ACADEMIC YEAR 2022-2023

First semester: October 3rd, 2022, to January 21th, 2023
Winter exams session: January 23rd, 2023, to February 25th, 2023
Second semester: February 27th, 2023, to June 17th, 2023
Summer exams session: June 19th, 2023, to July 22nd, 2023
Extra exams session: August 21st, 2023, to September 23rd, 2023

DOUBLE AND JOINT DEGREE PROGRAMMES

The University of Padua promotes joint or double degree programmes and guarantees ad hoc scholarships for participating students. Such international degree programmes are organised in cooperation with one or more partner institutions. A mobility period at the partner university is envisaged before or after attending a degree programme at the University of Padua.

Upon completion of the international programme, students will obtain a double degree (two or more national degrees issued by the partner universities) or a joint degree (jointly issued by two or more of the partner universities), in compliance with the different national rules and the agreements signed by the partner institutions.

- Second-cycle degree in Chemistry – curriculum Chemical Sciences
  See information on https://www.chimica.unipd.it/corsi/corsi-di-laurea-magistrale/laurea-magistrale-chimica/double-degree
- Second-cycle degree in Material Science – curriculum Material Sciences
  See information on https://www.chimica.unipd.it/corsi/corsi-di-laurea-magistrale/laurea-magistrale-scienza-dei-materiali/double-degree
- Second-cycle degree in Mathematics – curriculum MAPPA (Mathematical Analysis and Probability)
  See information on http://mappa.math.unipd.it/
- Second-cycle degree in Molecular Biology – curriculum Génétique Moléculaire
  See information on https://biologia-molecolare.biologia.unipd.it/en/masters-degrees/double-degree/

MULTILATERAL JOINT STUDY PROGRAMMES - CONSORTIUM

- Second-cycle degree in Mathematics – curriculum ALGANT (International Integrated Master course in Algebra, Geometry and Number Theory)
  See information on http://lauree.math.unipd.it/algant/ and https://www.algant.eu/

The ALGANT consortium consists of eight universities on four continents and offers a two-year world-class integrated master's course in pure mathematics, with strong emphasis on Algebra, Geometry and Number Theory. The consortium is coordinated by Universiteit Leiden (The Netherlands). The other partners are: Université Bordeaux 1 (France), Université Paris-Sud - Paris 11 (France), Università di Milano (Italy), Concordia University (Canada), Chennai Mathematical Institute (India), Stellenbosch University (South Africa).

ERASMUS MUNDUS MASTER COURSES

The Erasmus Mundus Joint Master Degrees are prestigious Master's degree programmes jointly delivered by at least three Universities of three different European countries. The study period is to be carried out in at least two countries, and a double or joint degree is issued by the involved institutions upon programme completion. EU-funded grants are provided.
Second-cycle degree in Data Science – curriculum BDMA (Big Data Management and Analytics)
See information on https://bdma.ulb.ac.be/
Second-cycle degree in Physics – curriculum NUPHYS – Nuclear Physics
See information on http://www.emm-nucphys.eu/

Catalogue of English Language Courses Index - A.Y. 2022/2023

- ASTROPHYSICS AND COSMOLOGY ORD. 2019
- CHEMISTRY ORD. 2018
- COMPUTER SCIENCE ORD. 2021
- CYBERSECURITY (ORD. 2020)
- DATA SCIENCE ORD. 2017
- ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021
- ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022
- EVOLUTIONARY BIOLOGY ORD. 2018
- GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)
- INDUSTRIAL BIOTECHNOLOGY ORD. 2014
- INDUSTRIAL CHEMISTRY ORD. 2015
- MARINE BIOLOGY ORD. 2021
- MATERIAL SCIENCE ORD. 2015
- MATHEMATICS ORD. 2011
- MATHEMATICS ORD. 2022
- MOLECULAR BIOLOGY (ORD. 2020)
- NATURAL SCIENCE ORD. 2014
- PHYSICS OF DATA ORD. 2018
- PHYSICS ORD. 2021
- SANITARY BIOLOGY
- STATISTICAL SCIENCES ORD. 2014
- SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021

SECOND CYCLE DEGREES WITH ALL THE COURSE UNITS HELD IN ENGLISH

ASTROPHYSICS AND COSMOLOGY ORD. 2019

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Dott. ALESSANDRO RENZI

Credits: 6 ECTS

Prerequisites:
Probability and statistics: definition of probability, probability distributions, mean value, variance and covariance, Bayes Theorem, basics of statistical estimation theory, maximum likelihood, confidence intervals, hypothesis testing. Cosmology: Hubble law, Robertson-Walker metric, Friedmann-Robertson-Walker equations. Cosmological perturbations: Jeans instability, power spectrum, growth factor.

Short program:
future cosmological surveys. Parts of the program might undergo changes, according to the composition and the competences of the class.

**Examination:**
The exam is comprised of two phases. 1) Resolution of assigned homework during the course, eventually to undertake in group. 2) Oral examination with discussion of the course topics.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP8082722/NO

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**ASTRONOMICAL INTERFEROMETRY**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, Second semester

**Lecturer:** Prof. MAURO D'ONOFRIO

**Credits:** 6 ECTS

**Prerequisites:**
A good knowledge of the Fourier transform and Calculus is required.

**Short program:**
1) Fundamentals of optical and radio astronomy. 2) Optical and radio telescopes. Resolution and observational techniques. 3) Elements of interferometry. 4) Optical and radio interferometry. 5) The UV plan. 6) Image synthesis at optic and radio wavelengths. 7) Elements of disturbance and calibration of interferometric observations. 8) Data reduction tests of interferometric data in the computer laboratory.

**Examination:**
Oral exam about the topics discussed in the lectures.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086348/NO

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**ASTRONOMICAL SPECTROSCOPY**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, Second semester

**Lecturer:** Dott. STEFANO CIROI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of Atomic Physics, Astronomy, Astrophysics 1 and 2, Laboratory of Astronomy.

**Short program:**
1) A brief introduction to spectroscopy as observational technique. 2) Characteristics of emission-line spectra: gaseous nebulae, Novae, Supernovae, Supernova remnants, star-forming regions, active galactic nuclei. 3) Fundamentals of atomic spectroscopy: atomic term symbols, energy levels, Grotrian diagrams, and selection rules. 4) Population of energy levels: Boltzmann and Saha equations, applications to some atomic species and comparison with absorption lines in stellar spectra. 5) Radiation transport. 6) Absorption lines and main broadening mechanisms. 7) Emission lines: collisional transitions, statistical equilibrium equations, two-level atom, optically thin recombination lines, dust extinction, forbidden lines, three-level atom. 8) Continuum sources: recombination, free-free, synchrotron. 9) Ionization equilibrium. 10) Ionization structure: the Stromgren sphere. 11) Thermal equilibrium.

**Examination:**
Oral exam on the topics discussed during the lectures.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCN1035986/NO

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**ASTROPARTICLE PHYSICS**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, Second semester

**Lecturer:** Prof. ANTONIO MASIERO

**Credits:** 6 ECTS

**Prerequisites:**
Taking for granted the notions of Quantum Mechanics and Relativity provided in previous undergraduate courses, the present course is self-consistent in so far as it intends to provide the necessary basic notions of relativistic quantum mechanics, quantum field theory and elementary particle physics, and cosmology.

**Short program:**
1) Introduction: the observable Universe and its expansion, dark matter, Big Bang relics; 2) Relativistic Quantum Mechanics: Klein-Gordon equation; Dirac
equation; particles and antiparticles; discrete symmetries: P, T, C and CPT theorem; 3) Quantum Field Theory: Klein-Gordon and Dirac quantum fields; quantum electrodynamics (QED); elements of the scattering theory: S matrix, propagators, Feynman rules, cross sections and decay rates 4) Spontaneous Symmetry Breaking (SSB); SSB of discrete and continuous symmetries; Goldstone theorem; SSB of local (gauge) symmetries; Higgs mechanism; Higgs; finite temperature SSB. 5) The Standard Model (SM) of Particle Physics: Fermi theory; V-A theory; Yang-Mills theories; electroweak standard theory; SSB of the electroweak symmetry; CP violation; baryon and lepton number conservation; Higgs boson searches and discovery. 6) Neutrino Physics: Dirac and Majorana masses; see-saw mechanism; neutrino oscillations; solar and atmospheric neutrinos; Supernovae neutrinos; 7(Beyond the SM: Grand Unified Theories (GUTs); SSB and the gauge hierarchy problem; proton decay. 8) Elements of General Relativity: equivalence principle; curved space-time; energy-momentum tensor; Einstein equations, Schwarzschild solutions 9) Elements of the Standard Model of Cosmology and its interplay with the Standr Model of particle physics and their fundamental interactions. 10) Thermodynamics of the Early Universe: thermodynamical equilibrium; entropy; decoupling temperature. 11) Dark Matter (DM): observational evidence; Boltzmann equations; cold and hot DM; Weakly Interacting Massive Particles (WIMPs); particle physics DM candidates; cosmological limits of the neutrino masses; direct and indirect DM searches. 12) Unification of the fundamental interactions and Inflation: the problems of the horizon, flatness and lifetime of the Universe; the problem of the cosmological monopoles; inflation mechanism; quantum fluctuations of the inflaton; inflation models; dark energy 13) Baryogenesis and the cosmic matter-antimatter asymmetry: Sacharov conditions; baryon and lepton violating interactions; matter-antimatter asymmetry and neutrino masses: leptogenesis.

Examination:
Oral examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081703/NO

ASTROPHYSICS LABORATORY 1: HIGH ENERGY INSTRUMENTATION

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019. First semester

Lecturer: Dott. STEFANO CIROI

Credits: 6 ECTS

Prerequisites:
Knowledge of astronomy and/or physics at undergraduate level

Short program:
1) optics of high-energy telescopes: focusing optics, non-focusing optics, detectors 2) current and future space missions, orbits of space missions, earth's atmosphere, astrophysical and instrumental background 3) high-energy observations, archives and data analyses 4) imaging analysis, spectral analysis, timing analysis and their astrophysical context 5) fitting of data

Examination:
The oral exam will focus on topics addressed during lectures and on a report of a high-energy observation analyzed by the student group during the lab experience.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCQ0093339/NO

ASTROPHYSICS LABORATORY 1: INFRARED AND OPTICAL INSTRUMENTATION

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019. First semester

Lecturer: Prof. ROBERTO RAGAZZONI

Credits: 6 ECTS

Prerequisites:
Fundamentals of Physics and Astronomy.

Short program:

Examination:
Oral exam about the topics discussed in the lectures.
ASTROPHYSICS OF THE INTERSTELLAR MEDIUM

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof. GIOVANNI CARRARO

Credits: 6 ECTS

Prerequisites:
The course assumes that the students well know general physics (thermodynamics, fluid dynamics, electromagnetism) and basics of atomic physics.

Short program:
1) Introduction. 2) Equations of hydro-dynamics, turbulence, thermal balance in the interstellar medium. 3) Shock waves, Riemann problem 4) Magnetohydrodynamics, Alfvén waves, Galactic magnetic field; generalized virial theorem; ambipolar diffusion 5) Numerical techniques for the solution of the magnetohydrodynamic equations (Eulerian vs Lagrangian approaches). 6) General picture of the interstellar medium: HI, CO, H₂, molecules. 7) Theories of star formation, Jeans criterion, sequential star formation. 8) HII regions, Stroemgren sphere. 9) Effects on the interstellar medium of stellar winds and supernovae remnants 10) Chemical enrichment of the interstellar medium: basic equations

Examination:
Oral exam possibly integrated by the presentation of a topic related to the program agreed in advance with the teacher.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCQ0093338/NO

CELESTIAL MECHANICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Dott. STEFANO CASOTTO

Credits: 6 ECTS

Prerequisites:
Students are expected to be familiar with Rational Mechanics and Mathematical Analysis, including the elementary theory of Ordinary Differential Equations. A fair amount of curiosity about dynamical phenomena observed in the Solar and other planetary systems is useful, together with an interest in their precise modeling and computation and the design of exploration missions.

Short program:

Examination:
Evaluation of the homework and final project report. Oral presentation of final report and discussion of the results and other topics covered during the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086353/NO

COSMOLOGY OF THE EARLY UNIVERSE

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof. NICOLA BARTOLO

Credits: 6 ECTS

Prerequisites:
Generally the bases useful to attend this course are provided by the various courses within a given chosen curriculum.

Short program:
General introduction. The problem of the initial conditions: primordial density perturbations at the origin of the formation of the Large Scale Structure of the Universe. - Short recall of the main problems of the standard cosmological model - Inflationary cosmology in the Early Universe as a solution to the problems of the standard model Modeling: - Inflationary models: vacuum energy and the inflation field; dynamics of a scalar field in a Friedman-Robertson-
Walker Universe; possible realizations of the inflationary scenario - Cosmological models of inflation and their main features (with examples also within high-energy particle physics) - Observational predictions of the inflationary models: from the quantum perturbations in an expanding universe to the primordial density perturbations; generation of primordial gravitational waves and their observability (cosmological and interferometric probes). Reheating phase and baryogengesis mechanisms Delta-N and in-in formalisms for the study of cosmological perturbations. Example: primordial non-Gaussianity

Cosmological perturbations in General Relativity: - scalar, vector and tensor perturbations - gauge transformations - Einstein equations (linearly) perturbed around the Robertson-Walker metric

Observational tests of the Early Universe

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081761/NO

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**EXOPLANETARY ASTROPHYSICS**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, First semester

Lecturer: Prof. GIAMPAOLO PIOTTO

Credits: 6 ECTS

Prerequisites: Basic knowledge (at bachelor level) of Physics, Astronomy and Astrophysics.

Short program:

Examination:
Oral exam on the course program, with a presentation of one or more papers recently published

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086352/NO

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**FLUID AND PLASMA DYNAMICS**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, First semester

Lecturer: Dott. TOMMASO BOLZONELLA

Credits: 6 ECTS

Prerequisites: None

Short program:

Examination:
Oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086351/NO

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**FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, First semester

Lecturer: Prof. SABINO MATARRESE
FUNDAMENTALS OF MODERN PHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof.ssa CHIARA MAURIZIO

Credits: 6 ECTS

Prerequisites: Fundamentals of quantum physics and structure of matter.

Short program:


Examination:

Two partial written exams will be scheduled (one at about half-course and the other one at the end) in which the student has to solve exercises and discuss some open questions. The full exam is made of a written part (or of the two written partials) plus an oral exam (needed only if the score of the written exam is

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086381/NO

GALACTIC DYNAMICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof.ssa CHIARA MAURIZIO

Credits: 6 ECTS

Prerequisites: Fundamentals of quantum mechanics and special relativity

Short program:


Examination:

Oral interview.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086380/NO
GENERAL RELATIVITY FOR ASTROPHYSICS AND COSMOLOGY

Master’s degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof. MARCO PELOSO

Credits: 6 ECTS

Prerequisites:
Knowledge of Special Relativity

Short program:

Examination:
Questions on the topics presented during the course and solution of a simple / medium problem.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCQ9086385/NO

GRAVITATIONAL PHYSICS

Master’s degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof. GIACOMO CIANI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of general relativity is suggested, but not mandatory.

Short program:

Examination:
Oral examination aimed at verifying the conceptual understanding of the topics presented and the ability to correctly approach and analyze specific problems related to GW theory and detection.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081719/NO

### MATHMATICL AND NUMERICAL METHODS

<table>
<thead>
<tr>
<th>Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester</th>
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<tr>
<td>Lecturer: Prof.ssa MICHELA MAPELLI</td>
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<tr>
<td>Credits: 6 ECTS</td>
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</table>

Examination:
Written exam (unless the covid-19 emergency requires to switch to an oral examination).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086342/NO

### MULTIMESSENGER ASTROPHYSICS

<table>
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<tr>
<th>Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester</th>
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<tbody>
<tr>
<td>Lecturer: Prof.ssa ELISA BERNARDINI</td>
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<td>Credits: 6 ECTS</td>
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<tr>
<td>Prerequisites: This course is addressed to students with basic knowledge of elementary particles and their interactions and nuclear physics.</td>
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<tr>
<td>Short program: The term &quot;multi-messenger&quot; is quite new and increasingly used in astronomy and astroparticle physics. It refers to combining information from different cosmic messengers (i.e. photons, cosmic rays, neutrinos and gravitational waves) to gain a deeper understanding of the astrophysical objects we observe in the sky. Visible light only reveals a very small portion of the mysteries of the Universe. Astronomical observations are nowadays routinely performed with different telescopes across the whole electromagnetic spectrum, from radio waves through visible light, all the way to gamma-rays. At the highest energies, the most violent processes in the Universe are at work. Whatever produces high energy gamma-rays, is expected to accelerate particles to energies that exceed the capabilities of man-made accelerators a billion times. Such particles can reach the Earth as cosmic rays, first discovered more than 100 years ago, still nowadays one of the most mysterious &quot;messages&quot; from our Universe. Cosmic rays may interact in the vicinity or their sources or even along their way to Earth, to produce elusive particles called neutrinos and gamma-rays. While cosmic rays are deflected during their journey by intergalactic magnetic fields, neutrinos and photons, being neutral particles, keep memory of their source's direction. Their trajectory becomes thus crucial to unravel the origin of cosmic rays. Neutrinos are extremely difficult to detect. Kubic-kilometer detectors are necessary to observe neutrinos at energies larger than few tens of GeV. The year 2013 witnessed the first clear observation of neutrinos from distant astrophysical objects by the IceCube detector at the South Pole, opening a new observational window to the Universe. The most extreme astrophysical objects, connected with the most violent phenomena in our Universe, are often associated with black holes or neutron stars. Whenever two such compact objects orbit around each other, they are expected to produce gravitational waves. The year 2015 witnessed the first direct observation of gravitational waves emitted by two merging black-holes (GW150914), measured by the LIGO detectors in the USA. The discovery was celebrated by the Nobel-prize for physics. The year 2017 witness the triumph of multi-messenger astrophysics with the detection of gravitational waves from two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A). Just few days after another event celebrated the success of multi-messenger astrophysics: the first identification of a source of cosmic neutrinos, the blazar TXS 0506+056, helped by the electromagnetic observations that followed the detection of a high energy neutrino (IceCube-170922A). Both results greatly demonstrate the potential of multi-messenger astrophysics in observing and understanding the most extreme and mysterious</td>
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</table>

Examination:
Oral examination aimed at verifying the conceptual understanding of the topics presented and the ability to correctly approach and analyze specific problems related to GW theory and detection.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP9086342/NO

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NUCLEAR ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof. ANTONIO CACIOLLI

Credits: 6 ECTS

Prerequisites:
Elements of quantum mechanics, nuclear physics, and general physics

Short program:
Thermonuclear reactions. Definition of nuclear cross section, astrophysical S-factor, reaction rate, and Gamow peak. Nuclear burnings during hydrostatic and explosive stellar evolutionary phases. Elements of stellar modelling. Hydrogen burning: p-p chains, CNO, NeNa, MgAl cycles. Helium burning: triple-alpha reaction and alpha + 12C. Advanced nuclear burnings (C, Ne, O, Si). Neutron-capture reactions (s and r: slow and rapid) For each topic we provide an overview of the most relevant results in the recent literature. How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances) How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results) The environmental background and how to shield it (passive and active shielding) Underground experiment Brief discussion on ion beam accelerators Elements on detectors (gamma, neutrons, and charged particles) Experimental measurements of the cross section (from the experimental yield to the S-factor) Targets typology (gas, jet, and solid target). Target production techniques and how targets influence the experimental measurements. Brief discussion on indirect methods (Trojan Horse, ANC, …).

Examination:
A 10 minutes presentation on an aspect of the course (usually an astrophysical issue and a related reaction study) and some question related to the presentation and course program.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081762/NO

PLANETARY ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof. FRANCESCO MARZARI

Credits: 6 ECTS

Prerequisites:
Basic courses of the 3-year period.

Short program:
1) Dynamical and physical properties of planets and exoplanets. 2) Planetary formation from circumstellar disks, migration and planet-planet scattering. Tidal interaction between planets and disks. 3) Magnetic fields of the planets, origin and morphology. 4) Plasma motion in planetary fields, Van Allen Belts, magnetospheres and solar wind. 5) Tidal interaction planet-satellite and planet-star, lengthening of the terrestrial day and Moon outward drift. 6) Physics of planetary interiors, state and structure equations. 7) Non-gravitational forces acting on planetary precursors: Poyting-Robertson drag, Yarkowski effect, gas drag. 7) Three-body problem: Lagrangian points (Trojan orbits), their stability, Hill's sphere and its applications (cataclysmic variables, asteroid satellites). 8) Secular perturbations in multiple planet systems. 9) Navier-Stokes equations for fluidynamics and their application to circumstellar disks 10) Mean motion resonances

Examination:
Oral exam. If the present medical emergency persists, the exam may be taken on line (Zoom or Skype)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081805/NO

SELECTED TOPICS IN MODERN ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Dott. STEFANO BOVINO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of astrophysics, spectroscopy and programming languages (python and fortran)

**Short program:**

**Examination:**
Written exam

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCQ093379/NO

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**SUBNUCLEAR PHYSICS**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, Second semester

**Lecturer:** Prof.ssa DONATELLA LUCCHESI

**Credits:** 6 ECTS

**Prerequisites:**
Principles of nuclear and sub-nuclear physics, principles of quantum mechanics, relativistic dynamics, quantum field theory, Feynman graphs, interaction radiation with matter.

**Short program:**

**Examination:**
The exam will be based on an assignment given in advance to the students. It will be constituted by exercises or open questions and a discussion on open topics among those discussed during the lectures. During the discussion questions on the arguments of the class can be asked.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/000ZZ/SCP7081697/NO

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**ASTROPHYSICS LABORATORY 2**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, First semester

**Lecturer:** Dott. LUCA MALAVOLTA

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of astronomy and astrophysics, stellar astrophysics, photometry and spectroscopy. Basic knowledge of computer science (Python 3).

**Short program:**
The objectives of the course will be achieved through the practical study of a topical scientific case, namely the characterization of extrasolar planets. A. Frontal lessons in the classroom. 1) Main problems in the acquisition of CCD images for photometry. 2) Techniques for extracting high precision photometry from digital images, from ground and from space. 3) Techniques for extracting high precision radial velocities and effects of stellar activity. 4) Research methods for extrasolar planets. Planetary transits. Brief summary of the state of research and characterization of extrasolar planets. Techniques of light curve analysis for the research of variability phenomena (including planetary transits). Techniques for the combined analysis of photometry and radial velocities for the characterization of extrasolar planets. B. Observational experience at the Asiago Observatory. Preparation and execution of observations of a planetary transit through the 182 cm Copernico telescope. (virtually or in presence depending on the sanitary provisions). The data will then be reduced and analyzed during the laboratory experience. C. Laboratory experience. 1) Reduction of planetary transit data. 2) Analysis of the light curve obtained at the Asiago Observatory in combination with data from space. 3) Measurement of orbital and physical parameters (such as the central time of transit, inclination of the orbit, radius of the planet, semi-major axis / radius ratio). Inclusion of radial velocities for the measurement of planetary mass and comparison of planetary density with internal composition models.

**Examination:**
Evaluation of laboratory reports. Oral presentation of the work done. Oral exam about the topics of the course.

**More information:**

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**ASTROPHYSICS OF GALAXIES**

Master's degree in **ASTROPHYSICS AND COSMOLOGY ORD. 2019**, Second semester

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Lecturer: Prof. ALESSANDRO PIZZELLA

Credits: 6 ECTS

Prerequisites:
Basic knowledge of extra-galactic astrophysics. In particular, about morphology, photo-metric profiles, kinematics of galaxies.

Short program:

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/002PD/SCN1035987/NO

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OBSERVATIONAL ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof. SERGIO ORTOLANI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of general astronomy and physics.

Short program:
The first part is dedicated to instrumental techniques and observational aspects in photometry. One of the application is the instrumental and reddening corrections of the data. Then the interpretation of the near infrared color-magnitude and color-color diagrams of young stellar populations. The second part of the course is dedicated to the physical properties of the planets and to some basic concepts on the study of the extrasolar planets. The third part is a detailed analysis of emissions connected to the galactic interstellar medium evolution. 1) Basic concepts in astrophysics: magnitudes, distance modulus, metallicity indices. Distance measurements. 2) Signal-to-noise ratio of the observational data. Calibrations. 3) Interstellar reddening effects on the photometry. 4) Young stellar populations. HR diagrams and two color infrared diagrams. 5) General properties of the planets in the Solar System. 6) Atmosphere of the planets. Gas escape mechanisms. 7) Effective temperatures of the planets and greenhouse effect. 8) Origin and evolution of the Solar System. Urey and Lewis theory. Age of the Solar System. Formation of the Earth. 9) General characteristics of the planet Mars. 10) Basic principles of the extrasolar planets detection techniques. 11) The gas in the Galaxy. H I 21 cm line. 12) Supernovae remnants and basics of evolutionary models. 13) Stellar and interstellar maser sources.

Examination:
Oral or written exam with open questions on the topics discussed during the lectures.

More information:

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OBSERVATIONAL COSMOLOGY

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof.ssa GIULIA RODIGHIERO

Credits: 6 ECTS

Prerequisites:
The course is self-consistent, having acquired the whole fundamental notions of mathematics and physics of the 3-year degrees in Astronomy or Physics.

