&P 500 index market data. For both tasks the linearity of the model turns out to be the crucial tractability feature which allows to get fast and accurate calibrations results. We also consider an adaptation of the model that allows to price and calibrate VIX options fast and accurately.

Theory and Applications of Singular Stochastic Control

Prof. Giorgio Ferrari[1]

[1] Bielefeld University
Center for Mathematical Economics (IMW)
Email: giorgio.ferrari@uni-bielefeld.de

Timetable: 16 hrs. First lecture on March 22nd, 2023, 09:00 (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar),Torre Archimede, Room 2BC/30.

Course requirements: A previous knowledge of stochastic calculus with respect to standard Brownian motion is required.

Examination and grading: Seminar.

SSD: MAT/06 Probability and Mathematical Statistics

Course contents:

In this class we will introduce the theory of singular stochastic controls and examples of applications arising in Economics, Finance and Operations Research. In particular, we will investigate the intimate relation to optimal stopping theory and free-boundary problems, as well as to reflected diffusion processes.

Week 1 (4 hours)

1. Motivation of singular stochastic controls via an example;
2. Formalization of a general class of Markovian singular stochastic control problems in $\mathbb{R}^n$.

Week 2 (4 hours)

1. Dynamic Programming Principle Equation and Verification Theorem for Markovian singular stochastic control problems in $\mathbb{R}^n$;
2. The optimal policy in terms of the solution to a Skorokhod reflection problem.

Week 3 (4 hours)

1. An application to optimal irreversible investment;
2. Relation to a problem of optimal stopping.

Week 4 (4 hours)

1. Non-Markovian settings and the method of Bank-El Karoui;
2. An application to optimal irreversible investment and comparison to the dynamic programming principle method.

Meshless Approximation: Theory and Applications

Dott.ssa Maryam Mohammadi[1]

[1] 1Faculty of Mathematical Sciences and Computer, Kharazmi University, 50 Taleghani Ave., Tehran 1561836314, Iran
Email: m.mohammadi@khu.ac.ir

Timetable: 16 hrs. First lecture on January 9th, 2023, 14:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Advanced Numerical Analysis, Real Analysis, Functional Analysis.

Examination and grading: final oral exam.

SSD: MAT/08

Aim: The objective of this course is to teach in a unified manner the fundamentals of the scattered data approximation methods. The course will emphasize the radial basis function approximations. Students will learn the key concepts of multivariate scattered data approximation with kernel-based methods and learn how to apply these methods to the solution of partial differential equations (PDEs) and applications to real world problems.

Course contents:

- An overview on multivariate approximation with Radial Basis Function (RBF)
- Reproducing kernel Hilbert spaces
- Error bounds in Sobolev norms
- Stability and trade-off principles
- Weighted Residual Methods
- RBF collocation method to solving some classical PDEs
- New applications of RBF approximation

Material: Lecture Notes provided by the teacher.

Interface of Finance, Operations and Risk Management

Andrea Roncoroni[1]

[1] *ESSEC Business School, Cergy-Pontoise, France*
Email: roncoroni@essec.edu

Timetable: 16 hrs. First lecture on October, 2023, Torre Archimede, Room 2BC30.

Course requirements: Introductory financial derivatives and arbitrage pricing theory

Examination and grading: Project work

SSD:

Aim: This course offers an introduction to the Interfaces of Finance, Operations, and Risk Management (iFORM) with a focus on Integrated Risk Management (IRM). This is a relatively new research area dealing with timely, complex, and boundary-spanning issues in a variety of commercial and industrial setups. iFORM research work addresses ways to better integrate physical, financial, and informational flows by combining the operational choices of the firm with its financial decisions and merging information flows between the firm and its customers and suppliers with informational flows between the firm and its investors. We highlight the main standing, emerging, and forthcoming contributions in IRM.

