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

Doctoral Program in Mathematical Sciences

Catalogue of the courses 2023-2024

Updated January 18th, 2024
INTRODUCTION

This Catalogue contains the list of activities offered to the Graduate Students in Mathematical Sciences for the year 2023-2024.

The activities 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 activities:
   a) selected courses offered by the PhD school in Information Engineering;
   b) selected courses offered by other PhD schools or other Institutions;
   c) 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 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 (for such activities the PhD student must produce a brief summary on what she/he learned. These summaries should be attached to the annual report)

Students are warmly encouraged to take more courses than the minimum required by these rules, and to commit themselves to follow regularly these courses. It is also recommended that one half of the exams are taken during the first year. 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.

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. 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"), within which they are also required to deliver a talk and write an abstract.

b) Students are also strongly encouraged to attend the seminars of the research groups that are relevant for their work.

HOW TO REGISTER AND UNREGISTER TO COURSES

The registration to a Course must be done online.

Students can access the online registration form in the dedicated page of the Doctoral Course website at https://dottorato.math.unipd.it/current-activity/FutureActivities clicking on “click to enroll” of the chosen courses. The registration lists can be reached also via the website of the Department of Mathematics at https://prev-www.math.unipd.it/userlist/

In order to register, fill the registration form with all required data, and validate with the command “Subscribe”. 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 2024 or later, and as soon as possible for courses that take place until December 2023.

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. ssa Cristiana Bertolin
   Elliptic curves and Periods  
   DP-1

2. Prof. ssa Laura Caravenna
   Introduction to Optimal Transport  
   DP-2

3. Prof. Ramon Codina
   Mixed and stabilised finite element methods  
   DP-3,4

4. Prof. Christos Efthymiopoulos
   Perturbative methods in dynamical systems  
   DP-5,6

5. Prof. Francesco Esposito
   Introduction to Harmonic Analysis on Semisimple Groups  
   DP-7,8

6. Prof. Massimo Lanza de Cristoforis,  
   Integral operators in Hölder spaces  
   DP-9

Courses of the “Mathematics” area

1. Prof. Alexandr Buryak
   Integrable Systems of PDEs and their infinite dimensional algebra of symmetries  
   M-1,2

2. Dott. Alessandro Goffi, Giulio Tralli
   Nonlinear methods for linear equations: the low-regularity theory  
   M-3,4

3. Dott. Elio Marconi
   Flows of Sobolev vector fields  
   M-5

4. Prof. ssa Gabriella Pinzari
   Introduction to Kolmogorov-Arnold-Moser theory  
   M-6,7

5. Prof. Sergiy Plaks
   Monogenic functions and basic elliptic equations of mathematical physics  
   M-8,9

6. Prof. Fulvio Ricci
   Harmonic analysis on nilpotent groups  
   M-10

7. Prof. Eric Sommers
   Introduction to Hessenberg Varieties  
   M-11,12
Courses of the “Computational Mathematics” area

1. Dr. Manuel Francesco Aprile,
   Linear and non-linear formulations for Combinatorial Optimization  MC-1
2. Prof. Martin Buhmann
   Kernels and Partitions of Regular Domains and Compact Sets  MC-2
3. Dott.Alekos Cecchin
   Stochastic and mean field optimal control  MC-3
4. Dr. Alberto Chiarini, Prof. Giovanni Conforti
   A renormalisation group approach to log-Sobolev inequalities  MC-4
5. Prof. Andrea Roncoroni
   Interface of Finance, Operations and Risk Management  MC-5,6
6. Prof. Simone Scotti
   Hawkes processes: from theory to (financial) practice  MC-7,8

Soft Skills

1. Maths information: retrieving, managing, evaluating, publishing  SS-1
2. Introduction to the use of "Mathematica” in Mathematics and Science  SS-2

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/

To be confirmed

Calendar of activities on
https://calendar.google.com/calendar/u/0/embed?src=fvs19bgkbnhhkq5mmqpiurn6c@group.calendar.google.com&ctz=Europe/Rome

1. Prof. Subhrakanti Dey
   Distributed Machine Learning and Optimization: from ADMM to Federated and multiagent Reinforcement Learning  DEI-1,2
2. Prof. Giorgio Maria Di Nunzio  
Bayesian Machine Learning DEI-3,4

3. Prof. Marco Fabris  
Analysis and Control of Multi-agent Systems DEI-5,6

4. Prof. Gianluigi Pillonetto  
Applied Functional Analysis and Machine Learning DEI-7,8

5. Prof. Domenico Salvagnin  
Heuristics for Mathematical Optimization DEI-9

6. Prof. Gian Antonio Susto  
Elements of Deep Learning DEI-10,11

Courses in collaboration with the Doctoral School on  
“Economics and Finance”  
University of Verona

for complete Catalogue and class schedule see on  
https://www.dse.univr.it/?ent=oi&ava=&cs=1008&id=746&lang=en

1. Prof.ssa Sara Svaluto-Ferro  
Stochastic Processes in Finance VR-1
Courses of the Doctoral Program
Elliptic curves and Periods

Cristiana Bertolin

1Dipartimento di Matematica “Tullio Levi-Civita”
Email: cristiana.bertolin@unipd.it

Timetable: 24 hrs. First lecture on Thursday October 12th, 2023, 10:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Algebra, Calculus, Geometry, of the first level degree in mathematics

Examination and grading: Please contact the teacher of the course by e-mail

SSD:

Aim:
To discover the geometrical origin of some transcendental conjectures

Course contents:

- Introduction to algebraic curves
- Elliptic curves over the field of complex numbers
- Geometrical description of the law group on elliptic curve
- The Weierstras $\wp$-function, the Weierstrass $\zeta$-function, and the Serre $f_q$-function with their doubly periodicity
- The differential forms of the first, the second and the third kind
- The periods of an elliptic curves and their transcendence properties

 eventual: Seminar of Prof. Michel Waldschmidt

Bibliography:

Introduction to Optimal Transport

Laura Caravenna

Dipartimento di Matematica “Tullio Levi-Civita”
Email: laura.caravenna@unipd.it

Timetable: 24 hrs. First lecture on Monday October 23rd, 2023, 10:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Some functional analysis functional analysis, and some notions of basic PDEs. The essential required notions will be recalled in the course. Contact me for doubts.