Short program:

Examination:
Oral discussion

More information:

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**STELLAR ASTROPHYSICS**

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019. Second semester

**Lecturer:** Prof. ANTONINO MILONE

**Credits:** 6 ECTS

**Prerequisites:**
Fundamentals of stellar astrophysics (photometry, astrometry, spectroscopy, stellar evolution)

**Short program:**

**Examination:**
Oral exam based on the topics discussed during the lectures.

**More information:**

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**ADVANCED ASTROPHYSICS**

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019. First semester

**Lecturer:** Prof.ssa PAOLA MARIGO

**Credits:** 6 ECTS

**Prerequisites:**
General astrophysics, fundamentals of radiative processes and stellar evolution

**Short program:**

**Examination:**
COMPACT OBJECT ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, First semester

Lecturer: Prof. ROBERTO TUROLLA

Credits: 6 ECTS

Prerequisites:
Classical electrodynamics, special relativity, general astronomy and astrophysics

Short program:

Examination:
Oral examination

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/001PD/SCP9086382/NO

RADIATIVE PROCESSES IN ASTROPHYSICS

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof. ROBERTO TUROLLA

Credits: 6 ECTS

Prerequisites:
Classical electrodynamics, special relativity, general astronomy and astrophysics

Short program:

Examination:
Oral examination

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/001PD/SCP9086347/NO

THEORETICAL COSMOLOGY

Master's degree in ASTROPHYSICS AND COSMOLOGY ORD. 2019, Second semester

Lecturer: Prof. SABINO MATARRESE

Credits: 6 ECTS

Prerequisites:
**Short program:**
General introduction • Derivation of the Friedmann eqs. from Einstein's eqs. (after a very synthetic introduction to the latter), assuming the Robertson-Walker line-element. The Cosmic Microwave Background (CMB) Radiation • Boltzmann eq. and hydrogen recombination: beyond Saha equation • The Boltzmann eq. in the perturbed universe: the photon distribution function • The collision term • Boltzmann eq. for photons in the linear approximation • Boltzmann eq. for cold dark matter (CDM) in the linear approximation • Boltzmann eq. for baryons in the linear approx. • Evolution eq. for the photon brightness function • Linearly perturbed Einstein's equations (scalar modes) • Initial conditions • Super-horizon evolution • Acoustic oscillations and tight coupling • Free-streaming – role of the visibility function • Evolution of gravitational potential and Silk damping • Temperature anisotropy multipoles • Angular power-spectrum of the temperature anisotropy • Sachs-Wolfe effect • Small angular scales: acoustic peaks and their dependence on cosmological parameters The gravitational instability • Gravitational instability in the expanding Universe • Boltzmann eq. for a system of collisionless particles and the fluid limit • The Zel'dovich approximation • The adhesion approximation • Solution of the 3D Burgers equation • Approach based on the Schroedinger equation. Statistical methods in cosmology • The ergodic and the “fair sample” hypotheses • N-point correlation functions • Power-spectrum and Wiener-Khintchine theorem • Low-pass filtering techniques • Up-crossing regions and peaks of the density fluctuation field • Gaussian and non-Gaussian random fields • The path-integral approach to cosmological fluctuation fields

**Examination:**
The exam of this course can be made in two alternative ways: 1. Oral interview on the main topics analyzed during the course. 2. (only for the students who attended the classes) Short written dissertation on a topic discussed during the course, to be agreed with the lecturer. The dissertation should contain a detailed of the chosen subject, based upon one or a few review articles (and or some cosmology textbook chapters). The content of this dissertation, to be discussed with the professor is expected to show how much the student has become acquainted with the main concepts presented in the lectures.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2490/001PD/SCP9086384/NO
Oral exam. The student can choose either English or Italian language. During 20-30 minutes, the student will be asked to expose briefly and rigorously some topics and to make connections among involved topics.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087639/NO

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MAGNETIC SPECTROSCOPIES

Master's degree in CHEMISTRY ORD. 2018, Second semester

**Lecturer:** Prof.ssa MARILENA DI VALENTIN

**Credits:** 6 ECTS

**Prerequisites:**
Physics and quantum chemistry basics.

**Short program:**

**Examination:**
Oral examination

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087644/NO

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OPTICAL PROPERTIES OF MOLECULAR SYSTEMS

Master's degree in CHEMISTRY ORD. 2018, Second semester

**Lecturer:** Prof.ssa ELISABETTA COLLINI

**Credits:** 6 ECTS

**Prerequisites:**
Knowledge of the subjects taught in the basic classes of physical chemistry.

**Short program:**

**Examination:**
Final oral exam with the possibility to choose between two modalities: 1. 'classic' oral exam in which the teacher will ask questions on the course content to verify the student's preparation 2. 'journal club' type exam in which the student will present the results of a more in-depth study of a topic addressed in the course.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087642/NO

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PHYSICAL CHEMISTRY OF THE SOLID STATE AND OF MATERIALS

Master's degree in CHEMISTRY ORD. 2018, Second semester

**Lecturer:** Prof.ssa CAMILLA FERRANTE

**Credits:** 6 ECTS

**Prerequisites:**
The student should be familiar with concepts and notions of classical physics (mechanics, dynamics and electromagnetism). A knowledge of elements of quantum mechanics, thermodynamics and spectroscopy is also required (at the level of a bachelor or first degree in chemistry) as well as the knowledge of intermolecular forces which are part of the program of Physical Chemistry IV.

**Short program:**

Examination:
Oral exam whereby the student should report and explain one or more argument discussed in the lectures. Aim of the exam is to verify the knowledge acquired by the student and her/his ability to elaborate on them.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087640/NO

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**PHYSICAL METHODS IN ORGANIC CHEMISTRY**

Master's degree in CHEMISTRY ORD. 2018, First semester

Lecturer: Prof.ssa ESTER MAROTTA

Credits: 6 ECTS

Prerequisites:
Good understanding of organic chemistry and basic concepts of NMR spectroscopy and mass spectrometry

Short program:

Examination:
Written test

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087647/NO

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**PRINCIPLES AND APPLICATIONS OF ORGANOMETALLIC CHEMISTRY**

Master's degree in CHEMISTRY ORD. 2018, First semester

Lecturer: Prof. ANDREA BIFFIS

Credits: 6 ECTS

Prerequisites:
Basic knowledge in chemistry imparted in the undergraduate courses in Chemistry or Industrial Chemistry.

Short program:
Introduction Organometallic compounds: definition. Historical overview. General properties and preparation methods. Organometallic compounds in the periodic table: trends. Organometallic compounds of the main group elements The preparation methods, the properties and the applications of the most important organometallic compounds of the main group metals: nucleophilic organometallic compounds, organoelement compounds of group 13 and 14. Organometallic compounds of the transition metals The preparation methods, the properties and the applications of the most important classes organometallic compounds of the transition metals, such as compounds containing sigma M-C bonds, metal carbonyls, metal carbenes, metal olefin and metal alkyn complexes, allyl, polenyl and polyene complexes will be illustrated. Special attention will be given to applications in organometallic synthesis and catalysis.

Examination:
oral examination

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087645/NO

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**PROTEIN STRUCTURE AND DYNAMICS**

Master's degree in CHEMISTRY ORD. 2018, First semester

Lecturer: Dott. MASSIMO BELLANDA

Credits: 6 ECTS

Prerequisites:
Basic knowledge of physical-chemistry and biochemistry

Short program:

Examination:
Oral questions with the option to define with the lecturer a specific topic or a case study to discuss at the beginning of the exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087646/NO

THEORETICAL CHEMISTRY

Master's degree in CHEMISTRY ORD. 2018, Second semester

Lecturer: Dott. DIEGO FREZZATO

Credits: 6 ECTS

Prerequisites:
Basic knowledge in chemistry, physics and mathematics.

Short program:
1. Description of molecular stochastic dynamics: theory of stochastic processes, Fokker-Planck equation, stochastic differential equations; tools for the numerical solution; correlation functions and spectral densities; stochastic chemical kinetics. 2. Linear response theory: response of a classical system to weak perturbations. 3. Stochastic Thermodynamics: work fluctuation theorems and applications. 4. Laws of transformation under rotation: change of representation of scalar, vector and tensor properties under rotation of the reference frame; rotation of scalar fields; rotational stochastic dynamics. 5. Models for the dynamics of open quantum systems: density matrix and statistical ensembles, Bloch equations, quantum response theory for the computation of spectroscopic observables, models for the interaction with the environment and quantum master equations.

Examination:
Oral examination, with the possibility to analyse a specific problem and discuss a brief report on it.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1169/000ZZ/SCP9087641/NO

COMPUTER SCIENCE ORD. 2021

ADVANCED ALGORITHMS

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Dott. MICHELE SCQUIZZATO

Credits: 6 ECTS

Prerequisites:
Although there are no formal prerequisites, an undergraduate course in algorithms and a good knowledge of (discrete) probability are assumed.

Short program:
The course covers three main topics: 1) Graph algorithms for fundamental problems such as connected components, minimum spanning trees, and shortest paths; 2) Approximation algorithms for intractable problems such as vertex cover, set cover, and the traveling salesperson problem; 3) Randomized algorithms: main techniques and applications to problems such as sorting and minimum cuts.

Examination:
Written exam.
ADVANCED TOPICS IN COMPUTER AND NETWORK SECURITY

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. MAURO CONTI

Credits: 6 ECTS

Prerequisites:
No strict prerequisites on previous exams. However, it is suggested to have basic knowledge of networking, cryptography, and distributed systems (typically acquired in BSc degrees in Computer Science).

Short program:
Theory: RFID security, captcha, untrusted storage, smartphone security, attacks on smartphone, password protection, distributed Denial of Service attacks, deep learning, behavioural biometrics, VoIP security, secure content delivery, anonymous communications, keyloggers detection, anonymity in WSN, botnet detection, trusted HW, security of RFID ePassports, node replication attack in WSN, secure data aggregation in WSN, privacy issues in social networks, Google Android smartphone security, electronic voting, P2P botNet detection, taint mechanisms, browser security, privacy of location based services, Named Data Networking security, Named Data Networking privacy, cloud security, anonymity in wireless network, smartphone user profiling, SSL security issues in Android, circumvent censorship, secure messaging, operational technology security, cyber-physical systems security. Laboratory: advanced security tools, including; traffic analysis with machine learning tools, data inference, Android security tools, advanced analysis of malware systems and advanced persistent threat; web security; social network analysis tools, trusted platform modules.

Examination:
Project with written essay + oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1098249/NO

ADVANCED TOPICS IN COMPUTER SCIENCE

Master's degree in COMPUTER SCIENCE ORD. 2021, First and Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
No prerequisites.

Short program:
The course consists of series of lectures, illustrating advanced topics in computer science with the support of international experts.

Examination:
The exam assesses the ability of the student of dealing with advanced topics in computer science, which require the study of scientific articles and specialised literature.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP6076301/NO

ADVANCED TOPICS IN PROGRAMMING LANGUAGES

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Prof.ssa SILVIA CRAFA

Credits: 6 ECTS

Prerequisites:
Object-Oriented Programming and Logics.

Short program:
The course illustrates some of the advanced topics of modern programming languages, such that: the use of types to reason about programs, advanced object-oriented topics (structural typing, dynamic type checking, mixins), the integration of functional programming and object-oriented programming. These concepts will be carried over by a foundational study based on theoretical formal methods and an insightful analysis of the Scala, Java8 and Rust languages.

Examination:
To pass this course the student must succeed in a written test about the formalization of programming languages, and an oral examination focused on an advanced topic chosen by the student.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1098229/NO

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**ARTIFICIAL INTELLIGENCE**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. ALESSANDRO SPERDUTI

**Credits:** 6 ECTS

**Prerequisites:**
It is opportune to know basic notions of Probability Theory, Programming, and Algorithms.

**Short program:**
The structure and the topics of the course will be described in the following: - Introduction, Motivation, Intelligent Agents Architectures; - Problem Resolution and basics of Constraint-based Systems; - Adversarial Search; - Knowledge Processing by Propositional and First-order Logic; - Dealing with Uncertainty and Probabilistic Reasoning; - Basics of Machine Learning; - Basics of Computer Vision; - Basics of Natural Language Processing.

**Examination:**
The student must overcome a written exam. Moreover, the student must develop a project.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093639/NO

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**BIG DATA COMPUTING**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Prof. ANDREA ALBERTO PIETRACAPRINA

**Credits:** 6 ECTS

**Prerequisites:**
The course has the following prerequisites: competences regarding the design and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

**Short program:**
The course will cover the following topics: Introduction to the Big Data phenomenon. Distributed frameworks: MapReduce, Apache Spark. Clustering for data analysis and summarization. Analysis of data streams. Dimensionality reduction. Association Analysis.

**Examination:**
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 2-3 students, and of an individual written test comprising both theory questions and exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079297/NO

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**BIOINFORMATICS**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. GIORGIO VALLE

**Credits:** 6 ECTS

**Prerequisites:**
There are no particular prerequisites other than what is expected from a master student in informatics. However, a basic knowledge of genetics and molecular biology will help in the understanding of the biological motivations of bioinformatics. The course is in English, therefore the students should have a reasonable command of spoken and written English.

**Short program:**
This is a six credits course: five credits will be from lessons while one credit will be from practical activities, either the implementation and of some algorithm or the in-depth investigation of the literature on given arguments. The lessons are divided in three main parts. The first part is an extensive introduction on Biology presented as a scientific field centered on Information. The mechanisms that facilitate the transmission and evolution of biological information is used to introduce some biological problems that require computational approaches and bioinformatics tools. The second part of the course describes the main algorithms used for the alignment of biological sequences, including those designed for “next generation sequencing”. The algorithms used for de novo genomic assembly are also described. Finally, the third part of the course covers several aspects of bioinformatics related to functional
genomics, such as the analysis of transcription, gene prediction and annotation, the search of patterns and motifs and the prediction of protein structures. The role of Bioinformatics in individual genomic analysis and personalized medicine is also discussed.

Examination:
The exam will be articulated into three parts: 1) a practical session in which the student must describe a project of data analysis, that must be submitted at least two days before the date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the exam day, 3) an oral discussion in which the student must describe his/her project and answer questions on the topics of the course. A continuous process of assessment will be carried out throughout the course, to verify the level of understanding of the students.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079405/NO

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COMPUTABILITY

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. PAOLO BALDAN

Credits: 6 ECTS

Prerequisites:
The course requires some familiarity with basic mathematical concepts such as relations, functions, sets, cardinality, partial orders, principles of induction. There are no propaedeutical courses.

Short program:

Examination:
Written and oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1098231/NO

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CRYPTOGRAPHY

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. ALESSANDRO LANGUASCO

Credits: 6 ECTS

Prerequisites:
For the first part (Prof. Languasco; 6 credits): The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): OS, Programming.

Short program:

Examination:
For the first part (Prof. Languasco; 6 credits): Written exam in class; if, due to the pandemic situation, this will not be possible the written exam will be done using the available videoconferencing tools. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): Written Exam, Homeworks, oral test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093658/NO
CYBERPHYSICAL SYSTEMS AND IOT SECURITY

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
Basic knowledge on computer networks and computer science. Basic coding skills.

Short program:
Fundamentals Introduction to Cyber-Physical Systems (with examples of famous attacks) Control Theory Architectures Internet of Things (IoT) and Industrial IoT (IIoT) Cybersecurity Concepts in CPS Attacks to control systems Anomaly and Intrusion Detection Hardware Security Remote attestation Privacy in distributed systems Cybersecurity of CPS applications Automotive Drones and swarms Industrial Control Smart grid IoT and IIoT

Examination:
Written test. An oral examination could be provided as an alternative only for specific and documented cases.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ2101239/NO

DATA MINING

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Prof.ssa ANNAMARIA GUOLO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of Computer science, Databases. Basic knowledge of Probability and Statistics is useful although not essential.

Short program:
- Introduction to the course: Data analysis as a tool for decision support. Motivations and context for data mining. - Simple linear and multiple linear regression model: estimation, confidence intervals, hypothesis test, p-value, prediction, model selection, residual analysis, spurious correlation, multicollinearity - Classification methods: logistic regression, linear discriminant analysis and extensions - Model selection criteria: cross-validation, adjusted R2, AIC, BIC, automatic selection - Regularisation: ridge regression and lasso - Principal components regression - Semiparametric regression: regression splines, smoothing splines, generalized additive models

Examination:
The examination is composed by two parts. 1) The first part is a written examination carried out in laboratory using Moodle (35 minutes). The examination is about linear regression models and it includes questions with multiple choices and open questions. The questions regard the analysis of a real dataset, including numerical evaluations, interpretation of results from R and comments on graphical outputs. The first part of the examination will take place after the middle of the course. During the practical examination students are allowed to bring with them and consult a copy of the textbook, the slides of the course, the laboratory notes. 2) The second part is a practical examination carried out in laboratory (2 hours) and it is constituted by the analysis of a real data set using R. The student is required to collect the results of the analysis, with appropriate comments, in a brief report. During the practical examination students are allowed to bring with them and consult a copy of the textbook, the slides of the course, the laboratory notes. The final evaluation will be the mean of the results from the two parts. Students who do not take the first assessment in the middle of the course will have a written examination immediately after the practical final examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SC01111799/NO

DEEP LEARNING (EVEN STUDENT ID NUMBERS)

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Prof. ALESSANDRO SPERDUTI

Credits: 6 ECTS

Prerequisites:
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

Short program:
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.

Examination:
DEEP LEARNING (ODD STUDENT ID NUMBERS)

Master’s degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Dott. NICOLO’ NAVARIN

Credits: 6 ECTS

Prerequisites:
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

Short program:
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.

Examination:
The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP9087561/NO

ECONOMICS AND MANAGEMENT OF INNOVATION

Master’s degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof.ssa SILVIA RITA SEDITA

Credits: 6 ECTS

Prerequisites:
No pre-requirement required

Short program:
The course aims to address and deepen the following topics: - The main innovations that have influenced the evolution of the capitalist system. - Innovation in economic theories (Smith, Ricardo, Marx, neoclassical theory, Schumpeter, Nelson and Winter) - sources of innovation - types of innovation - innovation and firm strategies - innovation and competition

Examination:
The final written test will be a based on open questions and, for attending students, also on their presentations during the course (such presentations are discretionary)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1098279/NO

FORMAL METHODS FOR CYBER-PHYSICAL SYSTEMS

Master’s degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. DAVIDE BRESOLIN

Credits: 6 ECTS

Prerequisites:
The course requires familiarity with automata theory, theory of computation and calculus. There are no preparatory courses.

Short program:

Examination:
Written exam and project

More information:
**FUNCTIONAL LANGUAGES**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Dott. ALVISE SPANO'

**Credits:** 6 ECTS

**Prerequisites:**
Suggested a basic knowledge of lambda calculus, type systems and compiler constructions; experience in structured programming with strong-typed languages.

**Short program:**

**Examination:**
Oral exam at the end of the course. Optional project. Optional exercises.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0089514/NO

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**GAME THEORY**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** ELVINA GINDULLINA

**Credits:** 6 ECTS

**Prerequisites:**
A course, even a basic one, on probability theory.

**Short program:**

**Examination:**
For all the students, in any event the exam includes a mandatory open-book written test, containing problems of game theory focusing on different topics of the course. Every exercise involves multiple questions, typically three. For the students with regular attendance to the course, the exam may also involve, if they want so, the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer. If the written test is sufficient, students can directly finalize the passing score. Projects can be discussed with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). The project discussion integrates the mark of the written test.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079401/NO

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**IT SERVICE MANAGEMENT**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Dott. FRANCESCO CLABOT

**Credits:** 6 ECTS

**Prerequisites:**
There are no prerequisites: all the information necessary to understand the topics covered will be provided during the course. The goal is to become
familiar with IT terminology and IT-related work experience.

Short program:
This course provides students with a practical understanding of the key concepts, common language, principles and practices that enables successful management of modern IT-enabled services. It also prepares the trainee for the ITIL Foundation Examination. The course is based on the ITIL 4 best practice service value system. WHAT YOU’LL LEARN The course will help students to understand: - Key IT Service Management concepts - How ITIL guiding principles can help and organization to adopt and adapt service management - The 4 dimensions of service management - The purpose and components of the service value system - The activities of the service value chain and how the interconnect - Know the purpose of key ITIL practices - Preparation to sit the ITIL4 foundation examination COURSE OUTLINE - IT Service Management definitions; Service, Utility, Warranty, Customer, User, Service management, Sponsor - Key concepts of value creation - Key concepts of service relationships; service offering; service provision; service consumption; service relationship management - The nature, use and interaction of 7 ITIL guiding principles; Focus on value; Start where you are; Progress iteratively with feedback; Collaborate and promote visibility; Think and work holistically; Keep it simple and practical; Optimize and automate - The 4 dimensions of service management; Organizations and people; Information and technology; Partners and suppliers; Value streams and processes - The ITIL service value system - The service value chain, its inputs and outputs, and its role in supporting value streams - Service value chain elements; Plan, Improve, Engage, Design & transition, Obtain / Build, Deliver & support - Detail of how the following ITIL practices support the service value chain: Continual Improvement (including continual improvement model); Change control; Incident management; Problem Management; Service request management; Service desk; Service level management - The purpose of the following ITIL practices: Information security management; Relationship management; Supplier management; Availability management; Capacity and performance management; Service configuration management; IT asset management; Business analysis; Service continuity management; Deployment management; Monitoring and event management; Release management

Examination:
Multiple choice written test and small project/report on a real case.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093638/NO

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**KNOWLEDGE REPRESENTATION AND LEARNING**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
Suggested basic knowledge of logics and statistics.

Short program:
(A) Logics for knowledge representation: (A.i) introduction to propositional logics, syntax, semantics, decision procedure. Satisfiability, weighted satisfiability, and best satisfiability, (A.ii) First order logics, syntax, semantics, resolution and unification, (A.iii) Fuzzy logics, syntax, semantics, and reasoning. (B) statistical relational learning: (B.i) Graphical models (B.ii) Markov Logic Networks (B.iii) Probabilistic prolog, (B.iii) Logic Tensor Networks

Examination:
Final examination based on a combination of written examination and project development.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093643/NO

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**LANGUAGES FOR CONCURRENCY AND DISTRIBUTION**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Prof. PAOLO BALDAN

Credits: 6 ECTS

Prerequisites:
There are no propaedeutical courses.

Short program:
The structure and themes of the course will be as follows: - Introduction to concurrency and mobility: from automata to reactive and concurrent systems. - Calculus of Communicating Systems (CCS), a basic language for the description of concurrent systems. Process equivalence: transition systems and bisimulation. - Hennessy-Milner logic and tools for verification. Mutual exclusion, deadlock freeness, fairness. Safety and liveness properties. Verification with automated tools. The Concurrency Workbench and the Mobility Workbench. - From specification languages to programming languages: advanced languages for concurrency (Google Go and channel-based concurrency, Erlang and the actor model, Clojure and functional concurrency) - Orchestration languages (ORC) and languages for service-oriented programming (Jolie).

Examination:
Class exercises, solution and oral discussion of some advanced exercises, presentation on a theme choosen by the student. Among the options, there is the possibility of realizing a small project.
**MACHINE LEARNING**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. FABIO AIOLLI

**Credits:** 6 ECTS

**Prerequisites:**
The student should be familiar with basic concepts in Probability and Analysis of multivariate functions. It is also advisable to have basic knowledge of Programming and Artificial Intelligence. The course does not have prerequisites.

**Short program:**
The course will cover the topics listed below - Introduction: When to apply Machine Learning techniques; Machine Learning Paradigms; Basic ingredients of Machine Learning. - Learning Concepts: The complexity of the Hypothesis Space; Complexity Measures; Examples of Supervised Learning Algorithms; - Decision Trees: Learning Decision Trees; Treatment of Numerical Data, Missing Data, Costs; Pruning Techniques and Derivation of Decision Rules. - Probabilistic Learning: Bayesian Learning; Examples of Application to Supervised and Unsupervised Learning (clustering); Optimal Bayes classifier; EM. - Neural Networks and Support Vector Machines: Introduction to Neural Networks; Classification Margin, Support Vector Machines for Classification and Regression, Kernel Functions. - Application Issues: Classification Pipeline, Data Representation, and Selection of Variables; Model Selection; Clustering; Ensemble Learning; Recommender Systems.

**Examination:**
The student has to pass a written examination and if deemed necessary by the teacher, an oral examination. There is also a project that can be replaced by activities during the course.


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**MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Dott. WOLFGANG ERB

**Credits:** 6 ECTS

**Prerequisites:**

**Short program:**
1. Ranking with eigenvectors • Recapitulation of important results from linear algebra • The vector iteration: calculation of dominant eigenpairs • Ranking of web pages: PageRank and Hils. 2. Numerical methods for large scale linear systems • Krylov subspace methods for large eigenvalue problem: Arnoldi and Lanczos • Krylov subspace methods for sparse systems of equations: GMRES and MINRES • Krylov subspace methods for the computation of matrix functions. 3. Spectral graph theory • Graphs, the graph Laplacian, graph signals, the Cheeger constant • The graph Fourier transform, graph convolution, filtering and decomposition of graph signals • Dimensionality reduction with Laplacian eigenmaps • Centrallities on graphs. 4. Clustering algorithms • k-center clustering and hierarchical k-center clustering • The k-means algorithm • Spectral clustering 5. Low rank matrix approximations • Singular value decomposition (SVD): basic properties, numerical computation and best rank-k approximation • Principal component analysis and dimensionality reduction. 6. Multiway Data Analysis • Tensors and tensor decomposition • Higher order singular value decomposition (HOSVD): definition and numerical computation. 7. Applications: Face Recognition Using tensor SVD and Tensor Data Fusion • Kernel methods for data analysis

**Examination:**
Written examination at the end of the course. Regular homework assignments during the lecture period will provide additional feedback and extra credits for the final exam.


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**METHODS AND MODELS FOR COMBINATORIAL OPTIMIZATION**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester
Lecturer: Prof. LUIGI DE GIOVANNI

Credits: 6 ECTS

Prerequisites:
Basic notions of Operations Research, Linear Programming, and computer programming.

Short program:

Examination:
Oral examination about course contents and homework on the application of optimization methods to solve realistic problems. Each student may chose to present a short project concerning a case study about models and exact/heuristic solution methods for a realistic application of combinatorial optimization.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079402/NO

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MOBILE PROGRAMMING AND MULTIMEDIA

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Prof.ssa OMBRETTA GAGGI

Credits: 6 ECTS

Prerequisites:
Operating Systems, Web Technologies

Short program:

Examination:
The exam will require the development of a project and an oral test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7080184/NO

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MOBILE SECURITY

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

Lecturer: Dott.ssa ELEONORA LOSIOUK

Credits: 6 ECTS

Prerequisites:
Any object-oriented programming language.

Short program:
Network security - network analysis and monitoring; securing internet communications; packet sniffing and spoofing; TCP attacks; firewalls. Hardware security - meltdown attack; spectre attack. Web security - cross-site scripting attack; HTTP request smuggling. Pwn - shellcode; buffer overflow; return-to-libc; format string attack; race condition vulnerability. Reverse-engineering - static analysis; reversing in x86; reversing; patching; gdb; debuggers; symbolic execution.

Examination:
Students have two options. (Option 1) Practical exam, where students solve exercises on Android security; (Option 2) Project, where students face a research objective assigned by the Lecturer and illustrate the achieved results in an oral presentation.
**PROCESS MINING**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. MASSIMILIANO DE LEONI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of algorithms, data structure and programming, as acquired in course "Fundamental of Information Systems" o in Bachelor's degrees in Computer Science or similar

**Short program:**
The course will cover the topics listed below:
1. MODELING VIA PETRI NETS - Basic concepts of Petri nets - Usage of Petri Nets to model business processes - Structural analysis of Petri Nets - Soundness of business process models: Principles and Verification - Usage of Woped as software tool to model and check the soundness of process models.
3. BUSINESS PROCESS SIMULATION - Principle and Methodologies for simulation: definitions of warm-up and cool-down intervals, management of the simulation stochasticity via multiple, independent runs, analysis of the outcome - Definitions of the elements of a scenario of business process simulation: arrival rate, branching probabilities, resource pools, activity-duration probability distributions - Usage of BPMN for the specification of business process simulation models - Use of Process Mining to mine business process simulation models - Methodologies for the definition of "What-if" scenarios - Usage of BIMP as software tool to simulate business processes.