Course contents:

1. iFORM and IRM (3h)
    - A closed-loop view of operations-finance interfaces.
    - A framework for integrated risk management.
    - Risk identification, integration conditions, and operational vs. financial flexibility.
    - IRM optimization: relationship analysis and approach choice.
2. Static hedging (3h)
    - Contingent claim design: linear, piecewise linear, parametric, custom.
    - Business exposure. Examples: Primary commodity production, Stochastic clearance price model, Generalized newsvendor model, Multinational production capacity allocation.
    - Direct hedging, cross hedging, and combined hedging.
    - Mathematical formulations of optimal custom static hedging. Operational handling integration.
3. Sample models (4h)
    - Claim design models: Brennan-Solanki (1981), Carr-Madan (2001).
    - Static hedging models with nonclaimable risk: McKinnon (1967), Rolfo (1980), Brown-Toft (2002).

- IRM models: Ritchken-Tapiero (1986), Chowdhry-Howe (1999), Gaur-Seshadri (2005), Ding-Dong-Kouvelis (2007), Chen et al. (2015).
- The simplest IRM model with combined custom hedging.

4. Combined custom hedging (6h)
   - Problem statement and solution existence and uniqueness. Examples.
   - The design integral equation system.
   - Corporate value assessment.
   - Newsvendor IRM with combined custom hedging: solution and analysis.

Bibliography:

1. Birge, J.R. (2015). OM Forum-Operations and Finance Interactions. Manufacturing & Service Operations Management 17(1), 4-15.
2. Brennan, M.J., Solanki, R. (1981). Optimal Portfolio Insurance. Journal of Financial and Quantitative Analysis 16(3), 279-300.
3. Brown, G.W. and Toft, K.B. (2002). How Firms Should Hedge. Review of Financial Studies 14, 1283-1324.
4. Chen, L., Li, S., Wang, L. (2014). Capacity Planning with Financial and Operational Hedging in Low-Cost Countries. Production and Operations Management 23, 1495-1510.
5. Chowdhry, B., Howe, J. T. B. (1999). Corporate Risk Management for Multinational Corporations: Financial and Operational Hedging Policies. European Finance Review 2, 229-246.
6. Ding, Q., Dong, L., Kouvelis, P. (2007). On the Integration of Production and Financial Hedging Decisions in Global Markets. Operations Research 55, 470-489.
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8. Guiotto, P., Roncoroni, A. (2022). Combined Custom Hedging. Operations Research 70(1), 38-54.
9. Roncoroni, A. (2022): Lecture notes.
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11. Ritchken, P.H., Tapiero, C.S. (1986). Contingent Claims Contracting for Purchasing Decisions in Inventory Management. Operations Research 34(6), 864-870.
12. Rolfo, J. (1980). Optimal Hedging under Price and Quantity Uncertainty: The Case of a Cocoa Producer. Journal of Political Economy 88, 100-116.
13. Zhao, L., Huchzermeier, A. (2015). Operations–Finance Interface Models: A Literature Review and Framework. European Journal of Operational Research 244, 905-917.
14. Zhao, L., Huchzermeier, A. (2017). Integrated Operational and Financial Hedging with Capacity Reshoring. European Journal of Operational Research 260, 557-570.

Monte Carlo Methods in Python with Financial Applications

Dott. Piergiacomo Sabino[1]

[1] *Quantitative Risk Management, EON SE, Essen, Germany and*
Department of Mathematics and Statistics, University of Helsinki, Pietari Kalmin katu 5, 00014, Helsinki
Email: piergiacomo.sabino@helsinki.fi

Timetable: 16 hrs. First lecture on May 22nd, 2023, 09:00, Room 2BC30 (see calendar at https://dottorato.math.unipd.it/calendar)

Course requirements:

- Knowledge of the basic concepts of stochastic processes.
- Knowledge of basic mathematical finance could be helpful but not required.
- Basic programming experience with Python as well as basic knowledge of object-oriented programming.
- Visual Studio Code (preferable) or Pycharm (non-professional edition) will be used as editors.

Examination and grading: Project in Python.

SSD: MAT/06 Probability and Mathematical Statistics, SECS-S/06 Mathematical Methods for Economics, Actuarial Science and Finance.