Examination and grading: Oral examination on the content of the course, or presentation of a related research paper or research topic, according to the preferences of each student.

SSD: MAT/05

Aim: With the first part of the course, of about 16 hours, students will learn the main features of the theory of optimal transport. The last part will discuss selected applications to PDEs.

Course contents:
Monge formulation of Optimal Transport Problems and its limits. Kantorovich Formulation of Optimal Transport Problem, existence of optimal plans, Kantorovich- Rubinstein duality for general cost functions. Necessary and sufficient optimality conditions for transport plans, c-cyclical monotonicity, c-concavity, c-transforms in special cases. Optimal transport plans versus optimal transport maps and existence of optimal maps, with a special focus on Brenier’s theorem for the quadratic cost function. Connection with the Monge- Ampère equation. Wasserstein distances and basic properties. Selected applications to be sorted. Curves in the Wasserstein spaces and relation with the continuity equation, geodesics, Benamou-Brenier dynamical formulation, AC curves in the Wasserstein spaces. Introduction to gradient flows in metric spaces and the JKO minimization scheme for some evolution equation.

eventual The selection of which applications we focus on will be fixed during the first week of the course, depending on the interests of the students.

Bibliography:

- A. Figalli, F. Glaudo: An Invitation to Optimal Transport, Wasserstein Distances and & Gradient Flows, 2022
Mixed and stabilised finite element methods

Ramon Codina

Universitat Politècnica de Catalunya
Email: ramon.codina@upc.edu

Timetable: 24 hrs. First lecture on November 6, 2023 (dates already fixed see calendar on: https://dottorato.math.unipd.it/calendar) (6 hours a week for 4 weeks: 3 hours on Monday afternoon; 3 hours on Tuesday morning), Torre Archimede, 2BC30.


Examination and grading: 50% homeworks, 50% written exam or, alternatively if the student wishes, presentation of a recent research paper (to be agreed with the instructor)

Aim: To introduce several mixed problems in linear partial differential equations and to explain how to approximate them using the finite element method.

Course contents:

- **Introduction to the finite element method - 6 hrs.** Introduction to the theory and practice of conforming Galerkin FEM methods for elliptic equations.


- **Stabilised finite element methods - 2 hrs.** Basic concept. The variational multi-scale approach. Application to mixed problems.

- **Darcy’s problem - 2 hrs.** Primal form, dual form. Inf-sup conditions and examples of compatible approximations. Stabilised finite element approximation.

- **Stokes’ problem - 2 hrs.** Two-field formulation. Three-field formulation. Inf-sup conditions and examples of compatible approximations. Stabilised finite element approximation.

- **Maxwell’s problem - 2 hrs.** Kikuchi formulation. An example of inf-sup stable approximation. Augmented stabilised finite element approximation.


- **Introduction to hybrid methods - 2 hrs.** Hybridisation of Poisson’s problem. Inf-sup conditions. Stabilised finite element approximation.
Bibliography:

- S.C. Brenner and L.R. Scott. 

- D. Boffi, F. Brezzi and M. Fortin. 

  *Theory and Practice of Finite Elements* (Springer-Verlag, 2004)
Perturbative methods in dynamical systems

Christos Efthymiopoulos

Dipartimento di Matematica “Tullio Levi-Civita”
Email: christos.efthymiopoulos@unipd.it

Timetable: 24 hrs. First lecture on Thursday November 2nd, 2023, 14:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements:

Examination and grading: After the fourth lecture, students will be asked to choose a project to develop using mathematica. An oral exam will take place at the end of the course, including presentation of the project results and questions on the course material.

SSD: MAT/07

Aim: This course aims to provide a self-contained introduction to the use of the methods of perturbation theory in the study of both regular and chaotic motions in dynamical systems. After a short review of basic definitions pertinent to dynamical systems’ theory, the course will present two types of perturbative methods, both of use in the study of the characterization of the solutions and of the local structure of the phase space in the neighborhood of a basic solution of a dynamical system such as a fixed point or a periodic orbit:

i) direct methods (for example, Lindstedt), which aim to construct the solutions directly under the form of a power series in a suitably defined small parameter, and

ii) indirect or normal form methods (for example, the Poincaré normal form), which aim at introducing a transformation of the variables in the form of series in the small parameter.

The presentation will be example-driven, starting from a simple dynamical system representing a nonlinear oscillator with dissipation and external driving. The students will be motivated to make computations in perturbation theory using mathematica and solve some project problems. Some rigorous estimates on the dependence of the size of the perturbative terms as a function of the order of the theory, based on suitable norm definitions in functional spaces related to the dynamical system under study, will be given in the last part of the course.

Lectures plan:


Lectures 3-5: Introduction to basic methods of perturbation theory part I: direct methods The example of the Duffing oscillator with dissipation and external driving. Perturbative (series)
representation of the solutions in the neighborhood of the stable fixed point using Lindstedt
series. Perturbative (series) representation of the invariant manifolds emanating from the unsta-
ble fixed point using the parametrization method. Study of the intersections of the stable and
unstable manifolds by the Poincaré - Melnikov method.