**Examination:**
Written Exam and Project

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ2101240/NO

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**REAL-TIME KERNELS AND SYSTEMS**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Prof. TULLIO VARDANEGA

**Credits:** 6 ECTS

**Prerequisites:**
The class subject requires familiarity with the architecture of traditional computer systems as well as with the organization and activity of operating systems for those architectures, especially regarding their support for concurrency, synchronization and handling of I/O. The class does not place prerequisites on entry.

**Short program:**
- Introduction: industrial needs (brief) and system architecture (outline) - Reliability and fault tolerance - Scheduling: taxonomy of algorithms - Synchronization policies that enable resource sharing - System-level issues: understanding the technology stack - Extension to distributed systems - Extension to multiprocessors

**Examination:**
The exam takes one of two forms: one form consists in the production and presentation of a technical report that discusses the issues dealt with and the solutions adopted in the development of a comparatively small practical assignment which involves the analysis, design, implementation and verification of systematic improvements to a distributed concurrent application supplied by the instructor; the other form requires the study, critique and oral presentation of a fresh research paper, chosen by the student out of manuscripts selected by the instructor, which touches upon subjects addressed in class.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079235/NO

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**RUNTIMEs FOR CONCURRENCY AND DISTRIBUTION**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. TULLIO VARDANEGA

**Credits:** 6 ECTS

**Prerequisites:**
The subject matter addressed by the class assumes familiarity with the architecture of traditional computer systems and networks, as well as with the organization and activity of operating systems for those architectures, especially regarding their support for concurrency, synchronization, handling of I/O, and networking. This notwithstanding, the class does not place explicit prerequisites for admission: the class activities are designed to aid students to refresh and deepen their prior knowledge in said ambit.

**Short program:**
- Introduction to concurrency: how concurrency came about and how to understand it
- Processes, communication, and synchronization
- A concrete model of concurrency and some desirable extensions
- The timing dimension
- Virtualization (brief)
- Distribution
- Introduction: definitions and fundamental challenges
- Communication, synchronization, and concurrency in a distributed system
- The naming system and the notion of statelessness
- Example technologies: Java RMI; Ada DSA, CORBA
- The frontier of Cloud Computing
- Origin and motivation
- The distinguishing traits of cloud-native applications
- The dimensions of scalability

**Examination:**
The exam consists of the write-up and presentation of a technical report that discusses the issues involved with and the solutions adopted in the development of an assignment proposed by the instructor and agreed to by the student. All assignments include a component of bibliographic study of the topic background and state of the art, and practical experiments about aspects of the problem at hand.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093640/NO

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**SOFTWARE VERIFICATION**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. FRANCESCO RANZATO

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of programming languages. Formally prerequisite courses are not required.

**Short program:**
- Program semantics: This is a model of the dynamic behaviour of programs (in particular the input/output behaviour) by means of order and fixed point theory. (cf. https://en.wikipedia.org/wiki/Semantics_(computer_science) )
- Static program analysis and verification by abstract interpretation: Abstract interpretation is a well-known technique for approximating the semantics of programs that allows to specify how to statically deduce program properties and to prove their correctness. (cf. https://en.wikipedia.org/wiki/Abstract_interpretation )
- Dataflow program analysis: This is a technique for gathering information about the possible set of values calculated at various program points. A program's control flow graph is used to determine those parts of a program to which a particular value assigned to a variable might propagate. The information gathered is often used by compilers (such as gcc and javac) when optimizing a program. (cf. https://en.wikipedia.org/wiki/Data-flow_analysis )
- Software verification tools: e.g., Clousot (Microsoft, USA), Interproc (INRIA, France), Jandom (Univ. Pescara, Italy) (cf. https://en.wikipedia.org/wiki/List_of_tools_for_static_code_analysis )

**Examination:**
Oral examination and/or software project, possibly split into distinct parts.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0098915/NO

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**START-UP IN ICT**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Dott. FABIO D'ALESSI

**Credits:** 6 ECTS

**Prerequisites:**
None.

**Short program:**
- Introduction to innovation and entrepreneurship
- Innovation vectors: Internet of things. Blockchain. Augmented Reality. Cyber ??physical systems (edge, fog, cloud)
- Examples of business application
- Innovation processes: how should the start-up phase be managed, the most risky and intangible?
- Governance of the start-up phase
- How do you calculate the value of a company in the start-up phase?
- Institutional investors: business angels and venture capital
- How do they work, what are their goals, what are they looking for?
- Public support for the start-up phase
- Support programs in Italy and abroad
- Management of the equity of a start up
- The equity of a start up for motivating the team and raising funds necessary to open partnerships
- Illustration of the themes for group projects (case studies)
- Support for the start-up phase
- Innovation processes: when does the start-up phase end?
- Support programs in Italy and abroad
- Innovation processes: how to finance the scale up phase?
- Public support for the scale up phase

**Examination:**
Oral examination and/or software project, possibly split into distinct parts.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0099515/NO
Examination:
The students will form small groups (typically of 3 people), to work on the identification of a vector of innovation of interest, within a set of themes proposed by the instructor. Then they are required to define a value proposition to be submitted to the instructor and to external experts for a final evaluation. The project activity takes place in the second half of the semester.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7080377/NO

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**STRUCTURAL BIOINFORMATICS**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Prof. DAMIANO PIOVESAN

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of optimization methods and machine learning. Python programming language.

**Short program:**

**Examination:**
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Written midterm tests with theoretical and practical questions (ca. 20%) 2) Software project (ca. 40%) 3) Project presentation and critical evaluation (ca. 40%)

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP7079278/NO

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**TYPE THEORY**

Master's degree in COMPUTER SCIENCE ORD. 2021, Second semester

**Lecturer:** Prof.ssa MARIA EMILIA MAIETTI

**Credits:** 6 ECTS

**Prerequisites:**
It is recommended to have followed an introductory course on logic but it is not strictly necessary.

**Short program:**
In the course the student will be introduced to the main type-theoretic concepts in order to being able to appreciate some key relevant applications of type theory in computer science, mathematics and even philosophy. He will be able to grasp the following aspects of the multifaceted nature of type theory: 1) The computational nature of type theory seen a typed-lambda calculus a'la Church: type theory will be presented as a paradigm of a functional programming where to type programs with their specification in order to verify their correctness in computer-aided way. 2) The set-theoretic nature of type theory which makes it suitable to formalize proofs done in constructive mathematics and to extract their computational contents. 3)The predicative nature of dependent type theory a'la Martin-Löf where types are defined in terms of an inductive generation process which extends recursive definitions. Examples of non-predicative constructions will be described by employing the use of paradoxes. 4) The availability of intensional versions of type theory and extensional ones. These versions allows to get some decidable properties of type-checking useful to build a feasible and trustable proof-assistant to formalize mathematical proofs expressed in an every-day mathematical language in a computer-aided way. The course will include a laboratory activity which will introduce the students to the use of a proof-assistant (the French Coq or the Italian Matita or the Swedish Agda).

**Examination:**
Oral examination after completing some recommended exercises presented during the lectures.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1098250/NO

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**VISION AND COGNITIVE SYSTEMS**

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

**Lecturer:** Prof. LAMBERTO BALLAN

**Credits:** 6 ECTS

**Prerequisites:**
The student should have basic knowledge of computer programming and algorithms, as well as mathematics, probability theory and statistics, linear algebra. It is also advisable to be familiar with basic concepts in machine learning and pattern recognition.

Short program:
The course will cover the topics listed below: - Introduction: From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges. - Cognitive Services: Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies. - Machine Learning and applications: Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias. - Early Vision and Image Processing: Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching. - Visual Recognition and beyond: "Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm. - Hands-on Practicals: What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

Examination:
The student is expected to develop, in agreement with the instructor, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project, and answer a few questions about the topics addressed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ1097939/NO

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WEB INFORMATION MANAGEMENT

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. MASSIMO MARCHIORI

Credits: 6 ECTS

Prerequisites:
Students should be familiar with the fundamentals of the web (for instance as given in the introductory "Tecnologie Web" course), in particular HTML, CSS, XML, XSLT.

Short program:
+ Web Usability Usability and user interaction, multi-level analysis, how to build a successful web site. Comparison between the desktop and mobile worlds. + E-commerce The use case of e-commerce web sites, specialization of the client interaction. + Web Advertisement Advertisement and web sites, techniques and errors to avoid. + Web Search Web Site Search, Search Engine Optimization, text vs hypertext, the good and evil of the web, the Social Information Systems. + Web Naming The names of the Web, their uses and abuses. + Web of Knowledge Fundamentals of the Semantic Web, knowledge representation, ontologies, semantic querying, syntactic querying, web reasoning, complex systems.

Examination:
Each student must pass a written examination, and deliver a project. Above a certain minimum evaluation threshold, each student can optionally request an additional oral examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCP6076298/NO

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WIRELESS NETWORKS FOR MOBILE APPLICATIONS

Master's degree in COMPUTER SCIENCE ORD. 2021, First semester

Lecturer: Prof. CLAUDIO ENRICO PALAZZI

Credits: 6 ECTS

Prerequisites:
Computer Networks

Short program:

Examination:
Students are evaluated through individual/team projects and oral finals focused on all the topics discussed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2598/000ZZ/SCQ0093642/NO
**Foundations of Databases**

Master's degree in **Cybersecurity (Ord. 2020)**, First semester

**Lecturer:** Prof. Nicola Ferro

**Credits:** 6 ECTS

**Prerequisites:**
- Basic knowledge of the Java programming language

**Short program:**
- Overview of database management systems + Gathering, analysis and design of user requirements + The Entity-Relationship (ER) model --- conceptual design + The Relational model and the relational database management systems --- logical design --- relational algebra --- mapping from conceptual to relational model + The SQL language --- data definition language --- data manipulation language --- advanced concepts (indexes, views, stored procedures, foreign data wrappers) + Programmatic access to databases --- the JDBC APIs for the Java programming language

**Examination:**
- Written exam (individual exam) --- questions on the topics covered during the lectures --- exercise about designing and querying a database + Group project on the Implementation of an actual database application, carried out by means homeworks during the lecture period. + Oral presentation with slides and demo of the developed project

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089516/NO

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**Internet of Things and Smart Cities**

Master's degree in **Cybersecurity (Ord. 2020)**, First semester

**Lecturer:** Prof. Lorenzo Vangelista

**Credits:** 6 ECTS

**Prerequisites:**
Telecommunications' course; knowledge of the basic principles of telecommunications networks, especially the Internet protocols The student must know in depth the basic topics of telecommunications at the physical, MAC and network level such as - radio propagation - digital modulations - medium access control

**Short program:**
Introduction - Definition of Internet of things, its applications, scientific and market trends - The Internet of things and home automation - Internet of Things and industrial applications Internet of Things - Different approaches: Long range cellular (M2M), long range unlicensed frequencies, short range, RFID - Key scientific topics: the physical layer, addressing and routing, security - Standardisation bodies and consortiums: ETSI, IETF, IEEE etc. - Some key standards: ZigBee, 6LoWPAN, WiFi (802.11ah), Bluetooth Low Energy, SigFox, Lo-Ra, - Platforms for Internet of things: Microsoft, Amazon, Google - Analytics SmartCity - Definition of Smart City readiness for a city - Communication Architectures and applications - Regulatory issues and open data - Applications: metering, parking, monitoring - Analytics for Smart City - Privacy and security We will strictly follow the textbook up to chapter 9, as far as the Internet part of things is concerned

**Examination:**
Written exam

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089513/NO

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**Advanced Topics in Computer and Network Security**

Master's degree in **Cybersecurity (Ord. 2020)**, First semester

**Lecturer:** Prof. Mauro Conti

**Credits:** 6 ECTS

**Prerequisites:**
No strict prerequisites on previous exams. However, it is suggested to have basic knowledge of networking, cryptography, and distributed systems (typically acquired in BSc degrees in Computer Science).

**Short program:**
Theory: RFID security, captcha, untrusted storage, smartphone security, attacks on smartphone, password protection, distributed Denial of Service attacks,
deep learning, behavioural biometrics, VoIP security, secure content delivery, anonymous communications, keyloggers detection, anonymity in WSN, botnet detection, trusted HW, security of RFID ePassports, node replication attack in WSN, secure data aggregation in WSN, privacy issues in social networks, Google Android smartphone security, electronic voting, P2P botNet detection, taint mechanisms, browser security, privacy of location based services, Named Data Networking security, Named Data Networking privacy, cloud security, anonymity in wireless network, smartphone user profiling, SSL security issues in Android, circumvent censorship, secure messaging, operational technology security, cyber-physical systems security Laboratory: advanced security tools, including: traffic analysis with machine learning tools, data inference, Android security tools, advanced analysis of malware systems and advanced persistent threat; web security; social network analysis tools, trusted platform modules.

Examination:
Project with written essay + oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ1098227/NO

BIG DATA COMPUTING (CHANNEL 1)

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Prof. ANDREA ALBERTO PIETRACAPRINA

Credits: 6 ECTS

Prerequisites:
The course has the following prerequisites: competences regarding the design and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

Short program:
The course will cover the following topics: Introduction to the Big Data phenomenon. Distributed frameworks: MapReduce, Apache Spark. Clustering for data analysis and summarization. Analysis of data streams. Dimensionality reduction. Association Analysis.

Examination:
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 2-3 students, and of an individual written test comprising both theory questions and exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP7079297/NO

BIG DATA COMPUTING (CHANNEL 2)

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Prof. FRANCESCO SILVESTRI

Credits: 6 ECTS

Prerequisites:
The course has the following prerequisites: competences regarding the design and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

Short program:
The course will cover the following topics: Introduction to the Big Data phenomenon. Distributed frameworks: MapReduce, Apache Spark. Clustering for data analysis and summarization. Analysis of data streams. Dimensionality reduction Association analysis.

Examination:
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 2-3 students, and of an individual written test comprising both theory questions and exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP7079297/NO

BIOMETRICS

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Prof. SIMONE MILANI

Credits: 6 ECTS
Prerequisites:
In order to attend the course, students must possess a basic knowledge in Calculus and Probability Theory. Basic knowledge of machine learning strategies and Python programming language is required. Some preliminary knowledge on computer vision can be useful (although not strictly necessary).

Short program:
Introduction to biometric systems. Part a: Biometric sensors a.1 Fingerprint acquisition systems a.1.1 Optical a.1.2 Capacitive a.1.3 Thermal a.1.4 RF sensors a.1.5 Ultrasonic a.2 Face and Iris recognition systems a.2.1 Digital Cameras a.2.2 Infrared Cameras a.2.3 Thermal Cameras a.2.4 3D depth sensors a.2.5 3D scanners a.2.6 Retinal scanning a.3 Other sensors a.3.1 Hyperspectral imaging a.3.2 Motion analysis systems a.3.3 DNA acquisition Part b: Biometric algorithms b.1 Face recognition systems b.1.1 Overview of face recognition systems b.1.1 Face alignment and normalization b.1.2 Feature detection strategies b.1.3 Identification and verification strategies b.1.4 Challenges and attacks to face recognition systems b.2 Fingerprint identification b.1.1 General scheme for fingerprint identification b.1.2 Minutiae detection b.1.3 Fingerprint alignment b.1.4 Problems and attacks to fingerprint identification b.3 Iris recognition systems b.3.1 Iris identification b.3.2 Orientation, pose and scaling compensation b.3.3 Iris matching b.4 Voice recognition b.5 DNA analysis b.6 Gat analysis b.7 Other biometric measurements

Examination:
Final evaluation will be performed by means of a final written exam consisting in a multiple choice quiz and some open answer questions. The evaluation topics for the written exam will be clearly indicated during the course and in the course material. In case it is not possible to organize a written exam because of the Covid-19 emergency, the written test could be replaced by a remote oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089500/NO

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Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. MARCO ZORZI

Credits: 6 ECTS

Prerequisites:
The course requires preliminary knowledge of machine learning and probability theory. Familiarity with basic concepts of cognition and neuroscience may facilitate the understanding of the topics covered by the course.

Short program:
1. Introduction: computational and mathematical modeling in cognitive science and cognitive neuroscience. Overview of symbolic, emergentist and probabilistic approaches to simulate human cognition. 2. Probabilistic models of cognition: basics of Bayesian inference and probabilistic graphical models; inductive learning; probabilistic programming. 3. Neural network models of cognition: basics of neural computation; learning in neural networks; deep learning architectures. 4. Information coding in cognitive architectures: efficient coding, probabilistic coding, predictive coding. 5. Case studies: models of human perception and concept learning; language acquisition and language understanding; causal reasoning and decision making.

Examination:
Examination will consist in a written exam including open questions and multiple-choice questions. Each student will also be required to write an individual essay (or project report) assigned during the course and submit it (through the course Moodle) no later than the day before the written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089498/NO

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Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
Basic knowledge on computer networks and computer science. Basic coding skills.

Short program:
Fundamentals Introduction to Cyber-Physical Systems (with examples of famous attacks) Control Theory Architectures Internet of Things (IoT) and Industrial IoT (IIoT) Cybersecurity Concepts in CPS Attacks to control systems Anomaly and Intrusion Detection Hardware Security Remote attestation Privacy in distributed systems Cybersecurity of CPS applications Automotive Drones and swarms Industrial Control Smart grid IoT and IIoT

Examination:
Written test. An oral examination could be provided as an alternative only for specific and documented cases.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ2101239/NO
Master's degree in **CYBERSECURITY (ORD. 2020)**, First and Second semester

**Lecturer:** Prof. ALESSANDRO LANGUASCO  
**Credits:** 12 ECTS  
**Prerequisites:**  
For the first part (Prof. Languasco; 6 credits): The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): OS, Programming.  
**Short program:**  
**Examination:**  
For the first part (Prof. Languasco; 6 credits): Written exam in class; if, due to the pandemic situation, this will not be possible the written exam will be done using the available videoconferencing tools. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): Written Exam, Homeworks, oral test.  
**More information:**  

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Master's degree in **CYBERSECURITY (ORD. 2020)**, Second semester

**Lecturer:** Prof. ALESSANDRO SPERDUTI  
**Credits:** 6 ECTS  
**Prerequisites:**  
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.  
**Short program:**  
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.  
**Examination:**  
The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.  
**More information:**  
[https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP9087561/NO](https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP9087561/NO)

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Master's degree in **CYBERSECURITY (ORD. 2020)**, Second semester

**Lecturer:** Prof. SIMONE MILANI  
**Credits:** 6 ECTS  
**Prerequisites:**  
In order to attend the course, students must posses a basic knowledge in Calculus, Linear Algebra (including basic matrix operations, inversion and diagonalization), and Probability Theory (random variable, probability mass/density function and their properties). A basic knowledge of Python programming and main machine learning strategies is required as well. In case students did not master the mentioned subjects, they can be provided with some additional material for individual study to compensate the missing knowledge.  
**Short program:**
**ETHICAL HACKING**

Master's degree in **CYBERSECURITY (ORD. 2020)**, First semester

**Lecturer:** Dott.ssa ELEONORA LOSIOUK

**Credits:** 6 ECTS

**Prerequisites:** No strict prerequisites on previous exams.

**Short program:**
The course will cover the following topics: - Network security: network analysis and monitoring; securing internet communications; packet sniffing and spoofing; TCP attacks; firewalls - Hardware security: meltdown attack; spectre attack - Web security: cross-site scripting attack; HTTP request smuggling - Phishing; computer-related fraud; theft or unlawful use of a digital identity; computer privacy violations; computer crimes of copyright infringement; cryptolocker ransomware; cyberbullying; cyberterrorism. b.1.5. The criminal use of social media. b.1.6. Peculiar problems concerning the criminal responsibility of the ISP. b.2) Criminal Investigations b.2.1. Features of digital investigations. Immateriality, transnationality, cooperation. b.2.2. Types of digital investigations. Forensic, reactive and proactive investigations. b.2.3. Means for obtaining evidence. Inspections, searches, seizures, interceptions of communications or communications. b.2.4. Clone copy. Beat stream image. b.2.5. The role of the digital forensics expert and the role of defence.

**Examination:**
Final evaluation will be performed by means of a written exam and the development of a final project (to be document with a written report). Reports must be handed in at least one day before the final exam. The final score will be made of a weighted average of the evaluation of the written exam (60%) and the final project (40%). The evaluation topics for the written exam will be clearly indicated during the course and in the course material. In case it is not possible to organize a written exam because of the Covid-19 emergency, the written test could be replaced by a remote oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC2542/000ZZ/SCQ0089501/NO

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**FORMAL METHODS FOR CYBER-PHYSICAL SYSTEMS**

Master's degree in **CYBERSECURITY (ORD. 2020)**, First semester

**Lecturer:** Prof. DAVIDE BRESOLIN

**Credits:** 6 ECTS

**Prerequisites:**
The course requires familiarity with automata theory, theory of computation and calculus. There are no preparatory courses.

**Short program:**

**Examination:**
Written exam and project
GAME THEORY

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: ELVINA GINDULLINA

Credits: 6 ECTS

Prerequisites:
A course, even a basic one, on probability theory.

Short program:

Examination:
For all the students, in any event the exam includes a mandatory open-book written test, containing problems of game theory focusing on different topics of the course. Every exercise involves multiple questions, typically three. For the students with regular attendance to the course, the exam may also involve, if they want so, the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer. If the written test is sufficient, students can directly finalize the passing score. Projects can be discussed with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). The project discussion integrates the mark of the written test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP7079401/NO

HUMAN COMPUTER INTERACTION

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Prof. LUCIANO GAMBERINI

Credits: 6 ECTS

Prerequisites:
There are no specific prerequisites.

Short program:
Following the textbook we will explore the following topics: 1 What is Interaction Design? 2 The Process of Interaction Design 3 Conceptualizing Interaction 4 Cognitive Aspects 5 Social Interaction 6 Emotional Interaction 7 Interfaces 8 Data Gathering 9 Data Analysis, Interpretation, and Presentation 10 Data at Scale 11 Discovering Requirements 12 Design, Prototyping, and Construction 13 Interaction Design in Practice 495 15 Evaluation Studies: From Controlled to Natural Settings 16 Evaluation: Inspections, Analytics, and Models Detailed examples and training on research methods and techniques for the design and the evaluation of interactive systems will be discussed during lessons.

Examination:
The exam will be in written form and will include open and closed questions

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP7079403/NO

LAW AND DATA

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Dott.ssa ELISA SPILLER

Credits: 6 ECTS

Prerequisites:
No prerequisites

Short program:
MACHINE LEARNING

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. FABIO VANDIN

Credits: 6 ECTS

Prerequisites: Basic Knowledge of Mathematics, Probability Theory, Statistics, Linear Algebra, Algorithms, and basic Programming skills.

Short program:

Examination:
The evaluation of the acquired skills and knowledge will be performed using two contributions: 1. A written exam without the book, where the student must solve few problems, with the aim of verifying the acquisition of the main ingredients of a learning problem and of the main machine learning tools, the analytical ability to use these tools and the ability to interpret the typical results of a practical machine learning problem. 2. Computer simulations (optional) with the aim of acquiring the practical competences for using machine learning tools. These simulations, to be performed at home, allow to verify the ability of practically exploiting the acquired theoretical concepts. The student will have to provide a brief document explaining the employed methodologies used to solve the assigned problem together with the obtained results. The final grade will be based on the written test with a bonus up to 3 point for the students who will hand in also the lab assignments.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP8082660/NO

METHODS AND MODELS FOR COMBINATORIAL OPTIMIZATION

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. LUIGI DE GIOVANNI

Credits: 6 ECTS

Prerequisites: Basic notions of Operations Research, Linear Programming, and computer programming.

Short program:

Examination:
Oral examination about course contents and homework on the application of optimization methods to solve realistic problems. Each student may chose to present a short project concerning a case study about models and exact/heuristic solution methods for a realistic application of combinatorial optimization.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP7079402/NO
MOBILE SECURITY

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Dott.ssa ELEONORA LOSIOUK

Credits: 6 ECTS

Prerequisites:
Any object-oriented programming language.

Short program:
Network security - network analysis and monitoring; securing internet communications; packet sniffing and spoofing; TCP attacks; firewalls Hardware security - meltdown attack; spectre attack Web security - cross-site scripting attack; HTTP request smuggling Pwn - shellcode; buffer overflow; return-to-libc; format string attack; race condition vulnerability Reverse-engineering - static analysis; reversing in x86; reversing; patching; gdb; debuggers; symbolic execution

Examination:
Students have two options. (Option 1) Practical exam, where students solve exercises on Android security; (Option 2) Project, where students face a research objective assigned by the Lecturer and illustrate the achieved results in an oral presentation.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ2101240/NO

PRIVACY PRESERVING INFORMATION ACCESS

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Dott. GUGLIELMO FAGGIOLI

Credits: 6 ECTS

Prerequisites:
Requested competencies: + Undergraduate level knowledge of statistics + Background on algorithms and linear algebra + Basic knowledge of Databases

Short program:
The course focuses on how to face the principal privacy challenges that arise when developing information access solutions. The course will cover the following privacy-preserving information access related topics: The first part of the course details the definition of privacy from both societal and legal aspects. During the first module, the student learns about Solove’s Taxonomy and how to classify the different privacy-related aspects. The course provides basic elements of the European regulation on privacy protection. The second part of the course focuses on the most known computational techniques to grant privacy. The student learns the main computational and statistical approaches used to achieve privacy and/or anonymity, such as k-anonymity, l-diversity and t-closeness, and Differential Privacy. The main part of the course focuses on information access, privacy threats linked to the use of databases, search engines and recommender systems. The student learns how state-of-the-art techniques are used to preserve users’ privacy. More in detail, the following aspects will be covered: + Databases: interpretation of the threats in the Solove’s hierarchy framework, practical application of computational techniques previously learned, microdata and macrodata protection and geomasking. + Information Retrieval and Search Engines: interpretation of the threats in the Solove’s hierarchy framework, practical application of computational techniques previously learned, privacy risks linked to Search Engines and IR systems, development and evaluation of Privacy preserving IR models and Searchable encryption. + Recommender systems: interpretation of the threats in the Solove’s hierarchy framework, practical application of computational techniques previously learned, analysis of the risks associated with collaborative filtering and social recommender systems, federated learning for privacy-preserving RS.