Course contents:

Day 1 **Principles of Monte Carlo and simulation of basic processes (4 hours)**

- Crude Monte Carlo: central limit theorem and law of large numbers.
- Methods for the generation of random variables: inverse transform, rejection sampling.
- Examples: simulation from the exponential law, mixture laws, discrete distributions.
- Examples: simulation from the multidimensional Gaussian law. Cholesky decomposition, PCA.
- Examples: generation of the skeleton of the multidimensional Brownian motion and the Ornstein-Uhlenbeck process.
- Examples: Brownian bridge and basic subordination (Stretch).

References: Glasserman [3], Devroye [2].

Day 2 and day 3 **Python Applications (6 hours):**

- Python, virtual environments, and notebooks.
- Projects setting: cookiecutters, poetry, isort, flake8, mypy and all of that.
- All the way to pydantic and Utests.
- Examples: simulation of basic processes and the pricing of some financial contracts.

References: `https://www.python.org/`

Day 4 **Variance Reduction Techniques (3 hours)**:

- Principles and rationale.
- Control Variates and importance sampling.
- Stratification and Latin Hypercube Sampling, some words on Quasi-Monte Carlo.
- Examples: application to some common financial contracts.

References: Glasserman [3], Niederreiter [4].

Day 5 **Lévy-Processes and non-Gaussian Ornstein-Uhlenbeck processes (Stretch). (3h):**

- Simulation of Poisson and compound Poisson processes.
- Simulation of gamma, inverse Gaussian and tempered stable processes.
- Simulation of variance gamma and normal inverse processes.
- $\mathcal{D}$-OU vs OU-$\mathcal{D}$ processes (Stretch).
- Examples: Γ-OU, OU-Γ, IG-OU, OU-IG, VG-OU, OU-VG, NIG-OU, OU-NIG and their simulation (Stretch).

References: Glasserman [3], Cont and Tankov [1], Schoutens [8], Sabino and Cufaro Petroni [7], Sabino [5, 6]

References

[1] R. Cont and P. Tankov. *Financial Modelling with Jump Processes*. Chapman and Hall, London, 2004.

[2] L. Devroye. *Non-Uniform Random Variate Generation*. Springer-Verlag, New York, 1986.

[3] P. Glasserman. *Monte Carlo Methods in Financial Engineering*. Springer-Verlag New York, 2004.

[4] H. Niederreiter. *Random Number Generation and Quasi-Monte Carlo Methods*. S.I.A.M. Philadelphia, 1992.

[5] P. Sabino. Exact Simulation of Variance Gamma Related OU Proceses: Application to the Pricing of Energy Derivatives. *Applied Mathematical Finance*, 27(3):207–227, 2020.

[6] P. Sabino. Normal Tempered Stable Processes and the Pricing of Energy Derivatives. 2022. Accepted in SIAM Journal of Financial Mathematics.

[7] P. Sabino and N. Cufaro Petroni. Gamma-related Ornstein-Uhlenbeck Processes and their Simulation*. *Journal of Statistical Computation and Simulation*, 91(6):1108–1133, 2021.

[8] W. Schoutens. *Lévy Proceses in Finance: Pricing Financial Derivatives*. John Wiley and Sons Inc, Chichester, 2003.

The Mathematics of Energy Markets

Prof.Tiziano Vargiolu

Department of Mathematics "Tullio Levi-Civita", University of Padova
Email: vargiolu@math.unipd.it

Timetable: 12 hrs. First lecture on May 4th, 2023 09:00, (dates already fixed, see Calendar of Activities at https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements:

- Knowledge of the basic concepts of stochastic processes.
- Knowledge of basic mathematical finance could be helpful but not required.

Examination and grading: Seminar.

SSD: MAT/06 Probability and Mathematical Statistics, SECS-S/06 Mathematical Methods for Economics, Actuarial Science and Finance.

Course contents: The program (with emphasis on the mathematical sophistication) will be fixed with the audience according to the mathematical level of the students.
A tentative list of contents is the following:

- An overview of financial and energy markets. Basic contracts (forwards, call and put options) and their evaluation.
- Structured contracts: swing and virtual storage contracts.
- Stochastic control and evaluation of structured contracts.
- Optimal installation of power plants and impulsive/singular control.