**Lectures 6-7:** Introduction to basic methods of perturbation theory part II: indirect methods
Linear normal forms and their classification. The Poincaré normal form in the neighborhood of
a stable fixed point. The Moser normal form in the neighborhood of an unstable fixed point.

**Lectures 8-9:** Normal Forms in Hamiltonian dynamical systems Basic review of Hamiltonian
mechanics. Symplectic transformations and Poincaré invariants. The method of generating
functions. Near-to-identity canonical transformations with the method of Lie series. The nor-
mal form of Birkhoff. A review of stability in nearly-integrable Hamiltonian systems. Lecture
10: Rigorous estimates in perturbation theory Norms for polynomial and for real-analytic func-
tions. Divisors. Norm estimates on the basis of iterative lemmas.

**Lectures 11-12:** The passage to systems with many (or infinitely many) degrees of freedom.
Perturbation theory in the example of a system with N non-linearly coupled oscillators, with
N large. The limit of 1+1 (space and time) field equations. Perturbative computation of the
spectrum of the Schrödinger equation in a one-dimensional nonlinear oscillator model, and in
the perturbed hydrogen atom.

**Bibliography:**

1. J.A. Sanders, F. Verhulst and J. Murdock, Averaging Methods in Nonlinear Dynamical sys-


Additional bibliography: Parts of openly available lecture notes by i) G. Benettin, ii) F. Fasso‘,
iii) M. Guzzo. Some lecture notes tailored to the needs of the course will be provided by the
insegnant.
Introduction to Harmonic Analysis on Semisimple Groups

Francesco Esposito

1 Dipartimento di Matematica “Tullio Levi-Civita”
Email: francesco.esposito@unipd.it

Timetable: 24 hrs. First lecture on Tuesday May 7th, 2024, 14:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: The prerequisites are reduced to the minimum:
- standard notions from first and second year courses in analysis
- elementary linear algebra
All other needed concepts will be illustrated in the course.

Examination and grading: Lectures will be complemented with exercise sheets which may be handed in for grading. Alternatively, the exam may consist in an oral examination where the student is supposed to deliver a lecture on a chosen argument.

SSD: MAT02/03/05

Aim:
Classically, harmonic analysis deals with the expansion of functions of one or more real variables as series or integrals of simple harmonics. A natural setting of the theory is that of locally compact commutative topological groups. Applications range from number theory to differential equations. Noncommutative harmonic analysis on Lie groups is more recent and was initially forged for the needs of invariant theory and quantum mechanics. It studies possibly infinite-dimensional representations of a Lie group, the special functions on the group afforded by the matrix coefficients, and the expansion of functions on the group in terms of these. The course is meant as an introduction to the representation theory and harmonic analysis on semisimple Lie groups. The introduction will succinctly survey the commutative theory and some of its applications. Next, theory for compact groups will be dealt in greater detail, up to the Peter-Weyl theorem. Finally, the course will concentrate on infinite-dimensional representations of semisimple Lie groups, representations of its Lie algebra, and characters of these. The basic example will be the group $SL(2, \mathbb{R})$.

Course contents:
1. Introduction
2. Compact groups
3. Unitary representations of locally compact groups
4. Parabolic induction, principal series and characters
5. Representations of the Lie algebra
6. Plancherel formula
7. Invariant eigendistributions
8. Harmonic analysis on the Schwartz space

Bibliography:

1. An introduction to harmonic analysis on semisimple Lie groups” V.S. Varadarajan.
Integral operators in Hölder spaces

Massimo Lanza de Cristoforis

1 Dipartimento di Matematica “Tullio Levi-Civita”
Email: mldc@math.unipd.it

Timetable: 24 hrs. First lecture on October 5th, 2023, 16:45 (date already fixed, see calendar on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30

Course requirements: Calculus, basics of real and functional analysis.

Examination and grading: Written/oral questions.

SSD: MAT/05

Aim: Develop basic skills in the theory of integral operators and their applications to potential theory and partial differential equations.


Bibliography:


5 M. Lanza de Cristoforis, Student hand-outs, Academic Year 2022/23.
Courses of the “Mathematics” area
Integrable Systems of PDEs and their infinite dimensional algebra of symmetries

Alexandr Buryak

Faculty of Mathematics National Research University Higher School of Economics, Moscow
Email: aburyak@hse.ru

Timetable: 24 hrs. First lecture on June 2024,..., Torre Archimede, Room 2BC30.

Aim: The goal of this course is to introduce the students to the notion of integrable system of evolutionary PDEs, study their properties and illustrate several examples and some of their applications in very diverse branches of mathematics.

Classical integrable systems find their origin in analytical mechanics and can be formalized as Hamiltonian systems of ODEs (i.e. Hamiltonian vector fields on a symplectic manifold) possessing sufficiently many (globally defined) conserved quantities in involution to give rise to a Lagrangian torus foliation in their phase space. This geometry makes it possible to solve these systems in a remarkably explicit form. One can generalize the notion of integrable system to a non-Hamiltonian setting, considering dynamical systems (i.e. vector fields on any manifold) with a rich algebra of infinitesimal symmetries.

The modern theory of integrable systems, which is the object of this course, deals with analogous concepts when transported to the context PDEs. Started in the second half of the 20th century mostly with motivations from mathematical physics, it had a resurgence in the last 30 years in light of the discovery of several surprising connections with entirely different branches of mathematics, with the notable example of algebraic geometry (in particular the theory of algebraic curves and the intersection theory of their moduli spaces).