Examination:
Individual written Exam with questions and exercises on the topics covered during the lectures (Moodle quiz). Cutting-edge research papers presentation: each student will prepare a presentation of a paper (chosen among a given pool or autonomously chosen and agreed with the instructor). The paper will be presented and discussed with the rest of the class. Active participation in the lectures and presentations. students will be required to read priorly papers that are planned to be presented, send a set of questions regarding the paper to the instructor, and discuss them with the rest of the class after the paper has been presented.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ2101279/NO

QUANTUM CRYPTOGRAPHY AND SECURITY

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. GIUSEPPE VALLONE

Credits: 6 ECTS

Prerequisites:
The class requires fundamental knowledge on quantum physics, quantum information, information theory, cryptography and security A brief review of the
necessary notions in quantum information and technologies, in security and cryptography will be given at the start of class.

**Short program:**
Introduction: review of quantum information and technologies, security services, mechanisms and measures Quantum random number generators (QRNGs): discrete- and continuous- variable QRNGs, technological issues, Bell certified QRNGs, semi device independent QRNGs, randomness extractors, Quantum key distribution (QKD): protocols (prepare-and-measure, entanglement-based, continuous-variable), technological aspects and non idealities, attack models, post processing algorithms and security proofs, use of decoy states, device independent QKD, twin-field QKD, QKD networks, quantum memories and repeaters Other quantum security mechanisms: direct secret communication, quantum information commitment, quantum secret sharing, quantum digital signature.

**Examination:**
The students must submit individual reports for the laboratory experiences, and take a traditional oral exam with analytical questions and critical discussions on the class material.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089519/NO

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**QUANTUM INFORMATION AND COMPUTING**

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

**Lecturer:** Prof. GIUSEPPE VALLONE

**Credits:** 6 ECTS

**Prerequisites:**
Linear algebra.

**Short program:**
PART I: general concepts What is a qubit: introduction to quantum mechanics Hilbert spaces, operators and projectors Quantum measurements Time evolution, decoherence Entanglement: definition, generation and detection Quantum state tomography Bell Inequalities PART II: Quantum Information Classical Information versus Quantum Information Quantum channels and no cloning Dense coding Teleportation Quantum Key distribution Quantum Random Number Generators Quantum Metrology PART III: Quantum Computation Classical Computation versus Quantum Computation From FFT to QFT Shor’s algorithm Quantum Database Search Quantum Simulations Physical Implementations

**Examination:**
The exam is constituted of three parts: - homeworks (20%) - reports on lab activity (20%) - oral (60%) The final grade will be the weighted average with the above reported percentage

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCP8082721/NO

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**SECURITY AND RISK: MANAGEMENT AND CERTIFICATIONS**

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

**Lecturer:** Dott. SIMONE SODERI

**Credits:** 6 ECTS

**Prerequisites:**
No strict prerequisites on previous exams.

**Short program:**
The course deals with the assessment of cyber risks that can damage a corporate information system, the methodologies to mitigate these risks and the necessary countermeasures to be applied with the aim of making the company or public institution secure from an IT point of view. Gradually students will be introduced to principles, concepts, and practices for governing, managing, and auditing cybersecurity in accordance with international standards, generally accepted professional best practices, certifications and reference frameworks. Course program: - Course Introduction; - Basic Concepts; - Planning for Cybersecurity; - Cybersecurity Operations and Management; - Security Assessment and use cases; - Certification and Frameworks for Organizations and management systems; - Certification of products and technologies; - Frameworks that describe the competencies; - Certification of people; - Most common Certifications available on the market; - Audit techniques and approach examples.

**Examination:**
Students will take an exam at the end of the course. The final exam covers all material for the semester.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089517/NO

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**SERVICE MANAGEMENT**
Master's degree in **CYBERSECURITY (ORD. 2020)**, First semester

**Lecturer:** Prof. MARCO UGO PAIOLA  
**Credits:** 6 ECTS  

**Prerequisites:**  
Students should have a basic knowledge of management, business strategy and marketing fundamentals, as well as innovative value-creating strategies.

**Short program:**  
This course unit aims to provide students with fundamental theoretical and professional competences useful to understand modern service business growth in B2B companies, with special attention to digital transformation processes. The course unit will cover the following topics:  
- Why services? The service imperative: servitization drivers and B2B services challenges and categories.  
- Are manufacturing firms fit for services? Resources, capabilities and organization; pricing challenges; sales and distribution channels management.  
- Service strategy alignment: Building a service culture At the beginning of the course, a detailed course schedule will be provided with a more fine-grained representation of class contents.

**Examination:**  
Attending students' knowledge and skills will be assessed through:  
- A written exam – students will be asked to answer 2 open questions (one related to a broad course topic, one related to a specific issue treated in the course). Skills C1, C2, C3, C4 will be assessed.  
- Group works – teams will work on themes agreed upon directly with selected local firms and apply the course’s concept to a real case. They will have to prepare a presentation and a final report. Skills P1, P2, T1, T2, T3 will be assessed. Non attending students’ knowledge and skills will be assessed through:  
- A written exam – students will be asked to answer 3 open questions (two related to a broad course topic, one related to a specific issue described in the course). Skills C1, C2, C3, C4 will be assessed.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089465/NO

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**SOFTWARE VERIFICATION**

Master's degree in **CYBERSECURITY (ORD. 2020)**, First semester  

**Lecturer:** Prof. FRANCESCO RANZATO  
**Credits:** 6 ECTS  

**Prerequisites:**  
Basic knowledge of programming languages. Formally prerequisite courses are not required.

**Short program:**  
- Program semantics: This is a model of the dynamic behaviour of programs (in particular the input/output behaviour) by means of order and fixed point theory. (cf. https://en.wikipedia.org/wiki/Semantics_(computer_science) )  
- Static program analysis and verification by abstract interpretation: Abstract interpretation is a well-known technique for approximating the semantics of programs that allows to specify how to statically deduce program properties and to prove their correctness. (cf. https://en.wikipedia.org/wiki/Abstract_interpretation )  
- Dataflow program analysis: This is a technique for gathering information about the possible set of values calculated at various program points. A program’s control flow graph is used to determine those parts of a program to which a particular value assigned to a variable might propagate. The information gathered is often used by compilers (such as gcc and javac) when optimizing a program. (cf. https://en.wikipedia.org/wiki/Data-flow_analysis )  
- Software verification tools: e.g., Clousot (Microsoft, USA), Interproc (INRIA, France), Jandom (Univ. Pescara, Italy) (cf. https://en.wikipedia.org/wiki/List_of_tools_for_static_code_analysis )

**Examination:**  
Oral examination and/or software project, possibly split into distinct parts.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089515/NO

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**STOCHASTIC PROCESSES**

Master's degree in **CYBERSECURITY (ORD. 2020)**, Second semester  

**Lecturer:** Prof. MICHELE ZORZI  
**Credits:** 6 ECTS  

**Prerequisites:**  
The course requires preliminary knowledge of: Mathematical Analysis, Probability, random variables and random processes, networks and protocols. For the examples treated, a basic course in networks and protocols is useful (through not required).

**Short program:**  
1. Review of probability and random processes  
2. Markov chains: definitions and main results  
3. Markov chains: asymptotic behavior  
4. Poisson processes: definitions and main results  
5. Renewal processes: definitions and main results, asymptotic behavior  
6. Renewal reward, regenerative, and semi-Markov processes  
7. Exercises and examples of applications  
A detailed list of the topics covered during the course, with specific reference to chapters and pages of the texts, is available on the course website through the e-learning platform.

**Examination:**
The assessment of the knowledge and skills acquired is carried out by means of a written test divided into two parts. Part A, with a duration of 90 minutes and open-book, consists of eleven numerical questions grouped into four exercises. Each question has a value of three points. Part B, with a duration of 60 minutes and closed-book, consists of three theoretical questions (typically proofs of theorems seen in class). Each question has a value of eleven points. If the student scores at least 15 points in part A and the average score of part A and part B is at least 18, the latter can be accepted as the final grade. If the score in part A is less than 15 or the average of the two tests is less than 18, the exam is not passed. Even if the final exam can be passed by a successful written exam (in two parts), the student can always ask to take an oral exam if he/she wants to improve the grade. In no case can the oral exam replace the written test. Examples of exams are available on the elearning platform course website, and are extensively covered in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089499/NO

VISION AND COGNITIVE SYSTEMS

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. LAMBERTO BALLAN

Credits: 6 ECTS

Prerequisites:
The student should have basic knowledge of computer programming and algorithms, as well as mathematics, probability theory and statistics, linear algebra. It is also advisable to be familiar with basic concepts in machine learning and pattern recognition.

Short program:
The course will cover the topics listed below: - Introduction: From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges. - Cognitive Services: Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies. - Machine Learning and applications: Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias. - Early Vision and Image Processing: Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching. - Visual Recognition and beyond: "Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm. - Hands-on Practicals: What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

Examination:
The student is expected to develop, in agreement with the instructor, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project, and answer a few questions about the topics addressed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ1097939/NO

WEB APPLICATIONS

Master's degree in CYBERSECURITY (ORD. 2020), Second semester

Lecturer: Prof. NICOLA FERRO

Credits: 6 ECTS

Prerequisites:
Requested competencies: - good and proactive programming skills and, in particular, the object-oriented paradigm and its design principles; - good knowledge of the Java programming language; - foundations of database management systems and, in particular, entity-relationship model, relational model, SQL, JDBC; - computer networks and, in particular, the HTTP protocol

Short program:
+ Design methodologies for Web applications --- Introduction to Web engineering --- Requirement analysis --- Modelling Web applications (contents, hypertext, presentation) --- Architectures for Web applications + Development of Web 1.0 Applications --- Model-View-Controller (MVC) paradigm --- Web programming (HTML5, CSS3, Javascript) --- Web server and Web browser architecture --- Java servlet and Java Server Pages, Apache Tomcat --- Development tools: git for code management and maven for the build process + Web Services --- REST Web services + Development of Web 2.0 Applications --- Introduction to Rich Internet Applications (RIA) and mash-ups --- Introduction to JSON and XML --- AJAX and revised MVC paradigm + Notions on Web 3.0 applications; --- semantic representation of the data and RDF --- open linked data

Examination:
Written Exam at computer: + questions on the topics covered during the lectures (Moodle quiz) Project to design, develop, implement, code and document an actual full-stack Web application, carried out in student groups via homeworks + git repository containing the project source code and all the related material + report documenting the developed full-stack Web application application + oral presentation of the project outcomes + demo of the developed full-stack Web application application

42/233
WIRELESS NETWORKS

Master's degree in CYBERSECURITY (ORD. 2020), First semester

Lecturer: Prof. CLAUDIO ENRICO PALAZZI

Credits: 6 ECTS

Prerequisites: Computer Networks

Short program:

Examination: Students are evaluated through individual/team projects and oral finals focused on all the topics discussed in class.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2542/000ZZ/SCQ0089467/NO

DATA SCIENCE ORD. 2017

ADVANCED DATABASES

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: to be defined

Credits: 5 ECTS

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093693/NO

BIG DATA MANAGEMENT

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: to be defined

Credits: 6 ECTS

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093697/NO

BIG DATA SEMINAR

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: to be defined

Credits: 2 ECTS
### BIOLOGICAL DATA

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. DAMIANO PIOVESAN

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of computer science, optimization methods and machine learning. Python programming language.

**Short program:**
The course consists of four parts, corresponding to different types of biological data: 1) Sequences 1.1) DNA and proteins 1.2) Databases 1.3) Alignments 2) Structures 2.1) Protein folding 2.2) Databases 2.3) Structure prediction 3) Literature 3.1) Scientific papers 3.2) Databases 3.3) Text mining 3.4) Function 4) Interaction networks 4.1) Non-globular regions 4.2) Biological interactions 4.3) Databases 4.4) Emergent properties

**Examination:**
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Mid-term test (ca. 17%) Open questions 2) Project (ca. 50%) Coding and analysis of biological dataset; written report 3) Final exam (ca. 33%) Oral, with questions on project and course

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079337/NO

### BUSINESS PROCESS MANAGEMENT

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** to be defined

**Credits:** 5 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093691/NO

### DATA MINING

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** to be defined

**Credits:** 5 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093698/NO

### DATA WAREHOUSES

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** to be defined

**Credits:** 5 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093690/NO

### DATABASES SYSTEMS ARCHITECTURE

Master's degree in **DATA SCIENCE ORD. 2017**, First semester
**Lecturer:** to be defined

**Credits:** 5 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093692/NO

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**DEEP LEARNING AND HUMAN DATA ANALYTICS**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. MICHELE ROSSI

**Credits:** 6 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ2101305/NO

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**LAW AND DATA**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Dott.ssa ELISA SPILLER

**Credits:** 6 ECTS

**Prerequisites:**

No prerequisites

**Short program:**
All the info about the course are on Moodle - Introduction to Law and Legal Studies - Introduction to the EU Law - Introduction to the EU GDPR - The concept of data; personal, sensitive and economic data; big data - Property of data, choices in the management of data - The right to be forgotten - Civil and criminal aspects of profiling activity - Automatic data processing, human responsibilities - The Data Protection Officer and DP Authorities - Civil and criminal protection of privacy - Sanctioning powers and system - Open Data for the public interest - Big data (collection, analysis, processing) and their influence on fundamental rights - Digital Surveillance - Facial Recognition: Open Issues - Disinformation - Artificial Intelligence in the EU law

**Examination:**
Written Exam

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079399/NO

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**MACHINE LEARNING**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP8082660/NO

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**SEMANTIC DATA MANAGEMENT**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester
STATISTICAL LEARNING

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. ALBERTO ROVERATO

Credits: 6 ECTS

Short program:
Part 1: - Data: summary statistics, displaying distributions; exploring relationships - Estimation: point estimation; the sampling distribution of an estimator; accuracy of estimation; interval estimation - Hypothesis testing - Likelihood: the likelihood, likelihood for several parameters - Estimation: maximum likelihood estimation; properties of maximum likelihood estimates

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ2101262/NO

STOCHASTIC METHODS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FERRANTE

Credits: 6 ECTS

Prerequisites:
Basic notions of differential and integral calculus, linear algebra and probability.

Short program:
1. Probability reviews. • discrete and continuous distributions • random variables, expectation and conditional expectation • Law of Large Numbers and Chernoff Bounds • approximation of probability distributions. 2. Markov chains and random walks • Discrete time Markov Chain and their stationary distribution • Monte Carlo (MCMC), convergence of MCMC-based algorithms. 3. High dimensional Gaussian random variables • Gaussian Annulus Theorem • Nearly orthogonal of independent random variables. 4. Introduction to Random Networks

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079197/NO

TIME-SERIES ANALYSIS FOR BUSINESS ECONOMIC AND FINANCIAL DATA

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof.ssa MARIANGELA GUIDOLIN

Credits: 6 ECTS

Prerequisites:
Program of Statistical Learning course

Short program:
- General introduction to business, economic and financial data –Preliminary concepts and illustrative examples –Moving beyond the linear model –Linear regression model: main ideas and assumptions –Nonlinear regression models for new product growth – Beyond linearity: regression splines, local regression, generalized additive models (GAM) - Tree-based methods: Regression trees, Bagging, Boosting -Time series analysis: Exponential Smoothing and ARIMA models

Examination:
--Practical exam --Oral exam

46/233
VIABILITY OF BUSINESS PROJECTS

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093723/NO

FINAL EXAMINATION

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Lecturer: to be defined

Credits: 15 ECTS

Short program:
The final exam consists in the preparation and discussion, under the guidance of a supervisor, of a thesis containing the results of a work in the data science area. This work, theoretical, experimental or applicative, can be possibly carried out in a research laboratory at the University of Padua or in an external (public or private) institution, in agreement with the University of Padua. The final evaluation, which will consider the full record of the student and of the expertise, knowledge and skills acquired, will be given by the Committee for the final examination, after the thesis defense.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079319/NO

BIG DATA COMPUTING

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof. ANDREA ALBERTO PIETRACAPRINA

Credits: 6 ECTS

Prerequisites:
The course has the following prerequisites: competences regarding the design and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

Short program:
The course will cover the following topics: Introduction to the Big Data phenomenon. Distributed frameworks: MapReduce, Apache Spark. Clustering for data analysis and summarization. Analysis of data streams. Dimensionality reduction. Association Analysis.

Examination:
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 2-3 students, and of an individual written test comprising both theory questions and exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079297/NO

BIOLOGICAL DATA

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. DAMIANO PIOVESAN

Credits: 6 ECTS

Prerequisites:
Basic knowledge of computer science, optimization methods and machine learning. Python programming language.

Short program:
The course consists of four parts, corresponding to different types of biological data: 1) Sequences 1.1) DNA and proteins 1.2) Databases 1.3) Alignments
2) Structures 2.1) Protein folding 2.2) Databases 2.3) Structure prediction 3) Literature 3.1) Scientific papers 3.2) Databases 3.3) Text mining 3.4) Function
4) Interaction networks 4.1) Non-globular regions 4.2) Biological interactions 4.3) Databases 4.4) Emergent properties

Examination:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Mid-term test (ca. 17%) Open questions 2) Project (ca. 50%) Coding and analysis of biological dataset; written report 3) Final exam (ca. 33%) Oral, with questions on project and course

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079373/NO

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**Cognitive, Behavioral and Social Data**

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. GIUSEPPE SARTORI

Credits: 6 ECTS

Prerequisites:
Notions of machine learning

Short program:
The aim of the course is to provide an overview of concrete data science applications in behavioural science, cognitive science, neuroscience and social science. The course gives an underground of methods to analyse and learn behavioural, cognitive and brain functional/structural data. It provide a review of studies, with several examples of recent practical applications, also according with the students interests. Limits in the state of the art and future directions will be discussed. The course contents are the following: • Basic concepts of human brain cognitive functioning (attention, memory, learning, language, etc.) and how to measure it • Basic concepts of social psychology and social behaviour (preferences, judgments, group identity, etc.) and how to measure it • What are behavioural measures and how to measure them (e.g., RT); implicit and explicit behavioural measures (e.g., the IAT) • Extracting and predicting information from behaviour (e.g., lie detection, predicting malicious behaviour from social networks activity, fake online reviews, security applications, etc.) • What are psychophysiological measures and how to measure them (e.g., HR variability, SCR, facial expressions, EEG, fMRI, etc.) • Extracting and predicting information from psychophysiological measures • Extracting and predicting information from brain activity: mind reading applications (e.g., psychopathology detection, reconstructing visual experiences from brain activity, brain computer interface devices, etc.) • Social and behavioural data for marketing application (e.g. skill assessment and prediction, psychology of taxes, predicting preferences and personality from social networks activity, sentiment analysis, etc.) • Issue related to the application of machine learning in behavioural research (e.g. the problem of reproducibility)

Examination:
Oral exam and project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079219/NO

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**Deep Learning**

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof. ALESSANDRO SPERDUTI

Credits: 6 ECTS

Prerequisites:
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

Short program:
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.

Examination:
The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP9087561/NO

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**Fundamentals of Information Systems**

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. GIORGIO MARIA DI NUNZIO

Credits: 12 ECTS

Prerequisites:
The student should have basic knowledge of computer programming and problem solving skills.

Short program:
The course is structured into 3 submodules: - Python Programming (for Data Science) This submodule provides students with the foundational coding skills they need as data scientists. First, the basics of the Python programming language are covered (i.e., built-in data types, functions, I/O, etc.) along with the environment which is used throughout the class (i.e., Jupyter Notebook). Afterwards, students will dig into a set of the most up-to-date data science Python packages; those are: numpy/scipy (for numerical/scientific computing), pandas (for data manipulation), matplotlib/seaborn (for data visualization), and finally scikit-learn (for learning from data). - Databases This submodule is dedicated to data storage, and it covers the following topics: Relational databases, Logical and Physical Design of a Relational Database. SQL Language: Data Definition and Data Manipulation Language. Database Query The PostgreSQL database: Creation and Definition of a Database, SQL Queries. Non Relational databases, graph databases, Cypher query language. Neo4J database: Creation and Definition of a Database, Graph Query Language. - Algorithmic Methods: Preliminaries: definition of problem, instance, solution, algorithm. Models of computation. Analysis of algorithms: correctness and running time. Asymptotic analysis. Basic data structures: lists, stacks, queues, Trees and their properties. Dictionaries and their implementation. Priority queues, Graphs: representation of graphs. Basic properties. Graph searches and applications. Divide and Conquer paradigm: the use of recursion. Case study: sorting. Eventually, at the end all the modules, students will be able to implement all the stages of a typical machine learning pipeline: from collecting data to building predictive models for solving efficiently a data analysis/prediction problem.

Examination:
Written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7078720/NO

INTRODUCTION TO MOLECULAR BIOLOGY

Master’s degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof.ssa MARIA PENNUTO

Credits: 6 ECTS

Prerequisites:
None

Short program:

Examination:
Written verifications that can complement the evaluation. Oral exam: The student will be asked to present a subject of his/her own choice. We will ask two more specific questions to the student. The student may use slides on the subject of choice.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP8084903/NO

MACHINE LEARNING

Master’s degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Dott. GIOVANNI DA SAN MARTINO

Credits: 6 ECTS

Short program:
The course cover the topics listed below: - Introduction: Artificial Intelligence and Machine Learning, when and why you should use Machine Learning techniques: the main machine learning paradigms and their applications; the key ingredients of machine learning. - Supervised learning: the foundations and the basic models Linear Regression; hypothesis space of polynomials and cost function; optimisation and gradient descent. Linear Classification Models; Logistic Regression; Regularisation and model selection. - Model complexity, its effectiveness and its evaluation Bias-Variance Tradeoff: how to deal with overfitting and underfitting problems; risk minimisation and learning theory; performance evaluation measures, examples and applications; diagnosing and debugging machine learning systems. - Supervised learning: neural networks and advanced models Artificial Neural Networks; perceptron, multilayer neural networks and deep learning; parameters learning, backpropagation and gradient descent. Support Vector Machines; kernel methods and nonlinear classification. “Alternative” approaches: non-parametric methods (k-NN) and their applications; decision trees and random forest. - Unsupervised learning Clustering: K-Means and the main approaches; PCA and dimensionality reduction. - Introduction to Recommender Systems and their application.
MATHEMATICAL CELL BIOLOGY

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MORTEN GRAM PEDERSEN

Credits: 6 ECTS

Prerequisites:
Knowledge of differential equations, linear algebra, probability theory.

Short program:

Examination:
Written exam (theory and computer exercises).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP8082660/NO

NETWORK SCIENCE

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. TOMASO ERSEGHE

Credits: 6 ECTS

Prerequisites:
This course has the following prerequisites: knowledge in Probability Theory, and Computer Programming in any language which is appropriate for network analysis (Python preferred, but MatLab, R, C, or Java would do); knowledge in Calculus and Linear Algebra; any further knowledge of networking processes in economics, biology, telecommunications, semantics, etc. might be useful.

Short program:
The module will cover the following topics: 1. Basic network properties - graphs, adjacency matrix, degree distribution, connectivity, distance and diameter, clustering coefficient. 2. Network models - Erdos-Renyi model; Random graphs with general degree distribution; Power laws and scale free networks; Small world phenomena; Hubs; Network generation and expansion; Barabasi-Albert model; Preferential attachment. 3. Centrality measures: Hubs and authorities; PageRank: teleportation, topic specific ranking, proximity measures, trust rank; betweenness, closeness, eigenvector and Katz centralities. 4. Other analytics: homophily ( assortativity), polarisation, innovation, clustering, link prediction. 5. Community detection - Girvan Newman method and betweenness; Louvain modularity optimisation; Spectral clustering; Consensus clustering; Model-driven algorithms; Algorithms for overlapping communities. 6. Network representation - Gephi and R/Python graphical functions; rationale of force directed graph layout algorithms. 7. Twitter Lab - How to extract a semantic network from Twitter data.

Examination:
The verification of the expected knowledge and skills is carried out with the DEVELOPMENT OF A PROJECT aimed at verifying the ability to apply theory in interdisciplinary contexts, and which requires: the choice, the collection of data, and the analysis of a different network for each student; computer implementation (in any programming language known to the student) of the algorithms required for the analysis; the drafting of an essay; the oral presentation of the main project outcomes. A bonus of up to 3 points is available for attending students that take part to an INTERDISCIPLINARY PROJECT with social science students attending the twin course on SOCIAL NETWORK ANALYSIS.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP0093722/NO

OMICS IN HUMAN DISEASE

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. DENIS DOMINIQUE MARTINVALET

Credits: 6 ECTS

Prerequisites:
Basic knowledge of statistics and programming

Short program:
The course consists of two parts: 1. Introduction to human physiology and complex disease (4 CFU): a. Introduction to biochemistry and cellular biology b.

Examination:
The exam covers two separate parts: Evaluation of the biological knowledge about human and cellular biology relative to complex disease. Evaluation of the skills acquired during practicals with the evaluation of the project about the computational analysis of a complex disease.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093738/NO

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**OPTIMIZATION FOR DATA SCIENCE**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

Lecturer: Prof. FRANCESCO RINALDI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of - Real Analysis and Calculus; - Linear Algebra; - Probability theory.

Short program:
1. Convex sets and convex functions (a) Convexity: basic notions; (c) Convex functions: Basic notions and properties (gradients, Hessians..); 2. Unconstrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Gradient-type methods; (d) Block coordinate gradient methods; (e) Stochastic optimization methods; 3. Constrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Polyhedral approximation methods; (d) Gradient projection methods; 4. Large scale network optimization (a) Network models in data science; (b) Methods for distributed optimization.

Examination:
- Written exam - Homeworks - Project (Optional)
  1) Homeworks will periodically be assigned based on reading and lecture and will be due at given deadlines. 2) Written exam consists of 4 open questions. 3) Project (optional) can be requested to better analyze specific topics. Written exams represents 85% of grade. Homeworks represent 15% of grade. Project can integrate/replace the written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079229/NO

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**STATISTICAL LEARNING**

Lecturer: Prof. ALBERTO ROVERATO

Prerequisites:
basic probability theory; multivariable calculus; linear algebra; basic computing skills

Examination:
written test and project work

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079226/NO

Moduli del C.I.:
Statistical Learning 1 (Mod. A)
Statistical Learning 2 (Mod. B)

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**STATISTICAL LEARNING 1 (MOD. A)**

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in **DATA SCIENCE ORD. 2017**, First and Second semester

Credits: 12 ECTS

Short program:
Part 1: - Data: summary statistics, displaying distributions; exploring relationships - Estimation: point estimation; the sampling distribution of an estimator; accuracy of estimation; interval estimation - Hypothesis testing - Likelihood: the likelihood, likelihood for several parameters - Estimation: maximum likelihood estimation; properties of maximum likelihood estimates

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**STATISTICAL LEARNING 2 (MOD. B)**

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in **DATA SCIENCE ORD. 2017**, First and Second semester
STOCHASTIC METHODS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FERRANTE

Credits: 6 ECTS

Prerequisites:
Basic notions of differential and integral calculus, linear algebra and probability.