Soft Skills

Doctoral Program in Mathematical Sciences

a.a. 2022/2023

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. First lecture will be held online on November 11th, 2022 (in presence: Room 2BC30 and online: link zoom will be sent from Organizer) as follow:

10:30 Preliminary meeting and presentation of the Course

Title: Information literacy for Maths Phd students: 1 - Digital Library, GalileoDiscovery and the advanced services of the library
Contents: The physical and electronic resources of the University libraries, remote access, document delivery and interlibrary loan.

11:30 Seminar "Open access" (see poster below)

March 15th, 2023

Scholarly publication: institutional repositories, licenses, authors' rights and copyright
time: 11:00-12.30
where: Meeting Room 7B1-7°floor and online via zoom on
https://unipd.zoom.us/j/88667156275?pwd=R3AyOGZaOTZ4cXdGcEZJM0FJaVMzdz09

NEW

MathSciNet: its advanced properties, bibliometric indexes and the bibliographic research strategies.
Date: May 3rd, 2023
time: 10:30-12.30
where: Meeting Room 7B1-7°floor and online via zoom on
https://unipd.zoom.us/j/88667156275?pwd=R3AyOGZaOTZ4cXdGcEZJM0FJaVMzdz09

UNIVERSITÀ DEGLI STUDI DI PADOVA

SISTEMA BIBLIOTECARIO DI ATENEO

IL SISTEMA BIBLIOTECARIO DI ATENEO
INVITA A PARTECIPARE AL SEMINARIO ONLINE

OPEN ACCESS

il contesto, le proposte e i servizi (anche economici) per gli autori dell'Università di Padova

L' incontro è destinato principalmente a **docenti, ricercatori, assegnisti e borsisti.**

E' gradita preiscrizione

30 settembre 2022
ore 11.30 - 13.00

per i dipartimenti del Polo "Vallisneri", Scienze Chimiche, Scienze del Farmaco

11 novembre 2022
ore 11.30 - 13.00

per i dipartimenti di Fisica e Astronomia, Matematica e Geoscienze

OPEN ACCESS

Per ulteriori informazioni contattare la Biblioteca

Doctoral Program in Mathematical Sciences

a.a. 2022/2023

SOFT SKILLS

Advanced LaTeX skills

Prof. Enrico Gregorio (University of Verona)

Timetable: 6 hrs. Lectures on:

Thursday March 30th,	16:00,	Room 2BC30
Monday April 3rd,	16:00,	Room 2BC30
Thursday April 13th,	16:00,	Room 2BC30

Course Content:

1. Major TeX errors and introduction to presentations
2. TikZ
3. Beamer

Doctoral Program in Mathematical Sciences

a.a. 2022/2023

SOFT SKILLS

Introduction to the use of “Mathematica” in Mathematics and Science

Prof. Francesco Fassò

Timetable: 5 hrs. Lectures on

Course content:

The aim of this course is to provide the basic competences to use the symbolic, numerical and graphical capabilities of Mathematica, with a focus on the needs of mathematicians and scientists. The course is a hands-on course, which takes place entirely in a computer lab, and is organized in two sessions.

If there were students interested in the **more advanced** (functional) programming capabilities of Mathematica, it might be possible to organize a second part of the course devoted to these topics.

Doctoral Program in Mathematical Sciences

a.a. 2022/2023

SOFT SKILLS

Designing and delivering an effective talk

Timetable

March 17^{th}	17.00-19.00	Room	2BC30
March 20^{th}	14.30-16.30	Room	2BC30
March 31^{st}	15:00-17:00	Room	2BC60*

*Lecture held by Dr. Alan Crivellaro,
further information at http://www.presenting-scientist.com/

Doctoral Program in Mathematical Sciences

a.a. 2022/2023

SOFT SKILLS

A critical introduction to bibliometric indices and to their use and abuse in evaluations