This course will mainly concentrate on the notion of integrable system as a system of partial differential equations possessing an infinite dimensional algebra of infinitesimal symmetries. Our approach will be mostly formal, with next to no prerequisites, from analysis or other fields. Regarding the class of partial differential equations, we will consider systems of evolutionary PDEs with one spatial variable. We will discuss classical examples of such integrable systems, like the Korteweg-de Vries (KdV) equation, and we will prove general theorems on their behaviour and properties, focusing in the second half of the course on the theory of the famous Kadomtsev–Petviashvili (KP) hierarchy. In the final lectures we will prove Okounkov’s theorem, which states that the generating function of simple Hurwitz numbers (the number of coverings of the Riemann sphere, of given genus and degree, with simple ramification points) solves the KP hierarchy.

Course contents: The course will be structured in five modules, each of approximately 4/5 hours.

Motivations and the KdV equation: The Korteweg-de Vries equation is the main and historically most relevant example of integrable evolutionary PDE. It describes surface waves in shallow water. We will derive it from Euler equations and the continuity equation. It will serve as running example and motivation for the first part of the course.
Algebraic formalism for evolutionary PDEs: Here we start developing the algebraic tools for studying evolutionary PDEs in the language of differential polynomials and local functionals, for one and several independent space variables.

The KP hierarchy: The Kortzovtsev-Petviashvili hierarchy of integrable PDEs is a system in one space variable and infinite unknown functions. It is defined through a Lax representation using pseudodifferential operators. Its importance lies in the fact that in contains, as its reductions, an infinite family of other integrable hierarchies (including KdV).

Tau functions of KP and Sato Grassmannian: We introduce technical tools to study the KP hierarchy and its solutions, namely dressing operators, tau functions, the Fock space and the Sato Grassmannian.

Okounkov theorem on KP and Hurwitz numbers: After a very quick reminder of Hurwitz theory, we prove Okounkov famous result that the generating series of simple Hurwitz numbers (the number of covers of given degree of the Riemann sphere by a Riemann surface of given genus with simple ramification) is a tau function of the KP hierarchy.

Reference for the Course:
Detailed notes of the course, based on the notes [Bur22] for a similar PhD course delivered at the Faculty of Mathematics of the HSE University in Spring 2022, will be made available for participants. Material will be drawn from several research articles, including, but not restricted to [BRZ21, DKJM83, Dic03, Dor78, LL87, Ok00, SG69].

Reference:

Bur22 A. Buryak. Integrable systems as systems of PDEs with an infinite dimensional algebra of symmetries. Notes for a PhD course delivered at the Faculty of Mathematics of the HSE University in Spring 2022. Available at https://sites.google.com/site/alexandrburyakhomepage/home.


Nonlinear methods for linear equations: the low-regularity theory

Alessandro Goffi\textsuperscript{1}, Giulio Tralli\textsuperscript{2}

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Dipartimento di Ingegneria Civile, Edile e Ambientale (DICEA)
Email:giulio.tralli@unipd.it

**Timetable:** 16 hrs First lecture on Tuesday March 5th, 2023, 10:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30..

**Course requirements:** Basic knowledge of classical functional spaces, without PDE requirements.

**Examination and grading:** The exam will be oral and tailored on the students’ interests.

**SSD:** MAT/05

**Aim:** Introduce some classical and modern methods to study regularity properties of solutions to the Laplace equation, focusing on nonvariational techniques based mostly on the maximum principle.

**Course contents:**
- Introduction and motivations: the importance of the regularity theory for elliptic equations;
- Review of maximum principles and applications;
- Weak-Harnack inequalities via Aleksandrov-Bakel’man-Pucci techniques;
- Harnack inequalities and Hölder a priori estimates;
- The notion of viscosity solution;
- The Bernstein technique to obtain a priori gradient estimates;
- Hölder/Lipschitz regularity estimates via doubling variables: the Ishii-Lions method;
- Lipschitz regularity estimates via doubling variables: the weak Bernstein method.

**Bibliography:**

Flows of Sobolev vector fields

Elio Marconi

1Dipartimento di Matematica “Tullio Levi-Civita”
Email: elio.marconi@unipd.it

Timetable: 16 hrs.; First lecture on Wednesday November 29th, 2023, 14:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Sobolev spaces, measure theory, weak formulation of PDEs.

Examination and grading: seminar about a research paper on the subject.

Aim: The aim of this course is to provide an introduction to the theory of the ODE and the associated continuity equation for weakly differentiable vector fields, and to illustrate some research directions in this domain.

Course contents:
1. Preliminaries on ODEs and the continuity equation (PDE) in the classical setting: regularity estimates of the flow and the method of characteristics.
3. The Eulerian point of view: the uniqueness theorem by Di Perna and Lions.
4. The Lagrangian point of view: the a priori regularity estimate by Crippa and De Lellis.

Bibliography:

Introduction to Kolmogorov-Arnold-Moser theory

Gabriella Pinzari

Dipartimento di Matematica “Tullio Levi-Civita”, Università di Padova
Email: gabriella.pinzari@math.unipd.it

Timetable: 16 hours. First lecture on April 3rd, 2023, 11:00 (dates already fixed, see on: https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: minimal knowledge of Hamiltonian systems (canonical coordinates; symplectic transformations; Liouville-Arnold Theorem)

Examination and grading: 45’-1 hr seminar by the candidate

SSD: MAT/07 and MAT/05.