Short program:
1. Probability reviews. • discrete and continuous distributions • random variables, expectation and conditional expectation • Law of Large Numbers and Chernoff Bounds • approximation of probability distributions. 2. Markov chains and random walks • Discrete time Markov Chain and their stationary distribution • Monte Carlo (MCMC), convergence of MCMC-based algorithms. 3. High dimensional Gaussian random variables • Gaussian Annulus Theorem • Nearly orthogonal of independent random variables. 4. Introduction to Random Networks

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2377/000ZZ/SCP7079197/NO

STRUCTURAL BIOINFORMATICS

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof. DAMIANO PIOVESAN

Credits: 6 ECTS

Prerequisites:
Basic knowledge of optimization methods and machine learning. Python programming language.

Short program:

Examination:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Written midterm tests with theoretical and practical questions (ca. 20%) 2) Software project (ca. 40%) 3) Project presentation and critical evaluation (ca. 40%)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2377/000ZZ/SCP7079278/NO

SYSTEMS BIOLOGY

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. GABRIELE SALES

Credits: 3 ECTS

Prerequisites:
The basic knowledge deriving from the subjects of the first year of the Master Degree

Short program:
Introduction to Systems Biology. (0.25 CFU) Basics of Derivatives, Integrals and Differential Equations Mathematical Modeling. (0.25 CFU) Static Network Models. (0.5 CFU) Markov Models. (0.5 CFU) Mutual Information, Relevance Networks and Bayesian Networks. (0.5 CFU) The Mathematics of Biological Systems. (0.5 CFU) Parameter Estimation from Noisy Data: Grid Searches, Hill Climbing, Genetic Algorithms. (0.5 CFU) Signaling Systems. (0.5 CFU)
Examination:
The evaluation of the acquired knowledge will be based on a written exam based on 4 open questions. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0094202/NO

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**BUSINESS ECONOMIC AND FINANCIAL DATA**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof.ssa MARIANGELA GUIDOLIN

**Credits:** 6 ECTS

**Prerequisites:**
Program of Statistical Learning course

**Short program:**
- General introduction to business, economic and financial data
- Preliminary concepts and illustrative examples
- Moving beyond the linear model
- Linear regression model: main ideas and assumptions
- Nonlinear regression models for new product growth
- Beyond linearity: regression splines, local regression, generalized additive models (GAM)
- Tree-based methods: Regression trees, Bagging, Boosting
- Time series analysis: Exponential Smoothing and ARIMA models

**Examination:**
- Practical exam
- Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079231/NO

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**COGNITION AND COMPUTATION**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. MARCO ZORZI

**Credits:** 6 ECTS

**Prerequisites:**
The course requires preliminary knowledge of machine learning and probability theory. Familiarity with basic concepts of cognition and neuroscience may facilitate the understanding of the topics covered by the course.

**Short program:**
1. Introduction: computational and mathematical modeling in cognitive science and cognitive neuroscience. Overview of symbolic, emergentist and probabilistic approaches to simulate human cognition.
2. Probabilistic models of cognition: basics of Bayesian inference and probabilistic graphical models; inductive learning; probabilistic programming.
4. Information coding in cognitive architectures: efficient coding, probabilistic coding, predictive coding.
5. Case studies: models of human perception and concept learning; language acquisition and language understanding; causal reasoning and decision making.

**Examination:**
Examination will consist in a written exam including open questions and multiple-choice questions. Each student will also be required to write an individual essay (or project report) assigned during the course and submit it (through the course Moodle) no later than the day before the written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0089498/NO

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**COGNITIVE, BEHAVIORAL AND SOCIAL DATA**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. GIUSEPPE SARTORI

**Credits:** 6 ECTS

**Prerequisites:**
Notions of machine learning

**Short program:**
The aim of the course is to provide an overview of concrete data science applications in behavioural science, cognitive science, neuroscience and social...
science. The course gives an underground of methods to analyse and learn behavioural, cognitive and brain functional/structural data. It provide a review of studies, with several examples of recent practical applications, also according with the students interests. Limits in the state of the art and future directions will be discussed. The course contents are the following: • Basic concepts of human brain cognitive functioning (attention, memory, learning, language, etc.) and how to measure it • Basic concepts of social psychology and social behaviour (preferences, judgments, group identity, etc.) and how to measure it • What are behavioural measures and how to measure them (e.g., RT); implicit and explicit behavioural measures (e.g., the IAT) • Extracting and predicting information from behaviour (e.g. lie detection, predicting malicious behaviour from social networks activity, fake online reviews, security applications, etc.) • What are psychophysiological measures and how to measure them (e.g., HR variability, SCR, facial expressions, EEG, fMRI, etc.) • Extracting and predicting information from psychophysiological measures • Extracting and predicting information from brain activity: mind reading applications (e.g., psychopathology detection, reconstructing visual experiences from brain activity, brain computer interface devices, etc.) • Social and behavioural data for marketing application (e.g. skill assessment and prediction, psychology of taxes, predicting preferences and personality from social networks activity, sentiment analysis, etc.) • Issue related to the application of machine learning in behavioural research (e.g. the problem of reproducibility)

Examination:
Oral exam and project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079219/NO

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**DEEP LEARNING**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** Prof. ALESSANDRO SPERDUTI  
**Credits:** 6 ECTS

**Prerequisites:**  
It is advisable to have the basic knowledge related to Probability, Programming, and Algorithms.

**Short program:**  
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.

**Examination:**  
The student must pass a written exam. In addition, the student must develop a notebook agreed with the teacher.

More information:  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP9087561/NO

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**FINANCIAL MATHEMATICS FOR DATA SCIENCE**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** Prof. MARTINO GRASSELLI  
**Credits:** 6 ECTS

**Prerequisites:**  
Stochastic analysis

**Short program:**  

**Examination:**  
Final examination based on: Written and oral examination.

More information:  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093689/NO

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**FUNDAMENTALS OF INFORMATION SYSTEMS**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester
**Lecturer:** Prof. GIORGIO MARIA DI NUNZIO  
**Credits:** 12 ECTS  
**Prerequisites:**  
The student should have basic knowledge of computer programming and problem solving skills.  

**Short program:**  
The course is structured into 3 submodules:  
- **Python Programming (for Data Science)**  
  This submodule provides students with the foundational coding skills they need as data scientists. First, the basics of the Python programming language are covered (i.e., built-in data types, functions, I/O, etc.) along with the environment which is used throughout the class (i.e., Jupyter Notebook). Afterwards, students will dig into a set of the most up-to-date data science Python packages; those are: numpy/scipy (for numerical/scientific computing), pandas (for data manipulation), matplotlib/seaborn (for data visualization), and finally scikit-learn (for learning from data).  
- **Databases**  
  This submodule is dedicated to data storage, and it covers the following topics: Relational databases, Logical and Physical Design of a Relational Database. SQL Language: Data Definition and Data Manipulation Language, Database Query The PostgreSQL database: Creation and Definition of a Database, SQL Queries. Non Relational databases, graph databases, Cypher query language. Neo4J database: Creation and Definition of a Database, Graph Query Language.  

**Examination:**  
Written exam.  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7078720/NO

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**HUMAN COMPUTER INTERACTION**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester  

**Lecturer:** Prof. LUCIANO GAMBERINI  
**Credits:** 6 ECTS  
**Prerequisites:**  
There are no specific prerequisites.  

**Short program:**  
Following the textbook we will explore the following topics:  
1. What is Interaction Design?  
2. The Process of Interaction Design  
3. Conceptualizing Interaction  
4. Cognitive Aspects  
5. Social Interaction  
6. Emotional Interaction  
7. Interfaces  
8. Data Gathering  
9. Data Analysis, Interpretation, and Presentation  
10. Data at Scale  
11. Discovering Requirements  
12. Design, Prototyping, and Construction  
13. Interaction Design in Practice  
15. Evaluation Studies: From Controlled to Natural Settings  
16. Evaluation: Inspections, Analytics, and Models  

Detailed examples and training on research methods and techniques for the design and the evaluation of interactive systems will be discussed during lessons.  

**Examination:**  
The exam will be in written form and will include open and closed questions  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079403/NO

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**HUMAN DATA ANALYTICS**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester  

**Lecturer:** Prof. MICHELE ROSSI  
**Credits:** 6 ECTS  

**Prerequisites:**  
Prior knowledge on Calculus and Linear Algebra (vector spaces, singular value decomposition, etc.), Probability Theory (random variables, conditional probability and Bayes formulas, probability distributions), and some basic computer programming (e.g., Matlab and some exposure to Python) is useful. Although not strictly required, basic knowledge of signal processing techniques (e.g., discrete Fourier transforms) is also helpful. Note that the instructor will review basic concepts from the above fields whenever necessary, providing material and/or pointer to refresh the related theories. So, although such previous knowledge is very helpful to the students, the course is intended to be self-contained. Although non mandatory, prospective students will benefit from prior attendance of a basic "Machine Learning" course.  

**Short program:**  
Part I – Introduction (2 hours)  
- Intro: course outline, graduation rules, office hours, etc.  
- Applications: health, activity-aware services, security and emergency management, authentication systems, analyzing human dynamics, natural language processing  
Part II – Vector Quantization (18 hours)  
- Aims, quality metrics  
- Clustering 1: K-means, soft K-means, Expectation Maximization (EM)  
- Clustering 1: X-means, DBSCAN (density based clustering)  
- Unsupervised VQ algorithms: --- Self-Organizing Maps (SOM), Gas Neural Networks (GNG): theory and algorithms -
Application to quasi-periodic biometric signals (ECG): (A) Logics for knowledge representation: (A.i) introduction to propositional logics, syntax, semantics, decision procedure. Satisfiability, weighted satisfiability, and best satisfiability. (A.ii) First order logics, syntax, semantics, resolution and unification. (A.iii) Fuzzy logics, syntax, semantics, and reasoning. (B) statistical relational learning: (B.i) Graphical models (B.ii) Markov Logic Networks (B.iii) Probabilistic log, (B.iii) Logic Tensor Networks

Examination:
This is a course on advance and applied machine learning techniques, that are applied to real world problem within the human data domain. Given this, the examination of the student will be carried out through a project which will involve the following phases of work: 1. The instructor will identify a problem to solve, using an open, rich, and freely accessible data set. The problem to tackle will be thus described by the instructor during a specific lesson where he will as well present how to carry out the final exam, which will consist of: 1) delivering a written report and 2) giving a conference-style talk 2. The students will split into groups, with a maximum of two students per group, and will start to work to the assigned project. The choice of the specific technique to use, the data pre-processing algorithm to obtain informative features, etc., will all be identified in full autonomy by the students, as a first step. The instructor will be available to steer the work and follow the students along all the work phases. Each group will solve the assigned problem using the selected technique and will: 1) present a final written report, 2) give a conference-style talk describing: the problem, the selected models / techniques, the software written as part of the project development, the obtained results. It is also recommended that the students will showcase their software during the presentation A final grade will be provided by the instructor upon a close inspection of the written report at point 1) and the assessment of the talk at point 2).

More information:
https://en.didattica.unipd.it/it/2022/LM/SC/SC2377/000ZZ/SCP7079397/NO

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KNOWLEDGE AND DATA MINING

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
Suggested basic knowledge of logics and statistics.

**Short program:**
(A) Logics for knowledge representation: (A.i) introduction to propositional logics, syntax, semantics, decision procedure. Satisfiability, weighted satisfiability, and best satisfiability. (A.ii) First order logics, syntax, semantics, resolution and unification. (A.iii) Fuzzy logics, syntax, semantics, and reasoning. (B) statistical relational learning: (B.i) Graphical models (B.ii) Markov Logic Networks (B.iii) Probabilistic log, (B.iii) Logic Tensor Networks

**Examination:**
Final examination based on a combination of written examination and project development.

More information:
https://en.didattica.unipd.it/it/2022/LM/SC/SC2377/000ZZ/SCP7079318/NO

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LAW AND DATA

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Dott.ssa ELISA SPILLER

**Credits:** 6 ECTS

**Prerequisites:**
No prerequisites

**Short program:**
All the info about the course are on Moodle - Introduction to Law and Legal Studies - Introduction to the EU Law - Introduction to the EU GDPR - The concept of data; personal, sensitive and economic data; big data - Property of data, choices in the management of data - The right to be forgotten - Civil and criminal aspects of profiling activity - Automatic data processing, human responsibilities - The Data Protection Officer and DP Authorities - Civil and criminal protection of privacy - Sanctioning powers and system - Open Data for the public interest - Big data (collection, analysis, processing) and their influence on fundamental rights - Digital Surveillance - Facial Recognition: Open Issues - Disinformation - Artificial Intelligence in the EU law

**Examination:**
MACHINE LEARNING

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Dott. GIOVANNI DA SAN MARTINO

**Credits:** 6 ECTS

**Short program:**
The course cover the topics listed below: - Introduction: Artificial Intelligence and Machine Learning, when and why you should use Machine Learning techniques; the main machine learning paradigms and their applications; the key ingredients of machine learning. - Supervised learning: the foundations and the basic models Linear Regression; space of hypotheses, representation and cost function; optimisation and gradient descent. Linear Classification Models; Logistic Regression; Regularisation and model selection. - Model complexity, its effectiveness and its evaluation Bias-Variance Tradeoff: how to deal with overfitting and underfitting problems; risk minimisation and learning theory; performance evaluation measures, examples and applications; diagnosing and debugging machine learning systems. - Supervised learning: neural networks and advanced models Artificial Neural Networks; perceptron, multilayer neural networks and deep learning; parameters learning, backpropagation and gradient descent. Support Vector Machines; kernel methods and nonlinear classification. "Alternative" approaches: non-parametric methods (k-NN) and their applications; decision trees and random forest. - Unsupervised learning Clustering: K-Means and the main approaches; PCA and dimensionality reduction. - Introduction to Recommender Systems and their application

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP8082660/NO

OPTIMIZATION FOR DATA SCIENCE

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** Prof. FRANCESCO RINALDI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of - Real Analysis and Calculus; - Linear Algebra; - Probability theory.

**Short program:**
1. Convex sets and convex functions (a) Convexity: basic notions; (c) Convex functions: Basic notions and properties (gradients, Hessians..); 2. Unconstrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Gradient-type methods; (d) Block coordinate gradient methods; (e) Stochastic optimization methods; 3. Constrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Polyhedral approximation methods; (d) Gradient projection methods; 4. Large scale network optimization (a) Network models in data science; (b) Methods for distributed optimization.

**Examination:**
- Written exam - Homeworks - Project (Optional) 1) Homeworks will periodically be assigned based on reading and lecture and will be due at given deadlines. 2) Written exam consists of 4 open questions. 3) Project (optional) can be requested to better analyze specific topics. Written exams represents 85% of grade. Homeworks represent 15% of grade. Project can integrate/replace the written exam.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079229/NO

PROCESS MINING

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. MASSIMILIANO DE LEONI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of algorithms, data structure and programming, as acquired in course "Fundamental of Information Systems" o in Bachelor's degrees in Computer Science or similar

**Short program:**
The course will cover the topics listed below: 1. MODELING VIA PETRI NETS - Basic concepts of Petri nets - Usage of Petri Nets to model business processes - Structural analysis of Petri Nets - Soundness of business process models: Principles and Verification - Usage of Woped as software tool to model and check the soundness of process models. 2. PROCESS MINING - Introduction to Process Mining and Event Logs - Basic Techniques for Process Discovery and Limitations - Advanced Techniques for Process Discovery: Heuristic Miner and Region Miner - Conformance checking based on token replay - Conformance checking based on alignments - Mining the Additional Perspectives on Decision, Time and Resource - Social Network
Analysis - Usage of open-source and commercial software tools for the analysis of business processes through Process Mining. 3. BUSINESS PROCESS SIMULATION - Principle and Methodologies for simulation: definitions of warm-up and cool-down intervals, management of the simulation stochasticity via multiple, independent runs, analysis of the outcome - Definitions of the elements of a scenario of business process simulation: arrival rate, branching probabilities, resource pools, activity-duration probability distributions - Usage of BPMN for the specification of business process simulation models - Use of Process Mining to mine business process simulation models - Methodologies for the definition of "What-if" scenarios - Usage of BIMP as software tool to simulate business processes.

Examination:
Written Exam and Project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079235/NO

STATISTICAL LEARNING

Lecturer: Prof. ALBERTO ROVERATO

Prerequisites: basic probability theory; multivariable calculus; linear algebra; basic computing skills

Examination: written test and project work

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079226/NO

Moduli del C.I.:
Statistical Learning 1 (Mod. A)
Statistical Learning 2 (Mod. B)

STATISTICAL LEARNING 1 (MOD. A)

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:
Part 1: - Data: summary statistics, displaying distributions; exploring relationships - Estimation: point estimation; the sampling distribution of an estimator; accuracy of estimation; interval estimation - Hypothesis testing - Likelihood: the likelihood, likelihood for several parameters - Estimation: maximum likelihood estimation; properties of maximum likelihood estimates

STATISTICAL LEARNING 2 (MOD. B)

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:

STOCHASTIC METHODS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FERRANTE

Credits: 6 ECTS

Prerequisites: Basic notions of differential and integral calculus, linear algebra and probability.

Short program:
1. Probability reviews. • discrete and continuous distributions • random variables, expectation and conditional expectation • Law of Large Numbers and Chernoff Bounds • approximation of probability distributions. 2. Markov chains and random walks • Discrete time Markov Chain and their stationary distribution • Monte Carlo (MCMC), convergence of MCMC-based algorithms. 3. High dimensional Gaussian random variables • Gaussian Annulus Theorem • Nearly orthogonal of independent random variables. 4. Introduction to Random Networks

Examination:
**BIG DATA COMPUTING**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** Prof. ANDREA ALBERTO PIETRACAPRINA

**Credits:** 6 ECTS

**Prerequisites:**
The course has the following prerequisites: competences regarding the design and analysis of algorithms and data structures, knowledge of fundamental notions of probability and statistics, and programming skills in Java or Python.

**Short program:**
The course will cover the following topics: Introduction to the Big Data phenomenon. Distributed frameworks: MapReduce, Apache Spark. Clustering for data analysis and summarization. Analysis of data streams. Dimensionality reduction. Association Analysis.

**Examination:**
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 2-3 students, and of an individual written test comprising both theory questions and exercises.

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**BIOINFORMATICS**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. GIORGIO VALLE

**Credits:** 6 ECTS

**Prerequisites:**
There are no particular prerequisites other than what it is expected from a master student in informatics. However, a basic knowledge of genetics and molecular biology will help in the understanding of the biological motivations of bioinformatics. The course is in English, therefore the students should have a reasonable command of spoken and written English.

**Short program:**
This is a six credits course: five credits will be from lessons while one credit will be from practical activities, either the implementation and of some algorithm or the in-depth investigation of the literature on given arguments. The lessons are divided in three main parts. The first part is an extensive introduction on Biology presented as a scientific field centered on Information. The mechanisms that facilitate the transmission and evolution of biological information is used to introduce some biological problems that require computational approaches and bioinformatics tools. The second part of the course describes the main algorithms used for the alignment of biological sequences, including those designed for “next generation sequencing”. The algorithms used for de novo genomic assembly are also described. Finally, the third part of the course covers several aspects of bioinformatics related to functional genomics, such as the analysis of transcription, gene prediction and annotation, the search of patterns and motifs and the prediction of protein structures. The role of Bioinformatics in individual genomic analysis and personalized medicine is also discussed.

**Examination:**
The exam will be articulated into three parts: 1) a practical session in which the student must describe a project of data analysis, that must be submitted at least two days before the date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the exam day, 3) an oral discussion in which the student must describe his/her project and answer questions on the topics of the course. A continuous process of assessment will be carried out throughout the course, to verify the level of understanding of the students.

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**BIOLOGICAL DATA**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Prof. DAMIANO PIOVESAN

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of computer science, optimization methods and machine learning. Python programming language.

**Short program:**
The course consists of four parts, corresponding to different types of biological data: 1) Sequences 1.1) DNA and proteins 1.2) Databases 1.3) Alignments 2) Structures 2.1) Protein folding 2.2) Databases 2.3) Structure prediction 3) Literature 3.1) Scientific papers 3.2) Databases 3.3) Text mining 3.4) Function 4) Interaction networks 4.1) Non-globular regions 4.2) Biological interactions 4.3) Databases 4.4) Emergent properties

Examination:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Mid-term test (ca. 17%) Open questions 2) Project (ca. 50%) Coding and analysis of biological dataset; written report 3) Final exam (ca. 33%) Oral, with questions on project and course

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079337/NO

BUSINESS ECONOMIC AND FINANCIAL DATA

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof.ssa MARIANGELA GUIDOLIN

Credits: 6 ECTS

Prerequisites:
Program of Statistical Learning course

Short program:
- General introduction to business, economic and financial data
- Preliminary concepts and illustrative examples
- Moving beyond the linear model: Linear regression model: main ideas and assumptions
- Nonlinear regression models for new product growth: Beyond linearity: regression splines, local regression, generalized additive models (GAM)
- Tree-based methods: Regression trees, Bagging, Boosting
- Time series analysis: Exponential Smoothing and ARIMA models

Examination:
- Practical exam
- Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079231/NO

COGNITION AND COMPUTATION

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO ZORZI

Credits: 6 ECTS

Prerequisites:
The course requires preliminary knowledge of machine learning and probability theory. Familiarity with basic concepts of cognition and neuroscience may facilitate the understanding of the topics covered by the course.

Short program:
1. Introduction: computational and mathematical modeling in cognitive science and cognitive neuroscience. Overview of symbolic, emergentist and probabilistic approaches to simulate human cognition. 2. Probabilistic models of cognition: basics of Bayesian inference and probabilistic graphical models; inductive learning; probabilistic programming. 3. Neural network models of cognition: basics of neural computation; learning in neural networks; deep learning architectures. 4. Information coding in cognitive architectures: efficient coding, probabilistic coding, predictive coding. 5. Case studies: models of human perception and concept learning; language acquisition and language understanding; causal reasoning and decision making.

Examination:
Examination will consist in a written exam including open questions and multiple-choice questions. Each student will also be required to write an individual essay (or project report) assigned during the course and submit it (through the course Moodle) no later than the day before the written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0089498/NO

COGNITIVE, BEHAVIORAL AND SOCIAL DATA

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. GIUSEPPE SARTORI

Credits: 6 ECTS

Prerequisites:
Notions of machine learning

Short program:
The aim of the course is to provide an overview of concrete data science applications in behavioural science, cognitive science, neuroscience and social science. The course gives an underground of methods to analyse and learn behavioural, cognitive and brain functional/structural data. It provide a review of studies, with several examples of recent practical applications, also according with the students interests. Limits in the state of the art and future directions will be discussed. The course contents are the following: • Basic concepts of human brain cognitive functioning (attention, memory, learning, language, etc.) and how to measure it • Basic concepts of social psychology and social behaviour (preferences, judgments, group identity, etc.) and how to measure it • What are behavioural measures and how to measure them (e.g., RT); implicit and explicit behavioural measures (e.g., the IAT) • Extracting and predicting information from behaviour (e.g. lie detection, predicting malicious behaviour from social networks activity, fake online reviews, security applications, etc.) • What are psychophysiological measures and how to measure them (e.g., HR variability, SCR, facial expressions, EEG, fMRI, etc.) • Extracting and predicting information from psychophysiological measures • Extracting and predicting information from brain activity: mind reading applications (e.g., psychopathology detection, reconstructing visual experiences from brain activity, brain computer interface devices, etc.) • Social and behavioural data for marketing application (e.g. skill assessment and prediction, psychology of taxes, predicting preferences and personality from social networks activity, sentiment analysis, etc.) • Issue related to the application of machine learning in behavioural research (e.g. the problem of reproducibility)

Examination:
Oral exam and project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079219/NO
Short program:
The course covers the full spectrum of information retrieval methodologies, starting from foundational approaches to offline system development, continuing with the new techniques for machine learning for search, and concluding with the most recent advances for online system development. More in detail, the course will address: + Offline system development: the student learns the foundations of information retrieval, covering text processing and indexing for efficient access and retrieval; and, basic and advanced retrieval models to match natural language queries to documents. The student learns how to evaluate the performance of an information retrieval system in terms of effectiveness, how to tune the different system parameters, and how to statistically validate the experimental results. Finally, the student learns the principles of Web search engines, Web crawling, search engine optimization, and knowledge graphs and semantic search. + Machine learning for search: the student learns the advanced applications of machine learning techniques for information search and filtering, namely recommender systems, learning-to-rank, and neural information retrieval. + Online system development: the student learns the principles of retrieval as interaction, i.e. the basics of search as a learning process for man and machine, by leveraging click models, A/B testing, interleaved comparison, and online learning-to-rank.

Examination:
Individual written Exam with questions and exercises on the topics covered during the lectures (Moodle quiz). Project to design, develop, implement, code, document, and evaluate an actual information retrieval application, carried out in student groups via homeworks: + git repository containing the project source code and all the related material + report on the contents and state of the project as well as the evaluation of the performance of the developed system; + oral presentation of the project outcomes by using slides; + demo of the developed application.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SC01123268/NO

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**KNOWLEDGE AND DATA MINING**

Master's degree in **DATA SCIENCE ORD. 2017**, Second semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
Suggested basic knowledge of logics and statistics.

**Short program:**
(A) Logics for knowledge representation: (A.i) introduction to propositional logics, syntax, semantics, decision procedure. Satisfiability, weighted satisfiability, and best satisfiability. (A.ii) First order logics, syntax, semantics, resolution and unification. (A.iii) Fuzzy logics, syntax, semantics, and reasoning. (B) statistical relational learning: (B.i) Graphical models (B.ii) Markov Logic Networks (B.iii) Probabilistic prolog, (B.iii) Logic Tensor Networks

**Examination:**
Final examination based on a combination of written examination and project development.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079318/NO

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**LAW AND DATA**

Master's degree in **DATA SCIENCE ORD. 2017**, First semester

**Lecturer:** Dott.ssa ELISA SPILLER

**Credits:** 6 ECTS

**Prerequisites:**
No prerequisites

**Short program:**
All the info about the course are on Moodle - Introduction to Law and Legal Studies - Introduction to the EU Law - Introduction to the EU GDPR - The concept of data; personal, sensitive and economic data; big data - Property of data, choices in the management of data - The right to be forgotten - Civil and criminal aspects of profiling activity - Automatic data processing, human responsibilities - The Data Protection Officer and DP Authorities - Civil and criminal protection of privacy - Sanctioning powers and system - Open Data for the public interest - Big data (collection, analysis, processing) and their influence on fundamental rights - Digital Surveillance - Facial Recognition: Open Issues - Disinformation - Artificial Intelligence in the EU law

**Examination:**
Written Exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079399/NO

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**MACHINE AND DEEP LEARNING (C.I.)**
Lecturer: Dott. GIOVANNI DA SAN MARTINO

Prerequisites:
The student should be familiar with basic concepts in Mathematics, Probability Theory and Statistics, Linear Algebra, and basic Programming skills.