Timetable: TBC

Course Content: TBD

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/

Please check regularly the website of the Doctoral Course

Calendar of activities on

`https://calendar.google.com/calendar/u/0/embed?src=fvsl9bgkbnhhkqp5mmqpiurn6c@group.calendar.google.com&ctz=Europe/Rome`

Introduction to Model Predictive Control with Case Studies in Automotive and Biomedicine

Prof. Ruggero Carli[1], Dr. Mattia Bruschetta[2], Dr. Simone Del Favero[3]

[1] *Department of Information Engineering, University of Padova*
email: carlirug@dei.unipd.it

[2] *Department of Information Engineering, University of Padova*
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[3] *Department of Information Engineering, University of Padova*
email: simone.delfavero@unipd.it

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

Course requirements: Basic Calculus and Linear Algebra.

Examination and grading: Homework and take home exam

SSD: Information Engineering

Aim: To provide the methodological tools needed to understand model-based control algorithms and to design a Model Predictive Control algorithm for a linear dynamical system. The course is tailored on students who have not received an extensive training on control theory. As case studies, the course focus on Automotive and Bioengineering applications.

Course contents:

1. Introduction to model-based control.
2. State Space Models: driving the state with inputs.
3. State Space Model: estimating the state form the output.
4. Linear Quadratic Regulator (finite and infinite horizon).
5. Model Predictive Control - Regulation: Formulation, Dynamic Programming Solution, Stability properties, MPC for Unconstrained Systems, MPC for Systems with Input Constraints, MPC for Systems with Input and State Constraints.
6. Offset-free Model Predictive Control: disturbance estimation, partial velocity form, full velocity form.
7. Elements of Nonlinear MPC.
8. Automotive case studies: Motion Cueing Algorithms, Virtual Rider, Autonomous Driver.
9. Biomedicine case study: the Artificial Pancreas, Automated Drug Infusion for Anesthesia.

References:
[1] J. B. Rawlings and D. Q. Mayne. Model predictive control: Theory and design. Nob Hill Publisher.
Other material and research papers will be available online for download.

Distributed Optimization and Applications

Prof. Subhrakanti Dey[1]

[1] *Signals and Systems, Uppsala University, Sweden*
Email: Subhra.Dey@signal.uu.se

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

Course requirements: Advanced calculus, and probability theory and random processes.

Examination and grading: A project assignment for students in groups of 2 requiring about 20 hours of work.

SSD:

Aim: The aim of this course is to introduce postgraduate students to the topical area of Distributed Optimization. As we enter the era of Big Data, engineers and computer scientists face the unenviable task of dealing with massive amounts of data to analyse and run their algorithms on. Often such data reside in many different computing nodes which communicate over a network, and the availability and processing of the entire data set at one central place is simply infeasible. One needs to thus implement distributed optimization techniques with message passing amongst the computing nodes. The objective remains to achieve a solution that can be as close as possible to the solution to the centralized optimization problem. In this course, we will start with some history on the origins of distributed optimization algorithms such as the Alternating Direction Method of Multipliers (ADMM), discuss its properties, and applications to both convex and non-convex problems, and explore distributed statistical machine learning methods, and finish with discussions on very recent and largely open areas such as networked optimization. This course will provide a glimpse into this fascinating subject, and will be of relevance to graduate students in Electrical, Mechanical and Computer Engineering, Computer Science students, as well as graduate students in Applied Mathematics and Statistics, along with students dealing with large data sets and machine learning applications to Bioinformatics.