Aim: to present the ideas of Kolmogorov-Arnold-Moser theory

Course contents:

• Recap on Hamiltonian systems; canonical coordinates; canonical transformations; Liouville-Arnold Theorem. Focus on holomorphic Hamiltonians; Cauchy inequalities; decay of Fourier coefficients of holomorphic periodic functions.
• Diophantine inequalities.
• Perturbative schemes: norms; Normal Form Theory; KAM algorithm and convergence; measure of the Kolmogorov set.
• Generalization to properly—degenerate hamiltonians;

if there is time enough

• Lower-dimensional quasi-periodic motions (whiskered tori).
• If there is time: generalization to vector-fields; some application

References:


Monogenic functions and basic elliptic equations of mathematical physics

Prof. Sergiy Plaksa

1 Institute of Mathematics of the National Academy of Sciences of Ukraine
Email: plaksa62@gmail.com

Timetable: 12 hrs. First lecture on November 6th, 2023, 12:30 (dates already fixed see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Basic notions on holomorphic functions in the complex plane and of elementary functional analysis.

Examination and grading: exam

Aim: studying properties of monogenic functions of a hypercomplex variable and their applications for constructing solutions of equations of mathematical physics

Course contents:
Determination of hypercomplex algebras associated with the three-dimensional Laplace equation and the biharmonic equation. Commutative harmonic algebras. A biharmonic algebra.

Differentiation in Banach algebras. The Lorch derivative and the Gâteaux derivative. The principal extension of analytic functions of a complex variable into a commutative Banach algebra.


and possibly also:

Monogenic functions in infinite-dimensional vector spaces associated with the three-dimensional Laplace equation.

Bibliography:

Main:


Additional:


Harmonic analysis on nilpotent groups

Fulvio Ricci

Scuola Normale Superiore di Pisa, Piazza dei Cavalieri 7, 56126 Pisa
Email: fulvio.ricci@sns.it

Timetable: 16 hrs. First lecture on January 29, 2024, 15:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar/), Torre Archimede, Room 2BC30.

Course requirements: Functional Analysis, Fourier series and Fourier transform in $\mathbb{R}^n$.

Examination and grading: Seminar and interview.

Aim: Fundamental notions and properties of analysis on Lie groups. Analysis of sublaplacians on nilpotent groups.

Course contents:

Bibliography: Notes to be distributed during the course.
Introduction to Hessenberg Varieties

Eric Sommers

Department of Mathematics and Statistics, University of Massachusetts Amherst, Amherst, MA 01003, USA
Email address: esommers@umass.edu

Timetable: 12 hours. First lecture on Monday, October 9, 2023, 14:00 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course Requirements: A year of abstract algebra, some exposure to algebraic varieties.

Examination and Grading: Students will give a talk on an aspect of the subject using a research article as a basis for the talk.

SSD: MAT/02 and MAT/03

Aim: Hessenberg varieties are projective subvarieties of the flag variety, which appear as fibers of proper maps to affine subvarieties of the Lie algebra. They are generalizations of the Springer varieties that play a central role in the representation theory of finite Chevalley groups, as well as the infinite-dimensional representation theory of real Lie algebras. Hessenberg varieties are smooth in the regular semisimple case and their cohomology carries a still mysterious representation of the Weyl group, but it is the geometry of the regular nilpotent Hessenberg varieties that play a more direct role in the singularities of the nilpotent cone and their local intersection cohomology groups. Hessenberg varieties are also interesting due to their connections to algebraic combinatorics via chromatic quasisymmetric functions. The aim of this course is to supply some of the background in Lie theory and combinatorics to read the current literature on Hessenberg varieties and their applications to representation theory and algebraic combinatorics.

Course contents:

1. Roots systems, Weyl groups, and related invariant theory.
2. The symmetric group setting. Symmetric functions.
4. Springer varieties and statement of the Springer correspondence. Examples for the symmetric group and in rank 2.
6. Connections to combinatorics: chromatic quasisymmetric functions, the dot-action representation, and the Stanley-Stembridge conjecture.
7. Computational methods. Example: computing the dimensions of irreducible representations of the Weyl groups via the Springer correspondence.
Bibliography


Courses of the “Computational Mathematics” area
Linear and non-linear formulations for Combinatorial Optimization

Manuel Francesco Aprile

Dipartimento di Matematica “Tullio Levi-Civita”, Università di Padova
Email: manuel.aprile@unipd.it

Timetable: 16 hrs. First lecture on Tuesday April 9th, 2024, 10:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: None. Familiarity with basic concepts in geometry of polyhedra and discrete optimization will be helpful.

Examination and grading: Seminar.

SSD: MAT/09

Aim: Combinatorial optimization problems are ubiquitous in many fields, spanning from logistics and artificial intelligence to computational biology. The crux of solving such problems lies in efficiently selecting an optimal solution from a finite but very large set of objects. This course aims to equip students with a toolkit of techniques to construct effective mathematical programming formulations for these combinatorial problems. Special emphasis will be placed on exploring “hot” topics that have undergone substantial advancements in recent years, such as extended formulations. Moreover, the course will delve into intriguing connections between combinatorial optimization and other fields such as computational complexity.

Course contents:
- Classical linear formulations from the literature.
- Extended formulations: Yannakakis’ theorem, connection with communication protocols.
- Positive and negative results on the existence of small extended formulations.
- Semidefinite formulations.
- Introduction to hierarchies: from Sherali-Adams to Sum of Squares.

Bibliography:
Relevant material and research papers will be provided during the course. Most of the topics covered can be found in: Conforti, Cornuéjols, Zambelli (2014).
Integer programming. Springer International Publishing.
Kernels and Partitions of Regular Domains and Compact Sets

Martin Buhmann¹

¹Justus-Liebig-Universität Giessen, Germany
Email: buhmann@math.uni-giessen.de

Timetable: 13 hrs. First lecture on November 21, 2023, 12:30 (date already fixed, see calendar on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Recommended: Numerical Analysis I and Analysis I and II or Approximation Theory

Examination and grading:

Aim: Understanding the particulars of the approximtion theory of many variables, namely kernel-based methods for regular and scattered data, interpolation vs. quasi-interpolation including polynomial reproduction, positive and strictly positive interpolation matrices and kernel functions, partitions of compact spaces and polynomial precision, topology of regular domains (mostly conic sections) and compact metric spaces.