Examination:
The student must develop a small project and present a written report. The exam will consist of a short presentation and discussion of the project carried out, and an oral exam about all the topics covered in class.

More information:
https://en.didattica.unipd.it/.../000ZZ/SCQ0093685/NO

Moduli del C.I.:
Machine and deep learning (Mod. A)
Machine and deep learning (Mod. B)

MACHINE AND DEEP LEARNING (MOD. A)
Lecturer: Dott. GIOVANNI DA SAN MARTINO

Master’s degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:
The course cover the topics listed below: - Introduction: Artificial Intelligence and Machine Learning, when and why you should use Machine Learning techniques; the main machine learning paradigms and their applications; the key ingredients of machine learning. - Supervised learning: the foundations and the basic models Linear Regression; space of hypotheses, representation and cost function; optimisation and gradient descent. Linear Classification Models; Logistic Regression; Regularisation and model selection. - Model complexity, its effectiveness and its evaluation Bias-Variance Tradeoff; how to deal with overfitting and underfitting problems; risk minimisation and learning theory; performance evaluation measures, examples and applications; diagnosing and debugging machine learning systems. - Supervised learning: neural networks and advanced models Artificial Neural Networks; perceptron, multilayer neural networks and deep learning; parameters learning, backpropagation and gradient descent. Support Vector Machines; kernel methods and nonlinear classification. "Alternative" approaches: non-parametric methods (k-NN) and their applications; decision trees and random forest. - Unsupervised learning Clustering: K-Means and the main approaches; PCA and dimensionality reduction. - Introduction to Recommender Systems and their applications

MACHINE AND DEEP LEARNING (MOD. B)
Lecturer: Prof. ALESSANDRO SPERDUTI

Master’s degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:
The topics covered in the course are as follows: - Introduction to the course contents; - Deep Feedforward Networks; - Regularization for Deep Learning; - Optimization for training Deep Models; - Basic concepts for Convolutional Neural Networks; - Recurrent Neural Networks and Transformers for sequence modelling; - Autoencoder - Deep Generative Models; - TensorFlow.

OPTIMIZATION FOR DATA SCIENCE
Lecturer: Prof. FRANCESCO RINALDI

Master’s degree in DATA SCIENCE ORD. 2017, Second semester

Credits: 6 ECTS

Prerequisites:
Basic knowledge of - Real Analysis and Calculus; - Linear Algebra; - Probability theory.

Short program:
1. Convex sets and convex functions (a) Convexity: basic notions; (c) Convex functions: Basic notions and properties (gradients, Hessians...); 2. Unconstrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Gradient-type methods; (d) Block coordinate gradient methods; (e) Stochastic optimization methods; 3. Constrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Polyhedral approximation methods; (d) Gradient projection methods; 4. Large scale network optimization (a) Network models in data science; (b) Methods for distributed optimization.

Examination:
- Written exam - Homeworks - Project (Optional) 1) Homeworks will periodically be assigned based on reading and lecture and will be due at given deadlines. 2) Written exam consists of 4 open questions. 3) Project (optional) can be requested to better analyze specific topics. Written exams represent 85% of grade. Homeworks represent 15% of grade. Project can integrate/replace the written exam.
PROCESS MINING

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MASSIMILIANO DE LEONI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of algorithms, data structure and programming, as acquired in course "Fundamental of Information Systems" or in Bachelor's degrees in Computer Science or similar

Short program:
The course will cover the topics listed below: 1. MODELING VIA PETRI NETS - Basic concepts of Petri nets - Usage of Petri Nets to model business processes - Structural analysis of Petri Nets - Soundness of business process models: Principles and Verification - Usage of Woped as software tool to model and check the soundness of process models. 2. PROCESS MINING - Introduction to Process Mining and Event Logs - Basic Techniques for Process Discovery and Limitations - Advanced Techniques for Process Discovery: Heuristic Miner and Region Miner - Conformance checking based on token replay - Conformance checking based on alignments -Mining the Additional Perspectives on Decision, Time and Resource - Social Network Analysis - Usage of open-source and commercial software tools for the analysis of business processes through Process Mining. 3. BUSINESS PROCESS SIMULATION - Principle and Methodologies for simulation: definitions of warm-up and cool-down intervals, management of the simulation stochasticity via multiple, independent runs, analysis of the outcome - Definitions of the elements of a scenario of business process simulation: arrival rate, branching probabilities, resource pools, activity-duration probability distributions - Usage of BPMN for the specification of business process simulation models - Use of Process Mining to mine business process simulation models - Methodologies for the definition of "What-if" scenarios - Usage of BIMP as software tool to simulate business processes.

Examination:
Written Exam and Project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079229/NO

STATISTICAL LEARNING

Lecturer: Prof. ALBERTO ROVERATO

Prerequisites:
basic probability theory; multivariable calculus; linear algebra; basic computing skills

Examination:
written test and project work

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079226/NO

Moduli del C.I.:
Statistical Learning 1 (Mod. A)
Statistical Learning 2 (Mod. B)

STATISTICAL LEARNING 1 (MOD. A)

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:
Part 1: - Data: summary statistics, displaying distributions; exploring relationships - Estimation: point estimation; the sampling distribution of an estimator; accuracy of estimation; interval estimation - Hypothesis testing - Likelihood: the likelihood, likelihood for several parameters - Estimation: maximum likelihood estimation; properties of maximum likelihood estimates

STATISTICAL LEARNING 2 (MOD. B)

Lecturer: Prof. ALBERTO ROVERATO

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS
STOCHASTIC METHODS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FERRANTE

Credits: 6 ECTS

Prerequisites:
Basic notions of differential and integral calculus, linear algebra and probability.

Short program:
1. Probability reviews. • discrete and continuous distributions • random variables, expectation and conditional expectation • Law of Large Numbers and Chernoff Bounds • approximation of probability distributions. 2. Markov chains and random walks • Discrete time Markov Chain and their stationary distribution • Monte Carlo (MCMC), convergence of MCMC-based algorithms. 3. High dimensional Gaussian random variables • Gaussian Annulus Theorem • Nearly orthogonal of independent random variables. 4. Introduction to Random Networks

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079197/NO

VISION AND COGNITIVE SYSTEMS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. LAMBERTO BALLAN

Credits: 6 ECTS

Prerequisites:
The student should have basic knowledge of computer programming and algorithms, as well as mathematics, probability theory and statistics, linear algebra. It is also advisable to be familiar with basic concepts in machine learning and pattern recognition.

Short program:
The course will cover the topics listed below: - Introduction: From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges. - Cognitive Services: Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies. - Machine Learning and applications: Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias. - Early Vision and Image Processing: Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching. - Visual Recognition and beyond: "Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm. - Hands-on Practicals: What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

Examination:
The student is expected to develop, in agreement with the instructor, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project, and answer a few questions about the topics addressed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ1097939/NO

COGNITIVE, BEHAVIORAL AND SOCIAL DATA

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. GIUSEPPE SARTORI

Credits: 6 ECTS

Prerequisites:
Notions of machine learning

Short program:
The aim of the course is to provide an overview of concrete data science applications in behavioural science, cognitive science, neuroscience and social science. The course gives an underground of methods to analyse and learn behavioural, cognitive and brain functional/structural data. It provide a review of studies, with several examples of recent practical applications, also according with the students interests. Limits in the state of the art and future directions will be discussed. The course contents are the following: • Basic concepts of human brain cognitive functioning (attention, memory, learning, language, etc.) and how to measure it • Basic concepts of social psychology and social behaviour (preferences, judgments, group identity, etc.) and how to measure it • What are behavioural measures and how to measure them (e.g., RT); implicit and explicit behavioural measures (e.g., the IAT) • Extracting and predicting information from behaviour (e.g. lie detection, predicting malicious behaviour from social networks activity, fake online reviews, security applications, etc.) • What are psychophysiological measures and how to measure them (e.g., HR variability, SCR, facial expressions, EEG, IRM, etc.) • Extracting and predicting information from psychophysiological measures • Extracting and predicting information from brain activity: mind reading applications (e.g., psychopathology detection, reconstructing visual experiences from brain activity, brain computer interface devices, etc.) • Social and behavioural data for marketing application (e.g. skill assessment and prediction, psychology of taxes, predicting preferences and personality from social networks activity, sentiment analysis, etc.) • Issue related to the application of machine learning in behavioural research (e.g. the problem of reproducibility)

Examination:
Oral exam and project

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079219/NO

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**FINANCIAL MATHEMATICS FOR DATA SCIENCE**

**Lecturer:** Prof. MARTINO GRASSELLI

**Credits:** 6 ECTS

**Prerequisites:**
Stochastic analysis

**Short program:**

**Examination:**
Final examination based on: Written and oral examination.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093689/NO

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**FUNDAMENTALS OF INFORMATION SYSTEMS**

**Lecturer:** Prof. GIORGIO MARIA DI NUNZIO

**Credits:** 12 ECTS

**Prerequisites:**
The student should have basic knowledge of computer programming and problem solving skills.

**Short program:**
The course is structured into 3 submodules: - Python Programming (for Data Science) This submodule provides students with the foundational coding skills they need as data scientists. First, the basics of the Python programming language are covered (i.e., built-in data types, functions, I/O, etc.) along with the environment which is used throughout the class (i.e., Jupyter Notebook). Afterwards, students will dig into a set of the most up-to-date data science Python packages; those are: numpy/scipy (for numerical/scientific computing), pandas (for data manipulation), matplotlib/seaborn (for data visualization), and finally scikit-learn (for learning from data). - Databases This submodule is dedicated to data storage, and it covers the following topics: Relational databases, Logical and Physical Design of a Relational Database. SQL Language: Data Definition and Data Manipulation Language, Database Query The PostgreSQL database: Creation and Definition of a Database, SQL Queries. Non Relational databases, graph databases, Cypher query language, Neo4J database: Creation and Definition of a Database, Graph Query Language. - Algorithmic Methods: Preliminaries: definition of problem, instance, solution, algorithm. Models of computation, Analysis of algorithms: correctness and running time. Asymptotic analysis. Basic data structures: lists, stacks, queues. Trees and their properties. Dictionaries and their implementation, Priority queues. Graphs: representation of graphs. Basic properties. Graph searches and applications. Divide and Conquer paradigm: the use of recursion. Case study: sorting. Eventually, at the end all the modules, students will be able to implement all the stages of a typical machine learning pipeline: from collecting data to building predictive models for solving efficiently a data analysis/prediction problem.
GAME THEORY

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: ELVINA GINDULLINA

Credits: 6 ECTS

Prerequisites: A course, even a basic one, on probability theory.

Short program:

Examination:
For all the students, in any event the exam includes a mandatory open-book written test, containing problems of game theory focusing on different topics of the course. Every exercise involves multiple questions, typically three. For the students with regular attendance to the course, the exam may also involve, if they want so, the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer. If the written test is sufficient, students can directly finalize the passing score. Projects can be discussed with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). The project discussion integrates the mark of the written test.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079401/NO

HIGH DIMENSIONAL PROBABILITY FOR DATA SCIENCE

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FORMENTIN

Credits: 6 ECTS

Prerequisites: A basic course in probability theory, basic knowledges of stochastic processes and a good command of undergraduate linear algebra. Some familiarity with metric, normed and Hilbert spaces and linear operators will be useful but not essential. Useful background will be reviewed during the course when needed.

Short program:
The course will cover as many aspects of the following topics as possible: - Preliminaries on random variables. Classical inequalities and limit theorems. - Concentration of sums of independent random variables: Hoeffding, Chernoff and Bernstein inequalities, sub-Gaussian and sub-exponential distributions. Applications to random graphs. - Random vectors in high dimension: concentration of the norm, covariance matrices and principal component analysis, high dimensional distributions, sub-Gaussian distributions in higher dimensions. Applications: Grothendieck's Inequality and semidefinite programming and maximum cut for graphs. - Non-asymptotic analysis of random matrices: nets, covering and packing numbers, bounds on sub-Gaussian matrices, covariance estimation and clustering. Applications to error correcting codes, community detection in networks and covariance estimation and clustering. - Concentration of Lipschitz functions on the sphere, Johnson--Lindenstrauss theorem, matrix Bernstein inequality, community detection in sparse networks. - Random processes: basic concepts, Slepian's inequality, bounds on Gaussian matrices, Sudakov's minoration inequality, Gaussian width, random projections of sets. - Chaining: Dudley's inequality, empirical processes, Vapnik-Chervonenkis dimension with applications to statistical learning theory.

Examination:
Weekly homework and oral exam. A final project is also possible.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093688/NO

HUMAN DATA ANALYTICS
MACHINE AND DEEP LEARNING (C.I.)

Lecturer: Dott. GIOVANNI DA SAN MARTINO

Prerequisites:
The student should be familiar with basic concepts in Mathematics, Probability Theory and Statistics, Linear Algebra, and basic Programming skills.

Examination:
The student should be familiar with basic concepts in Mathematics, Probability Theory and Statistics, Linear Algebra, and basic Programming skills.

More information:
https://en.didattica.unipd.it/offer/2022/LM/SC/SC2377/000ZZ/SCP7079397/NO

MACHINE AND DEEP LEARNING (MOD. A)

Lecturer: Dott. GIOVANNI DA SAN MARTINO

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester
Credits: 12 ECTS

Short program:
The course covers the topics listed below:
- Introduction: Artificial Intelligence and Machine Learning, when and why you should use Machine Learning techniques; the main machine learning paradigms and their applications; the key ingredients of machine learning.
- Supervised learning: the foundations and the basic models Linear Regression; space of hypotheses, representation and cost function; optimisation and gradient descent. Linear Classification Models; Logistic Regression; Regularisation and model selection. Model complexity, its effectiveness and its evaluation Bias-Variance Tradeoff; how to deal with overfitting and underfitting problems; risk minimisation and learning theory; performance evaluation measures, examples and applications; diagnosing and debugging machine learning systems.
- Supervised learning: neural networks and advanced models Artificial Neural Networks; perceptron, multilayer neural networks and deep learning; parameters learning, backpropagation and gradient descent. Support Vector Machines; kernel methods and nonlinear classification.
- "Alternative" approaches: non-parametric methods (k-NN) and their applications; decision trees and random forest.
- Unsupervised learning Clustering; K-Means and the main approaches; PCA and dimensionality reduction.
- Introduction to Recommender Systems and their application

MACHINE AND DEEP LEARNING (MOD. B)

Lecturer: Prof. ALESSANDRO SPERDUTI

Master's degree in DATA SCIENCE ORD. 2017, First and Second semester

Credits: 12 ECTS

Short program:
The topics covered in the course are as follows:
- Introduction to the course contents;
- Deep Feedforward Networks;
- Regularization for Deep Learning;
- Optimization for training Deep Models;
- Basic concepts for Convolutional Neural Networks;
- Recurrent Neural Networks and Transformers for sequence modelling;
- Autoencoder - Deep Generative Models;
- TensorFlow.

MATHEMATICAL CELL BIOLOGY

Lecturer: Prof. MORTEN GRAM PEDERSEN

Master's degree in DATA SCIENCE ORD. 2017, First semester

Credits: 6 ECTS

Prerequisites:
Knowledge of differential equations, linear algebra, probability theory.

Short program:

Examination:
Written exam (theory and computer exercises).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCQ0093722/NO

MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA

Lecturer: Dott. WOLFGANG ERB

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Credits: 6 ECTS

Prerequisites:
Basic knowledge in mathematical analysis and linear algebra Background in linear algebra and matrix theory: - Vector spaces, linear independence, basis in vector spaces - Inner product spaces and orthogonality - Type of matrices: diagonal, triangular, symmetric, positive definite - Spectrum of matrices: eigenvalues, eigenvectors and eigenspaces - Matrix factorizations: LU, Cholesky, QR - Solution of linear systems of equations Background in mathematical analysis - Metric and normed linear spaces - Continuity of functions and operators - Sequences and convergence Basic programming skills in Matlab or Python.
Short program:
1. Ranking with eigenvectors • Recapitulation of important results from linear algebra • The vector iteration: calculation of dominant eigenpairs • Ranking of web pages: PageRank and Hits. 2. Numerical methods for large scale linear systems • Krylov subspace methods for sparse systems of equations: GMRES and MINRES • Krylov subspace methods for the computation of matrix functions 3. Spectral graph theory • Graphs, the graph Laplacian, graph signals, the Cheeger constant • The graph Fourier transform, graph convolution, filtering and decomposition of graph signals • Dimensionality reduction with Laplacian eigenmaps • Centrality on graphs 4. Clustering algorithms • k-center clustering and hierarchical k-center clustering • The k-means algorithm • Spectral clustering 5. Low rank matrix approximations • Singular value decomposition (SVD): basic properties, numerical computation and best rank-k approximation • Principal component analysis and dimensionality reduction • Latent factor models and recommender systems • Matrix factorizations beyond SVD: Funk SVD and nonnegative matrix factorizations. 6. Multiway Data Analysis • Tensors and tensor decomposition • Higher order singular value decomposition (HOSVD): definition and numerical computation • Applications: Face Recognition Using tensor SVD and Tensor Data Fusion • Kernel methods for data analysis

Examination:
Written examination at the end of the course. Regular homework assignments during the lecture period will provide additional feedback and extra credits for the final exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079406/NO

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Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. TOMASO ERSEGHE

Credits: 6 ECTS

Prerequisites:
This course has the following prerequisites: knowledge in Probability Theory, and Computer Programming in any language which is appropriate for network analysis (Python preferred, but Matlab, R, C, or Java would do); knowledge in Calculus and Linear Algebra; any further knowledge of networking processes in economics, biology, telecommunications, semantics, etc. might be useful.

Short program:
The module will cover the following topics: 1. Basic network properties - graphs, adjacency matrix, degree distribution, connectivity, distance and diameter, clustering coefficient. 2. Network models - Erdos-Renyi model; Random graphs with general degree distribution; Power laws and scale free networks; Small world phenomena; Hubs; Network generation and expansion; Barabasi-Albert model; Preferential attachment. 3. Centrality measures: Hubs and authorities; PageRank: teleportation, topic specific ranking, proximity measures, trust rank; betweenness, closeness, eigenvector and Katz centralities. 4. Other analytics: homophily (assortativity), polarisation, innovation, clustering, robustness, link prediction. 5. Community detection - Girvan Newman method and betweenness; Louvain modularity optimisation; Spectral clustering; Consensus clustering; Model-driven algorithms; Algorithms for overlapping communities. 6. Network representation - Gephi and R/Python graphical functions; rationale of force directed graph layout algorithms. 7. Twitter Lab - How to extract a semantic network from Twitter data.

Examination:
The verification of the expected knowledge and skills is carried out with the DEVELOPMENT OF A PROJECT aimed at verifying the ability to apply theory in interdisciplinary contexts, and which requires: the choice, the collection of data, and the analysis of a different network for each student; computer implementation (in any programming language known to the student) of the algorithms required for the analysis; the drafting of an essay; the oral presentation of the main project outcomes. A bonus of up to 3 points is available for attending students that take part to an INTERDISCIPLINARY PROJECT with social science students attending the twin course on SOCIAL NETWORK ANALYSIS.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP8082723/NO

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Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof. FRANCESCO RINALDI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of - Real Analysis and Calculus; - Linear Algebra; - Probability theory.

Short program:
1. Convex sets and convex functions (a) Convexity: basic notions; (c) Convex functions: Basic notions and properties (gradients, Hessians,); 2. Unconstrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Gradient-type methods; (d) Block coordinate gradient methods; (e) Stochastic optimization methods; 3. Constrained convex optimization (a) Models in data science; (b) Characterizations of optimal sets; (c) Polyhedral approximation methods; (d) Gradient projection methods; 4. Large scale network optimization (a) Network models in data science; (b) Methods for distributed optimization.

Examination:
- Written exam - Homeworks - Project (Optional) 1) Homeworks will periodically be assigned based on reading and lecture and will be due at given deadlines. 2) Written exam consists of 4 open questions. 3) Project (optional) can be requested to better analyze specific topics. Written exams represents...
STATISTICAL LEARNING

**Lecturer:** Prof. ALBERTO ROVERATO

**Prerequisites:**
- basic probability theory; multivariable calculus; linear algebra; basic computing skills

**Examination:**
- written test and project work

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079229/NO

**Moduli del C.I.:**
- Statistical Learning 1 (Mod. A)
- Statistical Learning 2 (Mod. B)

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**STATISTICAL LEARNING 1 (MOD. A)**

**Lecturer:** Prof. ALBERTO ROVERATO

Master's degree in **DATA SCIENCE ORD. 2017**, First and Second semester

**Credits:** 12 ECTS

**Short program:**
- Part 1: - Data: summary statistics, displaying distributions; exploring relationships; estimation: point estimation; the sampling distribution of an estimator; accuracy of estimation; interval estimation; hypothesis testing; likelihood: the likelihood, likelihood for several parameters; estimation: maximum likelihood estimation; properties of maximum likelihood estimates

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**STATISTICAL LEARNING 2 (MOD. B)**

**Lecturer:** Prof. ALBERTO ROVERATO

Master's degree in **DATA SCIENCE ORD. 2017**, First and Second semester

**Credits:** 12 ECTS

**Short program:**
- Part 2: - Models: normal linear models; analysis of variance, analysis of covariance, inference for linear models; generalized linear models; inference for generalized linear models; classification: logistic regression classifier, linear discriminant analysis, quadratic discriminant analysis; cross validation and variable selection; shrinkage methods: ridge regression, lasso regression; networks: undirected graphical models

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**STATISTICAL METHODS FOR HIGH DIMENSIONAL DATA**

**Lecturer:** Prof. BRUNO SCARPA

**Credits:** 6 ECTS

**Prerequisites:**
- Statistical learning, Stochastic methods

**Short program:**
- Every year some of the following topics will be presented, according also to the preferences of the students.
  1. REGRESSION MODELS FOR HIGH-DIMENSIONAL DATA
     1.1 Incremental algorithms with limited memory, stochastic gradient descent, inference
     1.2 Sparsity, penalization inducing sparsity
     1.3 Recall of Lasso and Elastic-Net for GLM
     1.4 Extensions: adaptation, fusion, dealing with categorical variables
     1.5 Group LASSO
     1.6 Non-convex penalties
  2. STATISTICAL ANALYSIS OF NETWORK DATA
     2.1 Introduction to network structures of data
     2.2 Network and nodes indicators
     2.3 Community detection
     2.4 Basics statistical models and inference (Erdos-Renyi, p1, ERGM)
     2.5 Bayesian models (Stochastic block models, Latent space models)
  3. COMPUTATIONAL ISSUES

**Examination:**
- Practical and oral exams

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079226/NO
STOCHASTIC METHODS

Master's degree in DATA SCIENCE ORD. 2017, First semester

Lecturer: Prof. MARCO FERRANTE

Credits: 6 ECTS

Prerequisites:
Basic notions of differential and integral calculus, linear algebra and probability.

Short program:
1. Probability reviews: • discrete and continuous distributions • random variables, expectation and conditional expectation • Law of Large Numbers and Chernoff Bounds • approximation of probability distributions. 2. Markov chains and random walks • Discrete time Markov Chain and their stationary distribution • Monte Carlo (MCMC), convergence of MCMC-based algorithms. 3. High dimensional Gaussian random variables • Gaussian Annulus Theorem • Nearly orthogonal of independent random variables. 4. Introduction to Random Networks

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079197/NO

STRUCTURAL BIOINFORMATICS

Master's degree in DATA SCIENCE ORD. 2017, Second semester

Lecturer: Prof. DAMIANO PIOVESAN

Credits: 6 ECTS

Prerequisites:
Basic knowledge of optimization methods and machine learning. Python programming language.

Short program:

Examination:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis) 1) Written midterm tests with theoretical and practical questions (ca. 20%) 2) Software project (ca. 40%) 3) Project presentation and critical evaluation (ca. 40%)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2377/000ZZ/SCP7079278/NO

ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021

ANALYSIS OF MINERAL RESOURCES AND INDUSTRIAL DERIVATIVES

Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof.ssa MARIA CHIARA DALCONI

Credits: 6 ECTS

Prerequisites:
Essentials of mineralogy and analytical methods.

Short program:
1) Industrial clay-based ceramics: raw materials and their characterisation, production processes, classification of ceramic products and their physical properties. Case studies: clay minerals; traditional bricks; new mix-design with recycled materials. 2) modern hydraulic binders (Portland cement):
production process, characterization, cement classification, brief introduction to environmental issues related to cement and concrete production. 3) Asbestos containing wastes 4) X-ray powder diffraction: underlying theory, sample preparation and instrumental geometries, qualitative and quantitative analysis, analytical protocols for clay-minerals identification, advanced analysis of diffraction data (Rietveld method). Cases studies: clinker and cement, clay minerals, samples proposed by students. 5) image processing of 2D (SEM-BSE, PLM) images, and multispectral images (microchemical maps) for textural features (sand, matrix, pores) quantification and morphometric analysis. Case studies: ceramic materials, mortar-based materials, asbestos, and comparison with porous rocks.

Examination:
1) practical test (2 hours) including: a) quantitative phase analysis of a diffraction pattern and b) image processing of a SEM-BSE image; 2) oral exam

More information:

### ANTHROPOCENE SEDIMENTS AND ENVIRONMENTS

Master's degree in **ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021**, First semester

**Lecturer:** Prof. MASSIMILIANO GHINASSI

**Credits:** 6 ECTS

**Prerequisites:**
Basic view of geology and the main geological processes, geomorphology, sedimentary geology, stratigraphy and paleontology. Comprehensive knowledge of sedimentology (depositional dynamics and stratal architecture of different depositional environments)

**Short program:**
Anthropocene historical genesis and possible definitions: an interdisciplinary approach Establishing beginning of Anthropocene -chemostratigraphic signals - lithostratigraphic signals -Technofossils and Technostratigraphy - Societal implication Measuring microplastics in sediments: - sampling methodologies - processing tools for extraction of microplastics particles - physical properties and classification - analytical techniques for quantification and identification The source to sink perspective and the depositional environments in the Anthropocene time - microplastic production (the source system) and their hydrodynamic behavior - alluvial and coastal environments (the transfer system) - deep marine environments (the sink)

**Examination:**
Witten test. The test will be based on a number of questions, which will be provided consistently with the topics of the course.