Course contents:

- Lectures 1-3: Precursors to distributed optimization algorithms: parallelization and decomposition of optimization algorithms (dual de- composition, proximal minimization algorithms, augmented Lagrangian and method of multipliers), The Alternating Direction Method of Multipliers (ADMM): (Algorithm, convergence, optimality conditions, stopping criteria, constrained convex optimization)
- Lectures 4-5: Applications of ADMM to machine learning problems: l1 norm problems, ADMM based methods for solving consensus and sharing problems, ADMM for non-convex problems and examples
- Lectures 6-8: Applications of distributed optimization to distributed machine learning, Federated Learning, distributed Newton methods
- Lectures 9-10: Networked Optimization (e.g. over a graph) and fully distributed optimization under communication constraints

References:

1. S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein, Distributed Optimization and Statistical Learning via the Alternating Direction Method of Multipliers, Foundations and Trends in Machine Learning, 3(1):1122, 2011.
2. Dimitri Bertsekas and John N. Tsitsiklis, Parallel and Distributed Computation: Numerical Methods, Athena Scientific, 1997.
3. S. Boyd and L. Vandenverghe, Convex Optimization, Cambridge University Press.
4. M. Zhu and S. Martinez, Distributed Optimization-Based Control of Multi-Agent Networks in Complex Environments, Springer, 2015.

Relevant recent papers will be referred to and distributed during the lectures.

Bayesian Machine Learning

Giorgio Maria Di Nunzio[1]

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

Timetable: 20 hrs (see Class Schedule 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:

1. Introduction of classical machine learning problems.
    - Mathematical framework
    - Supervised and unsupervised learning
2. Bayesian decision theory
    - Two-category classification
    - Minimum-error-rate classification
    - Bayes decision theory
    - Decision surfaces
3. Estimation
    - Maximum Likelihood Estimation
    - Expectation Maximization
    - Maximum A Posteriori
    - Bayesian approach
4. Graphical models
    - Bayesian networks
    - Two-dimensional visualization
5. Evaluation
    - 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/)

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 Class Schedule 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: from regularization to deep networks

Prof. Gianluigi Pillonetto[1]

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

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

Enrollment: add the course to the list of courses you plan to attend using the Course Enrollment Form (requires SSO authentication) and, if you are taking the course for credits, to the Study and Research Plan.

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.
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. Support vector regression and classification. Extensions of the theory to deep kernel-based networks: multi-valued RKHSs and the concatenated Representer Theorem.

References:

1. G. Pillonetto, T. Chen, A. Chiuso, G. De Nicolao, L. Ljung. Regularized System Identification – learning dynamic models from data, Springer Nature 2022
2. W. Rudin. Real and Complex Analysis, McGraw Hill, 2006
3. C.E. Rasmussen and C.K.I. Williams. Gaussian Processes for Machine Learning. The MIT Press, 2006
4. 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 Class Schedule 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:
- 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

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 Class Schedule 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.

References:

1. Arjovsky, M., Chintala, S., Bottou, L. (2017). Wasserstein GAN. CoRR, abs/1701.07875.
2. Bahdanau, D., Cho, K., Bengio, Y. (2014). Neural Machine Translation by Jointly Learning to Align and Translate. CoRR, abs/1409.0473.
3. I. Goodfellow, Y. Bengio, A. Courville ‘Deep Learning’, MIT Press, 2016
4. Goodfellow, I.J., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., Courville, A.C., Bengio, Y. (2014). Generative Adversarial Nets. NIPS.
5. Hochreiter, S., Schmidhuber, J. (1997). Long Short-Term Memory. Neural computation, 9 8, 1735-80.

6. Kalchbrenner, N., Grefenstette, E., Blunsom, P. (2014). A Convolutional Neural Network for Modelling Sentences. ACL.
7. Krizhevsky, A., Sutskever, I., Hinton, G.E. (2012). ImageNet Classification with Deep Convolutional Neural Networks. Commun. ACM, 60, 84-90.
8. LeCun, Y. (1998). Gradient-based Learning Applied to Document Recognition.
9. Mikolov, T., Sutskever, I., Chen, K. (2013). Representations of Words and Phrases and their Compositionality.
10. Vincent, P., Larochelle, H., Lajoie, I., Bengio, Y., Manzagol, P. (2010). Stacked Denoising Autoencoders: Learning Useful Representations in a Deep Network with a Local Denoising Criterion. Journal of Machine Learning Research, 11, 3371-3408.
11. Zaremba, W., Sutskever, I., Vinyals, O. (2014). Recurrent Neural Network Regularization. CoRR, abs/1409.2329.