Course contents: 13 hours, one introduction, four parts with three hours each

• 0. Part: Introduction
• I. Part: Basics on Kernels and Quasi-Interpolation.
  1. Interpolation in several variables by polynomials and otherwise.
  2. Kernel functions for interpolation; radial basis functions and main examples. Complete and multiple monotonicity.
  3. Concept of Quasi-Interpolation and comparion with interpolation.
• II. Part: Positive Definite Functions on Regular Domains, especially Spheres.
  1. Positive definiteness, strictly and semi positive definiteness of functions and interpolation matrices.
  2. Positive definite functions on spheres in many dimensions.
  3. Positive definite functions on other conic sections and on simplices.
• III. Part: Polynomial Reproduction with Kernels.
  1. Concept of polynomial reproduction especially with quasi-interpolation.
  2. Relation of this to approximation orders; examples.
  3. Conditions for polynomial precision, examples especially with respect to partitions of unity.
• IV. Part: Partitions of Compact Sets.
  1. Quadrature methods.
  2. Partitions of compact sets for cubature.
Stochastic and mean field optimal control

Alekos Cecchin¹

¹Dipartimento di Matematica “Tullio Levi-Civita”, Università di Padova
Email: alekos.cecchin@unipd.it

Timetable: 16 hours; first lecture on November 6th, 2023, 10:30 (date already fixed, see calendar on https://dottorato.math.unipd.it/calendar), Torre Archimede, Room 2BC30.

Course requirements: Basic knowledge of stochastic calculus (Brownian motion, stochastic differential equations, filtrations, martingales, ...), as presented, for example, in the course on stochastic analysis of the master degree. Some concepts will be recalled during the course.

Examination and grading: Oral presentation of a research paper related to the topics covered in the course, based on student’s interest.

SSD: MAT/06 and MAT/05.

Aim: Introduce the classical tools to analyze stochastic optimal control problems (dynamic programming, viscosity solutions, backward SDEs, relaxed controls) and then use these methods to study the recent theory of mean field control problems.

Course contents: Introduction to the classical theory of stochastic control problems with some motivating example. These problems consist in minimizing a cost in which the state variable is given by a controlled stochastic differential equation driven by a Brownian motion. The course will then cover the following topics:

- Equivalence of weak and strong formulation, existence of optimal relaxed controls via weak convergence methods;
- Dynamic programming principle: value function, Hamilton-Jacobi-Bellman equation, verification theorem, viscosity solutions of second order PDEs;
- Backward stochastic differential equations: representation of the value function for the weak formulation, necessary conditions for optimality given by the stochastic Pontryagin’s maximum principle, relation with dynamic programming equation.

In the second part, we introduce the recent theory of mean field control problems, also called optimal control of McKean-Vlasov dynamics. In these problems, the cost and the coefficients of the state equation depend also on the law of the state process, and can be reformulated as optimal control of the Fokker-Planck equation. We show how to extend the results established for the classical problem to the mean field case. In particular, the Hamilton-Jacobi-Bellman equation is stated in the Wasserstein space of probability measures, which is infinite dimensional. Thus we introduce a notion of differentiability of functions defined on the Wasserstein space.
A renormalisation group approach to log-Sobolev inequalities

Alberto Chiarini¹, Giovanni Conforti²

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²Dipartimento di Matematica “Tullio Levi-Civita”, Università di Padova
Email: giovanni.conforti@unipd.it

Timetable: 16 hrs. First lecture on Monday March 4, 2024, 14:30 (dates already fixed, see on https://dottorato.math.unipd.it/calendar/), Torre Archimede, Room 2BC30

Course requirements: Elements of Stochastic Analysis and Partial Differential Equations;

Examination and grading: Oral exam;

SSD:

Aim: In this course we survey a novel renormalization group approach to log-Sobolev inequalities and to related properties of Glauber-Langevin dynamics. Interestingly, this approach is related to more or less recent theories, such as Eldan’s stochastic localization, optimal transport and stochastic control. In particular, the course will elucidate the link between the Polchinski flow and Hamilton-Jacobi-Bellman equations. The course is mainly based on the survey article [3] by Bauerschmidt, Bodineau and Dagallier.

Course contents:
The course is divided in 8 Lectures of 2 hours each to be spread in two/three weeks. The rough plan of the lectures is the following:

1. Introduction to Glauber-Langevin dynamics and convergence to equilibrium.
2. Log-Sobolev inequality, Hypercontractivity and Bakry-Émery Theorem.
3. Renormalized potential and the Polchinski equation.
5. Pathwise Polchinski flow and stochastic localisation perspective.
7. Application to a spin glass model.
8. Application to entropic optimal transport.

Bibliography:

Interface of Finance, Operations and Risk Management

Andrea Roncoroni

ESSEC Business School, Cergy-Pontoise, France
Email: roncoroni@essec.edu

Timetable: 16 hrs. First lecture on October 5th, 2023, 12:30, (date already fixed, see calendar on https://dottorato.math.unipd.it/calendar), 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.
   - Direct hedging, cross hedging, and combined hedging.
   - Mathematical formulations of optimal custom static hedging. Operational handling integration.