**More information:**

### BASIN ANALYSIS

Master's degree in **ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021**, Second semester

**Lecturer:** Prof. MASSIMILIANO GHINASSI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of Sedimentology, Structural Geology and Geophysics

**Short program:**
1) The foundations of sedimentary basins; classification and plate tectonics. 2) Basins due to lithospheric stretching: rifts and passive margins. 3) Basins due to lithospheric flexure: fordeep, foreland, buckling. 4) Strike-slip and pull-apart basins. 5) Subsidence and thermal history. 6) sequence stratigraphy: basic principles, base level changes and development of systems tracts, key bounding surfaces, parasequences. 7) Case-history: sedimentary basins of the Northern Apennines (Italy)

**Examination:**
The exam consists of an oral test based on questions related to the course and connected with the presentation of a topic agreed with the candidates.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2597/002PD/SCP3051165/NO

### CARBONATE FACIES ANALYSIS FOR PALEOCLIMATE RECONSTRUCTIONS

Master's degree in **ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021**, Second semester

**Lecturer:** Prof. NEREO PRETO

**Credits:** 6 ECTS
Prerequisites: Basic knowledge of sedimentary geology, sedimentology and chemistry.

Short program:
Part 1: carbonate rocks, depositional environments, carbonates and climate - Carbonate rocks in hand sample and under the microscope; the classification of carbonate rocks, or: where does the carbonate come from? - Carbon cycle and precipitation of carbonate sediments in seawater - carbon capture; - The concepts of carbonate factory and carbonate platform; - Types of carbonate platform; - Phanerozoic reefs, and present threats; - the Mg/Ca of seawater and the evolution of carbonate producers; - causes and effects of ocean acidification, today and in the past, i.e.: how ocean aciddification can be identified in the geological record? What are the effects of the surging acidification on the chemistry of seawater and on carbonate-secreting marine organisms? Part 2: Carbonate petrography - Skeletal and inorganic carbonate grains; - Fabrics of carbonate rocks; - Microbial carbonates; - Porosity of carbonate rocks; - Carbonate cements and carbonate diagenesis. Part 3: C and O stable isotopes in carbonates - Introduction to C and O stable isotopes; - Field excursion: logging a carbonate succession, sampling for thin sections and isotopic analyses; - Lab: sampling with dental drill - how to choose components; - Isotopic Ratio Mass Spectrometer: functioning and see the instrument; - Lab: sample preparation and set up of the instrument (preparation of a run); - Lab: representing and interpreting results with cross-plots, plot VS log, etc. and assessment of the diagenetic processes.

Examination:
The exam is based on practicals and a written test. The practicals are reports on the lab activities. The written test will include open questions on the contents of the lectures and labs, to which the student will answer with a brief explanatory text, and/or with schemes and sketches.

More information:

COASTAL ENVIRONMENTS UNDER CLIMATE CHANGE

Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Dott. ALVISE FINOTELLO

Credits: 6 ECTS

Prerequisites: Basic mathematics and physics (Calculus 1 and 2, Experimental Physics).

Short program:
- Morphodynamics and biogemorphodynamics. Short introduction to coastal systems and to their morphodynamic evolution in response to physical and biological forcings (0.5 CFU). - Relative sea level and its variations. Tides, waves, currents, and sediment transport processes in shallow water systems (1.5 CFU). - Morphology and evolution of barrier islands, lagoons, deltas, and estuaries (2.5 CFU). - A case study: The Venice Lagoon and its morphological evolution during the past centuries. Will Venice survive? (0.5 CFU). - General effects of a rising sea level. Natural and anthropogenic forcings. Effects of a changing climate. Effects on lagoons, deltas, and estuaries (1.0 CFU).

Examination:
Written exam (open questions and exercises). Possibility to take a further oral exam.

More information:

DIGITAL GEOLOGICAL MAPPING

Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, Second semester

Lecturer: Prof. GIORGIO PENNACCHIONI

Credits: 6 ECTS

Prerequisites: Basic geological knowledge and geological mapping skill

Short program:
The geological mapping and survey activities are nowadays performed with advanced technical approaches both in the field and at the stage of data analysis. The course will give particular emphasis on small-scale (km-scale or lower) mapping, Digital Outcrop Models reconstructions and analysis and simplified 3D geo-modelling applied on different geological contexts, application of different approaches of close range remote sensing. The main contents can be listed as follows: • Methodology and approaches of high-scale geological mapping in geo-structural, stratigraphic and applied geomorphological contexts; • UAV for geological mapping and softwares for planning UAV flight; • Field Move (and similar) application for digital geological mapping; importing and elaborating data in QGIS; • Photogrammetry, Digital Outcrop Models reconstruction and 3D geological analysis. • Basic concepts and applications of 3D Geological models (e.g. VRGS), and virtual reality geological mapping (VRGS e VR2Planet);

Examination:
Evaluation of the products derived from the practical activities and oral presentation
EARTH INTERIOR AND EVOLUTION

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof. GIORGIO PENNACCHIONI

Credits: 12 ECTS

Prerequisites:
General knowledge of the basic concepts of the different geological disciplines (mineralogy, petrography, geophysics, structural geology, stratigraphy).

Short program:

Examination:
Oral

EARTH SURFACE PROCESSES AND DEPOSITS

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof. ALESSANDRO FONTANA

Credits: 12 ECTS

Prerequisites:
Basic concepts of geology (structural geology, geodynamic settings), sedimentology (textural features of the main types of sediments and sedimentary rocks, sedimentary processes), geomorphology (main morphogenetic processes and recognition of landforms) and stratigraphy (temporal and spatial variability of depositional systems); basic experience in geological and geomorphological field survey.

Short program:
1. SEDIMENT TRANSPORT AND FACIES ANALYSIS landscape evolution from the catchment to a basin scale Description of sediments: basic concepts Tractive transport (bedforms) En-mass transport (debris flow-turbiditic currents) Erosive features Soft sediment deformations 2. SURFACE PROCESSES and REMOTE SENSING FOR Remote sensing: theory and methods Remote sensing: satellites and sensors Conventional Aerial photographs LIDAR and Structure From Motion technique Digital Elevation Models: methods, sources, analyses 3. DEPOSITIONAL ENVIRONMENTS AND GEOMORPHOLOGICAL HAZARDS 3.1 Slope and upstream environments Subaerial slopes, colluvial fans and alluvial fans Geomorphological hazards in the mountain catchments Landslide recognition and classification 3.2 Fluvial systems River styles, torrents, type of bars, overbank features Fluvial geomorphology, between natural dynamics and anthropogenic activity 3.3 Coastal systems Deltas, wave-dominated coasts, tide-dominant coasts Coastal erosion and examples of coastal management Evolution of alluvial and coastal plains during late Quaternary: deposits, landforms, soils 3.5 Marine processes Depositional systems from shelf to deep basin

Examination:
Oral test with open questions on the main themes illustrated in the frame of the course
GEOLOGICAL RESOURCES AND SUSTAINABLE DEVELOPMENT

Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof. PAOLO NIMIS

Credits: 12 ECTS

Prerequisites:
Good basic knowledge on geology, petrography, mineralogy and geochemistry.

Short program:

Examination:
Interview

More information:

GEOLOGY OF MOUNTAIN BELTS

Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof.ssa SILVANA MARTIN

Credits: 6 ECTS

Prerequisites:
The knowledge acquired during the previous courses in geology, mineralogy, petrology, geophysics and applied geology.

Short program:
Analysis of the structure of the orogenic belts from the tectonic, petrological, morphological and geophysical point of view. Focus on the Mediterranean belts and kinematics, by analyzing the spatial and chronological relations between e.g., Alps, Dinarides, Hellenides, Apennine, Pyrenees, Betic belt, Sierra Nevada, Alps, Caucasus and Himalaya Mesozoic-Cenozoic chains. Comparison with other world Phanerozoic chains. Notes on the geological hazard in the Alps. Analyses of various serial geological sections through different parts of an orogeny with the help of geological digital maps, orthophotos, thematic maps and seismic profiles.

Examination:
Analysis of a geological section across a mountain belt at scale 1:250,000 to 1:500,000 and the related geological literature. The geological section will be realized using all the available digital cartography. The geological section of each student will be discussed together with the students.

More information:

ISOTOPE GEOCHEMISTRY

More information:
Master's degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, Second semester

Lecturer: Dott.ssa CHRISTINE MARIE MEYZEN

Credits: 6 ECTS

Prerequisites:
All students must have a solid understanding of basic principles in chemistry, geology, mineralogy, igneous and metamorphic petrology.

Short program:
The course is designed to provide an introduction to the principles and applications of isotope geochemistry. We first focus our interest on what factors govern nucleus stability and trigger radioactivity. An understanding of how stable and radioactive nuclides are generated is then achieved by studying nucleosynthetic processes. The foundations of stable isotope geochemistry are then reviewed. A special emphasis is put on their use in cosmochemistry, geothermometry, hydrology and paleoclimatology. Isotopic systems discussed include the classic long-lived radiogenic systems (Rb-Sr, Sm-Nd, Lu-Hf and U-Th-Pb) as well as extinct radioactivities. Applications as chronometers or tracers are focused on a wide range of topics ranging from processes and timescales relevant to the formation of the planet and solar system, the evolution of the Earth system to environmental issues. Course consists of lectures, and practical sections to work through solving problems. DETAILED COURSE CONTENT: 1. Introduction 2. Atoms and nuclei: their physics and stability 3. Radioactivity 4. Nucleosynthesis: when, where and how chemical elements are formed? 5. Principles of stable isotope geochemistry 6. Tracing the hydrologic cycle with O and H isotopes 7. Law of radioactive decay and geochronometry 8. The Rb-Sr isotope method and its applications 9. The Sm-Nd isotope method and its applications 10. The Lu-Hf isotope method and its applications 11. The U-Pb, Th-Pb and Pb-Pb isotope methods and its applications

Examination:
Course learning goals will be assessed by written examinations.

More information:

Lecturer: Prof. OMAR BARTOLI

Credits: 6 ECTS

Prerequisites:
In order to take full advantage of the course and be able to fully follow the classes, the student needs basic knowledge of petrography, geochemistry and mineralogy, as well as of English.

Short program:
The course will provide deep insight into the main aspects of metamorphic petrology, such as: - Metamorphism: review of the basic concepts (definition and limits of metamorphism, factors controlling metamorphism, metamorphic grade, concept of metamorphic facies, types of metamorphism) - Equilibrium assemblages and metamorphic reactions - Chemographies and other graphical representations - Metamorphism of metapelites and metabasites - High-temperature metamorphism and anatexis (migmatites) - Microstructures of anatectic rocks (evidence of partial melting) - Thermodynamics, geothermobarometry, phase equilibria calculations - Melt and fluid inclusions in metamorphic rocks - Metamorphic record: secular change

Examination:
The acquired knowledge and skills will be assessed through an oral examination in English

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2597/002PD/SCO2045754/NO

Lecturer: Prof. LUCA VALENTINI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics, physics, chemistry and mineralogy.

Short program:

Examination:
1) Multiple choice written text and 2) oral presentation (PowerPoint) on a specific topic chosen by the student (approximately 15 minutes for the presentation and 15 minutes for the written test).

More information:

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**PAST LIFE AND CLIMATES**

Master's degree in **ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021**, First semester

**Lecturer:** Prof.ssa CLAUDIA AGNINI

**Credits:** 12 ECTS

**Prerequisites:**
Basic knowledge acquired during the BSc course (general geology, sedimentary geology, paleontology, geomorphology,...)

**Short program:**
1st Module: Past life One of the basic paradigms of geology is that the present is the key to the past. In recent years, however, and especially considering the increasingly important role played by humans in changing our Planet, scientists are turning that basic tenet around to the past is the key to the future. A proxy-based approach is fundamental to reconstruct past conditions. Proxies are physical, chemical and biological materials preserved in the geologic record allowing for the estimation of climatic or environmental parameters. Proxy-based reconstructions span all timescales, from year-to-year variations to those that occurred over millions of years and provide a tool in order to better understand how climate and environments has varied trough time both before and after human-related alteration of the Earth. In this context this course will focus on: 1) Main geological archives (sediments, corals, trees, ice cores, speleothems, instrumental datasets). Completeness, Resolution and time frame. 2) Main proxies in terms of their rationale, calibration (direct, indirect) and possible applications with the final aim to reconstruct past environments and climates. Proxies considered are: • Biotic: Terrestrial (pollen and spores; plant macrofossilos) and aquatic (foraminifers, calcareous nannofossils, ostracodes, diatoms, radiolarians and silicoflagellates, corals, dinoflagellates cysts, mollusks; • Chemical: composition of shells; biomarkers, elemental analysis; • Physical: Sediment Composition. Types of minerals and fossils; The information acquired will be applied by means of a discussion of a case study and would serve to emphasize the potential of the fossil record in reconstructing the past (e.g., modern analogues) as well as interpreting changes observed in perturbated present day environments. 2nd Module: Past Climates Compelling evidence indicates that, since the early days of its Byr-long history, our planet had to cope unceasingly with changes in regional and global climates, which occurred on different time scales and amplitudes. However, predictive models proved to fall short when attempting precise forecasts of future climate trends, since the Earth climate system is complex, manifold and hardly predictable in its behavior. Crucial insights are provided by investigating the climate history in the Geologic past, which holds the key for understanding the future of our planet. The Course will be organized as follows: 1 - Introduction to the Climate System (2.5 CFU). Climate: definitions and calculation of the Earth radiative balance. Elements of descriptive and dynamic Oceanography. The astronomical theory of climate. Stable oxygen isotopes for paleoclimate reconstructions. 2 - Past climates of the Earth (3 CFU) The great Proterozoic and Paleozoic glaciations. Mesozoic: from the Early Triassic wastelands to the Cretaceous Thermal Maximum. Paleogene: the beginning of the Southern Hemisphere Glaciation. The Neogene and the Northern Hemisphere Glaciation. The Pleistocene: evolution of climate cycles and orbitally-paced glacial dynamics. High-frequency climate variability: the Holocene. Climate cycles at the centennial and decadal scales. Open discussion (class lab).

**Examination:**
1st Module: Past life The knowledge/skills acquired during the course is/are checked by means of a written examination during which the concepts, the scientific terminology, the syntesis ability and the critical sprint will be evaluated. 2nd Module: Past Climates Student's grades will be ascertained by means of an oral, open-question exam, in order to gauge the ability of the candidate to engender connections between different subjects and to establish critical and original approaches to the matter in question.

More information:

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**PLANETARY GEOLOGY**

Master's degree in **ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021**, First semester

**Lecturer:** Prof. MATTEO MASSIRONI

**Credits:** 6 ECTS

**Short program:**
Course contents: - Physical parameters of the terrestrial planets - Impact cratering; process and products. - Crate Chronology - - Venus: topography, tectonism and volcanism, evolution in comparison with the Earth. - Moon: topography, internal structure, tectonic and cratering features, basin related tectonism, surface deposits and geological units, origin and evolution, water on the Moon - Mercury: physiographic provinces and geological units, internal structure, tectonic and volcanic features, cratering, surface composition and volatiles, origin and evolution. - Mars: topography, internal structure, tectonism and volcanism, water and water related morphologies, surface evolution. - Classification of the meteorites - Geology, structure and composition of comets and asteroids - Geology of the medicean satellites - Planetary space mission and related payloads - In Situ Resource Utilization (ISRU)

**Examination:**
Open ended questionnaire integrated with a potential oral examination on the course topics.
QUANTITATIVE METHODS FOR EARTH SCIENTISTS

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Dott. RICCARDO BIONDI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics and physics. Derivatives and integrals.

Short program:
- Initial review of basic concepts: single variable functions and multivariate functions; derivatives and partial derivatives; integrals; the study of functions, vectors and matrices; basic notions of probability and statistics with applications. - Methods for data analysis: Probabilistic treatment of geophysical data; Frequency and probability functions; Using statistics to describe and summarize datasets; Fitting a probability distribution of actual data; Probability distributions for relevant variables for earth scientists; Regression analysis (covariance and correlation, correlation coefficient, linear and non-linear regression). - Time series analysis. - Analysis of spatial data: Different interpolations methods; Application to actual data. - Basics of numerical methods and applications: Resolution of linear systems; Introduction to the numerical solution of ordinary and partial differential equations; Finite difference and finite element methods.

Examination:
Written exam. Students must write a short matlab code in which they apply the theoretical tools acquired during the course to solve a specific problem. In addition, two questions about hte theory will be asked.

More information:

QUATERNARY GEOLOGY

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof. ALESSANDRO FONTANA

Credits: 6 ECTS

Prerequisites:
Good theorical knowledge and field experience in geological and geomorphological survey, with skills in interpreting morphologies and deposits through remote sensing. Basic knowledge of GIS softwares.

Short program:
The course is divided into several main themes: - Theory and methods of Quaternary Geology. - Allostratigraphy and Unconformity Bounded Stratigraphic Units (UBSU): stratigraphic and cartographic criteria for the detection of the new geological map of Italy (CARG Project). - Recognition, characterization and detailed mapping of glacial, alluvial and slope deposits. - Evolution of Italy and neighboring areas during the Quaternary period. - Use of georeferenced databases and their management within CARG and for the cartographic production. - Use of Software and cartographic editing. - Survey, processing and mapping of information useful for the production of documents related to territorial planning such as Regional Planning Plans, Hydrogeological Planning Plans (PAI) and Environmental Impact Assessment (VIA in Italy). - Principles, techniques and instrumentation of the survey of Quaternary deposits in marine platforms for application purposes.

Examination:
The examination is oral and is based on questions about the program explained during the lectures and the discussion of the cartographic products (paper maps and digital version of maps, profiles and reports) produced during the excercitations in the lab and on the field.

More information:

REMOTE SENSING FOR GEOSCIENCES

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, First semester

Lecturer: Prof. SIMONE BIZZI

Credits: 6 ECTS

Short program:
Theoretical concepts: physical principles and spectrophotometry. Remote sensing platforms: introduction to technology such as satellites and drones (and associated sensors) to generate remotely sensed information. Image analysis: - Image pre-processing: atmospheric correction, geocoding, contrast enhancements, and convolution filters; - Image classification: Unsupervised methods such as band ratios and spectral indexes (e.g., vegetation indexes),
The course will focus both on the formation of anisotropies within magmatic and metamorphic rocks, so that distinguishing between deformations at melt present conditions versus subsolidus conditions will be clear. A major concern within metamorphic rocks is the interrelationship between deformation and mineral growth. Recognition of the relative timing between deformation and the evolution of metamorphic mineral assemblages can give key information for the reconstruction of “Pressure - Temperature - Deformation” (PTD) paths. We will dedicate part of the time to this important aspect. Microstructures tell us much on the reaction progress within the rocks, and preserve significant information on whether these formed under extensional or constrictional regimes. We may also be able to decipher the overprinting relationships between transient deformation regimes. Studying and understanding microstructures within rocks implies application of modern analytical techniques. In this course, besides transferring to the students the necessary theoretical background of microstructural analysis, we will apply Scanning Electron Microscope (SEM) - based analytical tools as Backscatter Electron (BSE) imaging together with (Energy Dispersive Spectroscopy) EDS and Electron Back Scatter Diffraction (EBSD) analysis to thoroughly understand nucleation, growth and deformation microstructures of minerals within magmatic and metamorphic rocks. This will be anticipated by observation and discussion of microstructures within HR-digitalized thin sections in plane and polarized light. • Rheological critical melt percentage (RCMP) or when melt bearing systems deform like solids. • Foliation development in the solid state: schistosities, S-C fabrics, crenulation cleavages, slaty cleavages. • Analysis of inclusion trails within porphyroblasts. • The concepts of pre-kinematic, syn-kinematic and post-kinematic porphyroblast growth. • Overprinting relationships between metamorphic planar anisotropies. • Preservation of high pressure mineral phases within garnet: implications on the reconstruction of PTt-path within metamorphic rocks. • Corona microstructures and their evidence for decompression during exhumation. • Compositional growth-zoning versus diffusion modified chemical profiles in metamorphic minerals. • Epitaxial growth of metamorphic mineral to overcome the energetic nucleation barrier. Evidence from microstructural analysis using EBSD. • Post-entrapment thermally-induced shape change of mineral inclusions within garnet. The role of surface energy control at high temperature metamorphism and the resulting implications on the relative timing of mineral inclusions within porphyroblasts. • Application of multiple novel SEM-FIB based analytical tools: Microtomography, STEM, EDS chemical mapping, EBSD analysis.
DIGITAL GEOLOGICAL MAPPING

Master’s degree in ENVIRONMENTAL GEOLOGY AND EARTH DYNAMICS ORD. 2021, Second semester

Lecturer: Prof. GIORGIO PENNACCHIONI

Credits: 6 ECTS

Prerequisites: Basic geological knowledge and geologic mapping skill

Short program:
The geological mapping and survey activities are nowadays performed with advanced technical approaches both in the field and at the stage of data analysis. The course will give particular emphasis on small-scale (km-scale or lower) mapping, Digital Outcrop Models reconstructions and analysis and simplified 3D geo-modelling applied on different geological contexts, application of different approaches of close range remote sensing. The main contents can be listed as follows: • Methodology and approaches of high-scale geological mapping in geo-structural, stratigraphic and applied geomorphological contexts; • UAV for geological mapping and softwares for planning UAV flight; • Field Move (and similar) application for digital geological mapping; importing and elaborating data in QGIS; • Photogrammetry, Digital Outcrop Models reconstruction and 3D geological analysis. • Basic concepts and applications of 3D Geological models (e.g. VRGS), and virtual reality geological mapping (VRGS e VR2Planet);

Examination:
Evaluation of the products derived from the practical activities and oral presentation

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2597/001PD/SCQ1098865/NO

ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022

APPLIED ECOLOGY AND ECOSYSTEM SERVICES

Master’s degree in ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022, First semester

Lecturer: Prof. ALBERTO BARAUSSE

Credits: 6 ECTS

Prerequisites: Ecology basics

Short program:

Examination:
oral examination

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101580/NO

APPLIED STATISTICS FOR NATURAL SCIENCES

Master’s degree in ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022, First semester

Lecturer: Prof. DAVIDE RISSO

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ENVIRONMENTAL BIOGEOGRAPHY

Master's degree in ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022, First semester

Lecturer: Dott. MASSIMO MEZZAVILLA

Credits: 6 ECTS

Prerequisites:
Basic knowledge of diversity of current living organisms (flora and fauna), basic ecology.

Short program:
- characteristics of European biodiversity, with reference to the main taxonomic groups present; - geographical diversity of the main taxonomic groups of Plants (angiosperms, gymnosperms, pteridophytes, bryophytes) and of Animals (mammals, birds, reptiles, amphibians, fish, insects, crustaceans, other arthropods, molluscs, etc.) present in Europe (e.g. overview of phytosociological alliances and their relationships with habitats in the European Nature Information System) in relation to environmental diversity and active processes. - spatial and temporal distribution of taxa, life forms, communities, biomes and natural or human-influenced ecosystems - patterns and dynamics of change in European flora and fauna over the last 15,000 years; - biogeographical regions of Europe: principles of their creation and development; - latitudinal and altimetric gradient concepts of biodiversity; - biodiversity scenarios for the 21st century; - EU 2030 Biodiversity Strategy; - Basic principles for studying biodiversity in the age of Big Data: advancing biogeography through high-throughput methodologies.

Examination:
Two partial examinations, one for each of the two parts, with the respective lecturers: Each partial examination will be oral for a total duration of approximately 30 minutes.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101581/NO

ETHICS AND ENVIRONMENTAL ECONOMICS

Master's degree in ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022, Second semester

Lecturer: to be defined

Credits: 9 ECTS

Prerequisites:
CONTENT NOT PRESENT

Short program:
CONTENT NOT PRESENT

Examination:
CONTENT NOT PRESENT

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101511/NO

GEORESOURCES AND GEOHERITAGE IN THE ANTHROPOCENE
Master's degree in **ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022**, First semester

**Lecturer:** Prof. PAOLO NIMIS

**Credits:** 6 ECTS

**Prerequisites:**
Good basic knowledge on geology, petrography and mineralogy.

**Short program:**

**Examination:**
Interview.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101583/NO

**PAST CLIMATE AND CLIMATE CHANGE**

Master's degree in **ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022**, First semester

**Lecturer:** Prof.ssa CLAUDIA AGNINI

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of Geology and Paleontology

**Short program:**
The course can be subdivided as follows: 1) Climatology and Paleoclimatology. Climate and climate changes. The climatic system and its components and interactions. Climate archives and proxies, data, and models. (1CFU). 2) stable isotopes (carbon and oxygen) in paleoclimatology. (1 CFU); 3) tectonic-scale climatic changes. CO2 and long-term climate evolution. Plate tectonics and long-term climate. Short-term climate changes. (0.5 CFU); 4) climate evolution from the Precambrian to the Quaternary. Faint young sun paradox. Icehouse climate. Greenhouse climate. From greenhouse to icehouse: the last 50 Myr. Orbital-scale climate change. Astronomic control on solar radiation. Insolation control of Monsoons. Insolation control of ice sheets. Orbital-scale changes in CO2 and CH4. Orbital-scale interactions and feedbacks. Deglacial climate change. Last Glacial Maximum. Millenial oscillations of climate. Humans and preindustrial climate. Climate changes during the last 1000 years. Causes of global warming and future climatic changes, the anthropocene. (2.5 CFU). 5) Ongoing climate changes: the IPPC reports. Causes of global warmi and possible furute scenarios: the anthropocene.

**Examination:**
The knownledge and skills acquired during the course is checked by means of an written examination (90%) during which the concepts, the scientific terminology, the syntesis ability and the critical spririt are evaluated. In addition skills will also be evaluated based on presentation given the student (team working) on assigned topic (10%).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101579/NO

**METHODS FOR WILDLIFE MONITORING**

Master's degree in **ENVIRONMENTAL SUSTAINABILITY AND EDUCATION ORD. 2022**, Second semester

**Lecturer:** Prof. LUCIO BONATO

**Credits:** 12 ECTS

**Prerequisites:**
Basic knowledge on: diversity of extant living organisms, especially with respect to development and reproductive biology, ecology, behaviour; methods and tools of statistical analysis and data georeferentiation. Therefore it is strongly recommended to have already attended the following courses of the 1st year of the programme: Environmental Biogeography, Applied Ecology and Ecosystem Services, Applied Statistics for Natural Sciences.