3. Sample models (4h)
• 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:

Hawkes processes: from theory to (financial) practice

Prof. Simone Scotti

1 Dipartimento di Economia e Management, Università di Pisa
Email: simone.scotti@unipi.it

Timetable: 16 hrs. First lecture in Spring 2024, to be defined..., 2024, Torre Archimede, Room 2BC30

Course requirements: Probability and Stochastic Calculus (basic)

Examination and grading: Oral presentation (seminar) of a research paper related to the topic of the course.

SSD: MAT/06, SECS-S/06

Aim: Events that are observed over time naturally show clustering phenomena: an earthquake happening increases the probability of so-called aftershocks, namely minor readjustments along the portion of a fault that slipped during the mainshock. Similar clustering patterns are observed, e.g., in criminology, when dealing with certain types of crime data, such as burglary and gang violence, due to crime specific patterns of criminal behaviour. As a last example, in financial markets, selling a huge amount of a stock could induce successive selling activity with relative jumps clustering in the price or, on a larger scale, the collapse of an investment bank could create a financial turmoil and shock-waves through the world’s financial centres.

Hawkes processes were introduced for the first time by A. Hawkes in 1971 to model the occurrence of seismic events. They are stochastic point processes particularly suitable to describe these self-exciting phenomena, in which the occurrence of an event increases the probability of a future arrival of another event. For this reason, they are also known under the name of “self-exciting point processes” and they have been applied in numerous fields throughout science, computer science, engineering, and human sciences.

More precisely, on a filtered probability space, denoting by \( N_t \) the counting process, i.e., \( N_t \) is the random variable counting the number of relevant events on the time interval \( (0; t) \), we define the conditional intensity

\[
\lambda_t := \lim_{\Delta \to 0} \mathbb{E} [N_{t+\Delta} - N_t | \mathcal{F}_t]
\]

where \( \mathcal{F}_t \) denotes the information available up to time \( t \). The original self-exciting process is defined via an intensity that is a function of past events:

\[
\lambda_t := \mu + \int_0^t \gamma(t-u) dN_u = \mu + \sum_{T_i < t} \gamma(t-T_i)
\]

where \( 0 < T_1 < T_2 < \cdots < T_n < \cdots \) are the time instants at which the relevant events occur, \( \mu \) is a base level for the intensity and \( \gamma(u) \geq 0, u > 0 \) is the exciting kernel. So, each event makes the intensity jump upwardly and then, between successive events, it decays according to the function \( \gamma \). A typical kernel is \( \gamma(u) = \alpha \beta e^{-\beta u} \), for \( \alpha, \beta > 0 \) and in this case the pair \( (N, \lambda) \) is a Markov process. The aim of this PhD course at the University of Padova is to provide a rigorous Mathematical introduction to point processes and a solid basis on the necessary
Stochastic Calculus tools needed to handle models based on Hawkes processes. Markovianity, which represents a desired theoretical property of typical stochastic models, will also be discussed, as opposed to modeling with memory, hence leading to non-Markovian settings. This dilemma Markov/non-Markov opens the door to technical challenges, some of which are still the object of an active debate and a rich stream of research. A Statistical overview, with many Mathematical hints, will be also given on simulation of Hawkes processes and estimation of Hawkes-based models. The connection with branching processes, alpha stable processes and Volterra processes (with and without jumps) will also be discussed. To conclude, recent applications to Finance will be covered, together with possible other uses, at the frontier of research, in different research fields.

**Course contents:** the 16 hours course will cover the following topics, in 8 lectures:


3 & 4 Hawkes Processes: definition, properties, the self exciting feature and dynamic contagion. Markovian and non-Markovian Hawkes processes: related challenges.

5 Simulation: the intensity-based and the cluster-based approaches. Estimation: parametric or non parametric?

6 Possible extensions: branching processes, alpha stable processes and Volterra processes with jumps.

7 Application to Finance: stochastic volatility nowadays, memory or not? Jumps cluster analysis.

8 Other applications: insurance and market microstructure

**References:**


Soft Skills
Doctoral Program in Mathematical Sciences
a.a. 2023/2024

SOFT SKILLS

MATHS INFORMATION: RETRIEVING, MANAGING, EVALUATING, PUBLISHING

(Information Literacy for Math Phd Students)

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.

Course Program: 5 Seminars (missing details will be communicated soon)

1. The advanced services of “Math Library” and of the “University Library System” (hrs 01:30)
   Digital Library and GalileoDiscovery: the use of the physical and electronic resources of the University libraries, in particular e-books and e-journals.
   The advanced services of the library: remote access, document delivery and interlibrary loan.
   **The Seminar is aimed at all Doctoral Students**

2. The Bibliographic research and advanced features of MathSciNet (hrs 02:00)
   MathSciNet: research strategies with examples.
   Advanced features: full-text retrieval in MSN, references export, the bibliometric index MCQ.
   A view of the multidisciplinary databases Web of Science and Scopus.
   **The Seminar is aimed at all Doctoral Students**

3. A reference manager for the management of bibliographies: Zotero (hrs 01:00)
4. Scientific communication and open access (hrs 02:00)
5. Where to publish and the evaluation of academic research (hrs 01:30)

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

Timetable:

Seminar 1  November 17th, 2023 – 10:30-12:30, room 2AB45
Seminar 2  December 5th, 2023 – 10:00-12:30, room 2BC30
Seminar 3
Seminar 4
Seminar 5

SS-1
Doctoral Program in Mathematical Sciences  
a.a. 2023/2024

SOFT SKILLS

Introduction to the use of “Mathematica”  
in Mathematics and Science  
Prof. Francesco Fassò

Timetable: 12 hours. First lecture on Friday October 6th, 2023, at 12:30, Room 1C150.

Practical infos:

All PhD students may have a license of Mathematica (provided by the campus Unipd license):  
https://asit.unipd.it/servizi/contratti-software-licenze/mathematica, installed on a personal machine

Course content:

The aim of this soft skill 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. A first part of the course, for a total of about 5-6 hours in 2-3 sessions, will assume no previous knowledge of Mathematica and provides the capabilities to use it at a basic ("everyday") level.

For interested students, a second and more advanced part of the course will provide an introduction to (functional) programming with Mathematica (with an eye on the needs of a mathematician, of course).
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=fvs19bgkbnhhkqp5mmqpiurn6c@group.calendar.google.com&ctz=Europe/Rome
Distributed Machine Learning and Optimization:
from ADMM to Federated and multiegent Reinforcement Learning

Prof. Subhrakanti Dey¹

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 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 Machine Learning and 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 communication efficient 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 distributed optimization algorithms such as the Alternating Direction Method of Multipliers (ADMM), and discuss its applications to both convex and non-convex problems. We will then explore distributed statistical machine learning methods, such as Federated Learning as well as consensus based fully distributed algorithms. The final topic will be based on multi-agent reinforcement learning and its applications to safe (constrained) data-driven (model free) control in a multi-agent setting. 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 1-4: 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, applications to machine learning problems)
- Lectures 5-7: Applications of distributed optimization to distributed machine learning, Federated Learning, fully distributed, consensus based methods under communication constraints
Lectures 8-10: Multiagent reinforcement learning, safe (constrained) reinforcement learning and its applications to data-driven multiagent control, inverse reinforcement learning

References:


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

Giorgio Maria Di Nunzio

Department of Information Engineering
Email: dinunzio@dei.unipd.it

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


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:

2. Christopher M. Bishop, Pattern Recognition and Machine Learning (Information Science and Statistics), Springer 2007
Analysis and Control of Multi-agent Systems

Marco Fabris

Department of Information Engineering
Email: marco.fabris.1@unipd.it

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

Course requirements: Linear Algebra and basic Calculus

Examination and grading: oral presentation of either any topic contained in the references [2], [3], [5], [6], [9], [10] or any other related work in the scientific literature that may also include the own student’s research

SSD: Information Engineering

Aim: Multi-agent systems (MASs), or networked dynamic systems (NDS), are systems composed of dynamic agents that interact with each other over an information exchange network. These systems can be used to perform team objectives with applications ranging from formation flying to distributed computation. Challenges associated with these systems are their analysis and synthesis, arising due to their decoupled, distributed, large-scale nature, and due to limited interagent sensing and communication capabilities. This course provides an introduction to these systems via tools from graph theory, dynamic systems and control theory. The course will cover a variety of modeling techniques for different types of networked systems and proceed to show how their properties, such as stability, performance and security, can be analyzed. The course will also explore techniques for designing these systems. The course will also cover novel applications by presenting recent results obtained in the secure-by-design consensus and optimal time-invariant formation tracking.

Course contents:

- Lecture 1. Introduction to MASs, synchronization and coordination, illustration of the course goals. Modeling NDSs and related examples such as opinion dynamics, wireless sensing networks, robot rendezvous, cyclic pursuit.
- Lecture 2. Elements of graph theory: basic notation and algebraic graph theory.
- Lecture 3. Consensus theory: the linear agreement protocol both in continuous and discrete time, firstly for unweighted graphs and then for weighted digraphs.
- Lecture 4. Secure-by-design linear agreement protocol against edge-weight perturbations seen as an application of the small-gain theorem.
- Lecture 5. The nonlinear agreement protocol along with examples such as coupled oscillators and the Kuramoto model. Passivity as a tool to analyze stability of the nonlinear agreement protocol.
- Lecture 8. The optimal time-invariant formation tracking (OIFT) problem as an application of the Pontryagin’s Maximum Principle. Distributed OIFT.

References:


Further potentially relevant recent papers will be referred to and distributed during the lectures.
Applied Functional Analysis and Machine Learning

Prof. Gianluigi Pillonetto

1Department 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:

References:
Heuristics for Mathematical Optimization

Prof. Domenico Salvagnin\textsuperscript{1}

\textsuperscript{1} Department of Information Engineering, Padova
email: dominios@gmail.com - domenico.salvagnin@unipd.it

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

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

\textbf{Examination and grading}: Final programming project.

\textbf{SSD}: Information Engineering

\textbf{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.

\textbf{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.

\textbf{References}:
1. Gendreau, Potvin “Handbook of Metaheuristics”, 2010
Elements of Deep Learning

Prof. Gian Antonio Susto

1Department 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/)

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:


Courses in collaboration with the Doctoral School on “Economics and Finance” of the University of Verona

for complete Catalogue and class schedule see on

https://www.dse.univr.it/?ent=oi&ava=&cs=1008&id=746&lang=en

Please check regularly the website of the Doctoral Course
Stochastic Processes in Finance

Sara Svaluto-Ferro\textsuperscript{1}

\textsuperscript{1}Dipartimento di Economia, Università di Verona
Email: sara.svalutoferro@univr.it

**Timetable:** 24 hrs. First lecture on April, 2024, University of Verona, PhD School of Economics and Finance.

**Examination and grading:** Individual written and reasoned report on one of the topics of the course.

**SSD:**

**Aim:** This is a graduate lecture on recent topics in stochastic processes in finance with particular attention to Markov processes.

**Course contents:**

**Part 1. - Markov processes**
1. Stochastic differential equations
2. Semigroups, generators and martingale problems
3. Kolmogorov equations
4. Affine and polynomial (jump)-diffusions

**Part 2. Applications**
1. Pricing methods for Markovian models
2. Interest rate theory
3. Risk management.

**References:**