**Short program:**
- general approaches and critical issues in searching, detecting, identifying, censusing and monitoring wildlife in the field; - main methods, tools and standards for searching, detecting, identifying, and censusing populations of species of the main ecological groups of fauna and flora, focussing on terrestrial and freshwater habitats: mammals, birds, fish, amphibians and reptiles, freshwater macroinvertebrates, soil arthropods, butterflies, dragonflies, beetles, algae, vascular plants, lichens; - methods for assessment of composition and structure of biocenoses, for zoonocenes and vegetation; - designing and planning surveys and monitoring programs on species or communities in an area; - methods for bibliographic search; conventions and standard for communication of the results.

**Examination:**

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Two partial examinations, one for each of two parts, with the respective teachers: - First part (7 CFU): general concepts and methodology, and specific methods for animals - Second part (5 CFU): specific methods for plants and vegetation Each partial examination will be oral and will comprise open questions, on at least five different topics chosen by the teacher within the program, for a total duration of about 30 minutes. The overall score will be calculated as the weighted average of the two partial scores of the two partial examinations (the weights will be proportional to the number of CFUs of the two parts), i.e.: overall score = 0.6 x (score of 1st part) + 0.4 x (score of 2nd part). The overall score will be approximated to the nearest unit.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2650/000ZZ/SCQ2101512/NO

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**BEHAVIOURAL GENETICS**

Master's degree in **EVOLUTIONARY BIOLOGY ORD. 2018**, First semester

**Lecturer:** Prof. MAURO AGOSTINO ZORDAN

**Credits:** 8 ECTS

**Prerequisites:**
Basic Genetics and possibly also Population Genetics. Ideally some background in programming with R (Rstudio)

**Short program:**
- Introduction to behavioural genetics: - Historical introduction: - Francis Galton, eugenics, racial laws and Nazism, behaviourism, birth of behavioural genetics; - Behaviour as gene-environment interaction (nature-nurture): Studies on human families - MZ and DZ twins and adoptive children; - Model organisms in behavioural genetics: Caenorhabditis, Drosophila, Zebrfish, mammals: rat, mouse, dog (behaviour and domestication). - Genetics of quantitative characters in the study of behaviour (behavioural quantitative traits) - Types of quantitative characters - Similarity between relatives and the concept of heritability - Artificial selection and realized heritability - Equation for the prediction of individual selection - Genetic models for quantitative characters - Components of phenotypic variation - Sources of genetic and environmental variation - Components of genetic variation - Covariance between relatives - Studies on twins and inferences on human heritability - Norm of reaction, threshold characters and genetic correlation - Norm of reaction and phenotypic plasticity - Threshold characters: Genes as risk factors in disease - Genetic correlation and correlated response - How to identify genes? Single genes or multiple genes? - Genes which influence quantitative characters - The number of genes which influence quantitative traits - Methods for mapping (Quantitative Trait Loci) QTL - Candidate genes - Genome Wide Association (GWA) - Single Nucleotide Polymorphisms (SNP) - Physiological behaviour and it's variations, considering also pathological aspects of selected behaviours. - circadian rhythms, sleep - learning and memory - socialization, aggressiveness - locomotion - orientation and navigation - sexual orientation - seeking novelties - Description of the molecular mechanisms and the neuronal circuits involved in the control of some of the behavioural patterns described in the preceding section. - Practicals: Methods to study behaviour in animal models (partly taught class, partly laboratory simulations) - Design of equipment, computer hardware and software, numerical and statistical analysis of data (i.e. videos, movement tracking).

**Examination:**
Written exam, at the end of the course, using the Moodle platform.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1179/000ZZ/SCQ1097221/NO

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**COMPARATIVE PHYSIOLOGY**

Master's degree in **EVOLUTIONARY BIOLOGY ORD. 2018**, First semester

**Lecturer:** Prof.ssa ELISA GREGGIO

**Credits:** 6 ECTS

**Prerequisites:**
Knowledge of General Physiology, Physics (especially the fluid dynamics), Cell Biology (in particular the trans-membrane transport systems), Biochemistry, Zoology and Evolutionary History of Vertebrates.

**Short program:**
The contents of the program are divided into 4 parts: 1) Introduction (0.5 CFU). Adaptation responses to the environment. Concept of homeostasis. 2) The perception of the environment (1.5 CFU). Relationship between sensory structures and adaptive needs. Photoreception; Mechanoreception; electoreception; chemoreception; magnetoreception. The characteristics of the sensory organs will be discussed in an adaptive and comparative key. 3) The exchange of gas and their transport (1.5 ECTS). Respiratory systems: surfaces and mechanisms for the exchange and transport of respiratory gases; animals with aquatic and aerial respiration; respiratory mechanics; gas exchange and transport; breathing control and acid-base regulation; adaptation to diving. 4) Osmoregulation and excretion (1.5 CFU). Elimination of nitrogen compounds; osmoregulation problems in extreme environments; osmoregulation and osmoconformity in aquatic animals; gills as a system of osmoregulation in aquatic animals; renal excretory organs; function of the nephron of mammals; urinary systems of other vertebrates and extrarenal organs; nervous and endocrine regulation.

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**Ethology**

**Master's degree in** **Evolutionary Biology Ord. 2018**, First semester

**Lecturer:** Prof. ANDREA AUGUSTO PILASTRO

**Credits:** 6 ECTS

**Prerequisites:**
Good knowledge in evolutionary biology, ecology, genetics, and zoology (advanced undergraduate course level)

**Short program:**
Main topics will regard the link between animal behaviour ecology and evolution, the development and control of behaviour: genes environment and neural mechanisms, the evolution of animal signals, adaptive responses to predators, foraging behaviour and optimality models, reproductive behaviour: male and female tactics, mating systems, parental care, sperm competition and sexual selection, sexual conflict, social behaviour, kin selection.

**Examination:**
Written test

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1179/000ZZ/SCP8084977/NO

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**Evolution and Conservation**

**Master's degree in** **Evolutionary Biology Ord. 2018**, First semester

**Lecturer:** Prof. GIL GUASTONI ROSENTHAL

**Credits:** 6 ECTS

**Prerequisites:**
Good knowledge in evolutionary biology, ecology, genetics, zoology and botany (advanced undergraduate course level)

**Short program:**
Lectures will be in English. While evolutionary biology has important theoretical and practical implications in conservation, it has often been neglected. The reason for this probably originates from the mistaken belief that evolution acts too slowly to be relevant on an ecological time scale. In this course we will combine the fields of evolutionary and conservation biology to emphasize the importance of evolutionary theories in conservation programs. This course will therefore focus on genetic and evolutionary applications to the problems of conservation, while reflecting the diversity of concerns that are relevant to conservation biology. Particular emphasis will be put on themes like measures of phylogenetic diversity and uniqueness, population genetic structure of natural and managed populations including the identification of 'evolutionary significant units' and 'management units' for conservation, assessment of levels of genetic variation within species and populations, Description of the main genetic processes associated with conservation. Management of genetic diversity for conservation purposes. Genetic markers for the study of diversity. Ex situ management of residual genetic diversity. Assessments of the effect of sexual selection mate choice and reproductive strategy on population conservation, forensic applications, methods for maximising genetic diversity during captive breeding programs and re-introduction schemes, effect of anthropogenic factors on evolutionary adaptation to local changes in the environment.

**Examination:**
Evaluation based on written exam. Oral test possible if required by the student (please contact the teacher in advance).

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1179/000ZZ/SCN1031442/NO

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**Molecular Phylogenetics**

**Master's degree in** **Evolutionary Biology Ord. 2018**, Second semester

**Lecturer:** Prof. ALESSANDRO GRAPPUTO

**Credits:** 8 ECTS

**Prerequisites:**
It would be useful to have acquired basic knowledge of Genetics, Evolutionary Biology, Systematics and Bioinformatics

**Short program:**
The course is subdivided in two parts: one of a series of frontal lectures (48 hours) and one of practical experience in a laboratory (32 hours of which 16 h will be online). The study of molecular evolution is a field of research that merge the most recent progress in molecular biology with those in bioinformatics. In the course will be shown the principal of molecular evolution ad phylogeny. In particular will be considered: the diverse type of molecular data and the techniques for their acquisition; the alignment of sequences; the comparison of DNA and protein sequences to calculate the genetic distance; the mechanisms of molecular evolution and the theory of neutrality; the models of nucleotide substitution; the molecular identification of species (barcoding of life); The phylogenetic reconstruction methods of maximum parsimony, genetic distance, maximum likelihood and Bayesian inference; the concept of molecular clock; trees and supertrees; the positive selection at the molecular level and the methods to identified it, genome sequencing projects and phylogenomics; Phylogeny of key taxonomic groups and examples of recent phylogenetic works. Laboratory; Molecular identification of species (barcoding); genomic DNA extraction from unidentified samples, PCR and sequencing of mitochondrial genes; Bioinformatics lab of which 2 sessions in presence (8h) and 4 sessions online (16h); In presence: chromatogram reading and analysis; use of GenBank and the barcode database BOLD to identify species and other specific softwares; Online: Phylogenetic reconstruction with the main algorithms using MEGA, MrBayes and Fasttree. Use of the software BEAST to date evolutionary events with molecular data.

Examination:
The student assessment will be achieved by a written examination on a PC using the e-learning platform. The test will consist of 9 questions: 6 questions with open answer to assess the acquired knowledge, comprehension and ability to synthetize the concepts developed during the course 3 more focused questions on the interpretation of examples of phylogenetic relationships of specific taxonomic groups and the methods to reconstruct the tree.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1179/000ZZ/SCP8084997/NO
APPLIED GEODESY

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
CONTENT NOT PRESENT

Short program:
CONTENT NOT PRESENT

Examination:
CONTENT NOT PRESENT

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCP8082557/NO

APPLIED GEOPHYSICS

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Prof. GIORGIO CASSIANI

Credits: 9 ECTS

Prerequisites:
Essential prerequisites include: basics of physics and mathematics.

Short program:
The course will be composed of three parts: part 1: introduction to exploration geophysics; this part will introduce the general concepts of applied geophysics with particular regard to: • physical principles of the main electrical, elettromagnetic, seismic, magnetic and gravimetric methods • concepts of resolution and penetration • general definition of geophysical inversion • basic concepts about data acquisition of the main methodologies Part 2: exploration methods: - seismic methods, with basics of reflection and refraction seisims, and basics of surface wave methods; - DC resistivity methods with tomographic applications; - Ground penetrating radar (GPR) - Electromagnetic Induction methods (EMI) - Gravimetric methods - Magnetic methods - Induced polarization methods For all methods special attention will be given to their applications, with examples from literature and from the experience of the lecturer. Part 3: Demonstration will be given of the main methods, followed by processing, inversion and interpretation of laboratory data.

Examination:
Oral examination. Possible discussion of a scientific paper to be chosen among the ones previously distributed to students.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089239/NO

APPLIED HYDROLOGY

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Prof. ANDREA D'ALPAOS

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics, physics, science, and elementary statistics is required for student success.

Short program:

Examination:
Written exam on theoretical issues and practical applications (open questions and exercises). Preliminary discussion of the results of the exercises carried
EARTHQUAKE GEOLOGY AND FAULT MECHANICS

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Prof. GIULIO DI TORO

Credits: 6 ECTS

Prerequisites:
Basic (not in depth) knowledge in geology, geophysics, physics and calculus.

Short program:
Topics: Stress and Strain, Deformation Processes in the Lithosphere, Brittle fracture and friction of rocks, Faults and Structure of Fault Zones, Fluids and Faults, Earthquake mechanics and the seismic cycle, Earthquakes and Tectonics, Earthquake forecasting and hazard, Human-induced seismicity

Examination:
Evaluation of the gained abilities will be evaluated with a final written test on the topics discussed in the classes plus power-point presentations of (1) the laboratory activities and (2) the field trip (see below).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089235/NO

ELECTROMAGNETISM

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Dott. ALVISE RACCANELLI

Credits: 6 ECTS

Prerequisites:
Physics 1 basics Calculus 1 fundamentals of vectorial calculus

Short program:
Electrostatics, Magnetostatics Vectorial differential and integral calculus Electromagnetic fields, potentials Maxwell equations

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ1098476/NO

ENVIRONMENTAL AND ENGINEERING GEOPHYSICS

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Prof. JACOPO BOAGA

Credits: 9 ECTS

Prerequisites:
Prerequisites are: the course of Applied Geophysics (1 year)

Short program:
The course has 3 parts: Part 1: Introduction to exploration geophysics methods and instruments for natural risk. Geophysical methods for hydrological risk and soil characterization for environmental aims. Part 2: Applied geophysics for the seismic risk. Introduction to applied seismology, seismic hazard and seismic risk. The seismic hazard in Italy and Europe. Global and local hazard maps. Response seismic scenarios. Coupled effects of seismic motion. Seismic response spectra. Geophysical methods for the seismic soil classification and for the local seismic response analysis. Part 3. Practical field work and exercise for the acquisition, the processing and the analysis of geophysical data for soil characterization. The course will focus on applied aspects of the several techniques with examples from literature and from teacher experiences. The methods will be compared in terms of limits and goals, in order to drive the most suitable choice of investigation case by case.

Examination:
Oral examination with discussion of a scientific paper from a list proposed by the Teacher.
EXPLORATION SEISMOLOGY

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Dott.ssa ILARIA BARONE

Credits: 6 ECTS

Prerequisites:
Basic physics and mathematics, digital data processing, elements of applied geophysics, elements of stratigraphic and structural geology.

Short program:

Examination:
This course involves an oral exam. Moreover, students will be asked to produce a descriptive report on the data analysed and processed during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089230/NO

FINALE EXAM

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: to be defined

Credits: 24 ECTS

Prerequisites: CONTENT NOT PRESENT

Short program: CONTENT NOT PRESENT

Examination: CONTENT NOT PRESENT

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089258/NO

GEOLOGY FOR GEOPHYSICS

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Dott. VALERIO OLIVETTI

Credits: 6 ECTS

Prerequisites:
Basic knowledge in geology and geophysics.

Short program:
The course is structured to provide the basic knowledge of geology that can be useful to a geophysicist in order to interpret observations made in the field. Rocks will be taught in relation to the geodynamic environments of formation, to describe the formation of sedimentary rocks, igneous rocks and metamorphic rocks. The course will have a practical character: from observation to interpretation. For this reason, there will be three days of field trips, in which observation will be carried out, geological data will be acquired, and field work will be learnt. The course includes the teaching of geological map reading. - Plate tectonics and Wilson's cycle. - The oceanic crust - Continental crust - Igneous intrusive rocks: formation and classification - Magmatism and volcanism of the Apennines - Volcanoes - Sedimentary rocks and sedimentary structures - Ice and glacial deposits: example of the Alpine glaciations -
**GEORESOURCES**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

**Lecturer:** Prof. MASSIMILIANO ZATTIN

**Credits:** 6 ECTS

**Prerequisites:**
Basic geological background

**Short program:**

**Examination:**
Written examination

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089221/NO

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**GEOTECHNICS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

**Lecturer:** Dott.ssa GIORGIA DALLA SANTA

**Credits:** 6 ECTS

**Prerequisites:**
There are no prerequisites

**Short program:**

**Examination:**
Oral exam. The student may give a presentation he or she has prepared regarding a specific topic of particular interest, then followed by further questions on the rest of the program. Some moodle tests will be used during the course to assess progression.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089225/NO

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**GEOTHERMICS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

**Lecturer:** Prof. ANTONIO GALGARO

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge in hydrogeology, thermodynamics, structural geology, geochemistry, physics of the Earth

**Short program:**

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The course aims to deepen the application aspects of geothermal energy in relation to the following contents: thermo-physical properties of natural materials; relation between geothermal reservoirs and structural traps, geochemical and isotopic survey methodologies finalized to geothermal exploration, on site thermo-physical properties measurement methodologies. Examples of the exploration and use of endogenous heat, as well as the use of the subsurface as a heat source and receptor, will be described in detail by assessing in particular the geological competence in a highly multidisciplinary perspective. Excursions in the geothermal construction site at various types of geoechange plants under construction, and in Larderello Area (Tuscany) visiting the geothermal power plants of Enel Green Power Company excursion to thermal storage facilities underground. The geothermal resource and the current energy framework, High and medium entalpia resources. National and international situation; scenarios and possible technical regulatory developments • Fundamentals of thermophysics • Thermophysical properties of materials, heat transmission mechanisms with emphasis on aspects of transitory conduction processes, flow and geothermal gradient. Endogenous heat, sources and energy assessments • Subsurface classification, aquifers, soil permeability, wells and piezometers, surveys and other forms of detection. Hydrogeological aspects aimed at determining the characteristics of hydrothermal systems. Exploration methods, geothermal drilling, geothermal reservoir characterization, geothermal reservoir simulation models, relationships between tectonic and geothermal assessment, unconventional geothermal resources, social, economic and environmental impact assessments. Geothermal systems for air conditioning proposes with open groundwater and closed-circuit systems with wells and ground heat exchangers. Types of ground heat exchangers, energy geo-structures (geo-foundations), introduction to thermal storage systems, underground thermal storage systems (ATES). • The drilling site, the work realization of geothermal probes (open-air lesson - visit on site). • Geothermal heat pumps, integration of geothermal air conditioning systems with other renewable sources and hybrid systems • Closed-circuit ground heat exchange systems; examples of vertical probe sizing; procedure, parameters of influence, simplified analytical methods of sizing geothermal probes; The Ground Thermal Response Test. Theory, working hypotheses, operational modes, data analysis, instrumentation for the test with heat injection and heat extraction, measurement uncertainties, innovative experimental techniques and data analysis. • Assessments of the undisturbed subsurface temperature and its relationship with the solar and endogenous sources. Time-variant analysis of ground probe relations. • Open-loop systems with groundwater use, building criteria and well sizing; numerical models of hydro-thermal simulation of pick-and-return well systems - applications of geothermal solution for space free cooling - day and seasonal thermal storage in the underground matrix and in aquifers. - The environmental component of geo-exchange, sustainability and renewable systems • International, national, regional and local legislation on the use of geothermal resources.

Examination:
Oral examination. The test involves discussing about a topic, prepared individually by the student, regarding one or more course items

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089232/NO

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**HIGH LEVEL PROGRAMMING**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

**Lecturer:** Prof. MARCO ZANETTI

**Credits:** 6 ECTS

**Short program:**
- Number representation, algorithmic complexity, data and memory management - The python programming language, from the bases to the advance programming for scientific computing; review of the modern libraries for the data management and analysis (numpy, scipy, pandas, scikit-learn, etc.) - Linear Algebra and related methods (SVD, PCA) - Monte Carlo methods for the simulation of physics phenomena - Techniques to assess and extract the statistical features of a physics datasets and comparison with model predictions - Visualisation and graphical representation of datasets and their properties

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089439/NO

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**MACHINE LEARNING**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

**Lecturer:** Prof. PIETRO ZANUTTIGH

**Credits:** 6 ECTS

**Short program:**

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCP8082660/NO

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**MANAGEMENT AND ANALYSIS OF PHYSICS DATASETS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester
Lecturer: Dott. JACOPO PAZZINI

Credits: 6 ECTS

Short program:
Part 1) Data Management Introduction to data structures Storage Models Reliability Authentication, Authorization Local and Distributed File systems Databases Part 2) Data processing Introduction to parallel processing Distributed Computing Systems Containerization Hadoop as a paradigm for big data processing Data processing with Spark Data processing with Dask Kafka as a distributed streaming platform

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089438/NO

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**MATHEMATICAL PHYSICS FOR THE EARTH SYSTEM**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

Lecturer: Prof. LAPO BOSCHI

Credits: 6 ECTS

Prerequisites:
High-school level maths and physics (trigonometry, derivatives, integrals, Newton's laws)

Short program:
• elements of calculus • elements of linear algebra • differential equations • Fourier series and Fourier transform • linear inverse problems

Examination:
Written and/or oral exams (depending on the number of students) with questions on the contents of the course, and problem solving based on the methods learned during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089222/NO

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**NUMERICAL METHODS FOR CONTINUOUS SYSTEMS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

Lecturer: Prof.ssa ANTONIA LARESE DE TETTO

Credits: 6 ECTS

Prerequisites:
Basic knowledge on: - partial differential equations (PDEs) - finite element analysis; - linear algebra (and elements of functional analysis); - programming (e.g., matlab, python, ...)

Short program:

Examination:
Oral exam and discussion of two mandatory projects

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089198/NO

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**NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

Lecturer: Dott. LUCA BERGAMASCHI

Credits: 6 ECTS

Prerequisites:
Basic vector calculus, numerical calculus, notion of partial differential equations, linear algebra

Short program:
Introduction, Krylov subspace methods for large and sparse linear systems. Numerical methods for ODEs. Implicit and explicit methods, multistep

Examination:
Oral exam in which the student will be asked to discuss theoretical aspects of the discretization methods studied during the course. Moreover, the student will present and critically discuss the results of a numerical project for the discretization by finite elements or finite differences of an elliptic or a parabolic equation.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089204/NO

NUMERICAL METHODS FOR GEOSCIENCES

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Prof. MANUELE FACCENDA

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics, physics and MatLab (provided during the Laurea Triennale)

Short program:
1. Mathematical basis for partial differential equations (derivatives, gradient, divergency, laplacian operator)
2. Rock physical properties (viscosity, elastic moduli, cohesion and friction coefficient, density, thermal conductivity and diffusivity, heat capacity)
3. Thermal, chemical, hillslope and fluid overpressure diffusion equations
4. Stress, strain and strain rate tensors and constitutive relationships
5. Visco-elasto-plastic deformation
6. Conservation of mass
7. Conservation of momentum
8. Conservation of energy
10. Solution of systems of equation with iterative (Gauss-Siedel) or direct (Gauss elimination) methods

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089223/NO

NUMERICAL METHODS FOR HIGH PERFORMANCE COMPUTING

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Prof. CARLO JANNA

Credits: 6 ECTS

Prerequisites:
Numerical Methods for Differential Equations

Short program:
1. Advanced numerical linear algebra: projection methods for non-symmetric systems (Bi-CG, QMR) and eigenproblems (Power Method, QR Method, Lanczos, DACC)
2. Multigrid
3. Preconditioning techniques: ILU, approximate inverses, AMG
4. Parallel numerical analysis: basic concepts, operations and communications, data structures
5. Parallel programming paradigms: OpenMP and Message Passing Interface standards
6. Parallel implementations: sparse linear algebra kernels, iterative methods, domain decomposition

Examination:
Oral discussion of the numerical project carried out during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089199/NO

PETROPHYSICS

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Dott.ssa ELOISA DI SIPIO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics, physics and geophysics acquired during the Bachelor degree.

Short program:

Examination:
An oral exam on the topics dealt with and discussed during the frontal lessons will verify the degree of knowledge acquired.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089224/NO

**PHYSICS DATA ANALYSIS**

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), Second semester

Lecturer: Prof. MARCO BAIESI

Credits: 6 ECTS

Short program:
- Gradient descent methods
- Ridge and LASSO regularization
- Supervised learning and unsupervised learning
- Deep neural networks and convolutional version
- Clustering
- Data visualization
- Energy-based models
- Restricted Boltzmann machines
- Combination of models: bagging, random forests, boosting, XGBoost

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089405/NO

**PROGRAMMABLE HARDWARE DEVICES**

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Dott. ANDREA TRIOSSI

Credits: 6 ECTS

Short program:
PART I Computer Architecture
A) Principles of Digital Electronics - Number systems and codes - Fundamentals of Boolean algebra - Combinatorial functions - Combinatorial logic elements - Arithmetic-logic units - Latches and Flip-flops - Sequential circuits - Memory elements
B) Simple As Possible computers - SAP-1 - SAP-2 - SAP-3

PART II Hands-on Laboratory
A) Building an 8-bit CPU - Clock module - Registers - Arithmetic Logic Unit - Program counter - Input and memory register - Random Access Memory - Control logic - Output register
B) Data management with System on Module (SOM) - Introduction to ARM processor - Assembling and compiling processes - Input/Output system

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089440/NO

**SEISMIC RESPONSE OF BUILT STRUCTURES**

Master's degree in GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020), First semester

Lecturer: Prof.ssa FRANCESCA DA PORTO

Credits: 6 ECTS

Prerequisites:
Structural Geology and Earthquakes

Short program:

Examination:
Assignment to be carried out at home during the course and oral discussion of the various topics of the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089227/NO

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**SOLID EARTH GEOPHYSICS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, First semester

**Lecturer:** Dott. PIERO POLI

**Credits:** 9 ECTS

**Prerequisites:**
High-school level maths and physics (trigonometry, derivatives, integrals, Newton’s laws)

**Short program:**
- seismology: the structure of the earth
- geochemistry: the composition of the earth
- geodynamics: the origin of mountains
- geodynamics: continental drift and plate tectonics
- geodynamics: rheology and convection

**Examination:**
Written and/or oral exam (depending on the number of students) with questions on the contents of the course, and problem solving based on the methods learned during the course. Each student will be asked to write, during the semester, a Matlab program, dealing with a topic of her choice: the student will discuss this work at the exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCQ0089218/NO

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**STATISTICAL MECHANICS OF COMPLEX SYSTEMS**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

**Lecturer:** Prof. AMOS MARITAN

**Credits:** 6 ECTS

**Prerequisites:**
Good knowledge of mathematical analysis, calculus and basic physics. For "Physics of Data" students the course has 6 CFU. However, if they are not adequately trained in statistical mechanics, they are encouraged to follow all 9 credits

**Short program:**
The program can be summarized as follows Statistical mechanics and Entropy Ising model Variational principles in statistical mechanics Complex networks Principle of maximum entropy and inference Diffusion Processes and stochastic dynamics Monte Carlo simulations Dynamics of and on networks Population dynamics with applications to ecosystems Percolation on networks. Neural networks

**Examination:**
The first part of the verification of the acquired knowledge will evaluate the homework exercises and the participation of the students in the class discussions. The second part will take place through a common written test with 1-2 exercises to be solved and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The third part is oral and it will be based on a discussion on the various topics of the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2543/000ZZ/SCP8082536/NO

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**STRUCTURE AND COMPOSITION OF THE DEEP EARTH**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of mineralogy and petrology

**Short program:**
This course is structured to provide the fundamental knowledge of mineralogy and petrology that may be useful to a geophysicist in order to interpret observations and provide meaningful input parameters to numerical models. After recalling the main processes – magmatism and metamorphism - shaping the mineralogical and petrological structure and composition of the deep Earth, the course will describe the progressively deeper layers of the planet: crust, mantle and core. Each layer will be described in terms of mineralogical and petrological features and peculiarities, with emphasis on dynamic aspects which provide the main engine for tectonic and volcanic activity at plate margins and within lithospheric plates. The course will also address the secular
changes of geodynamic style in the planet, due to warmer initial conditions. The course will also highlight some of the major issues and uncertainties in the mineralogical and petrological reconstructions of the deep Earth, and their implications for geophysics. The teaching units will cover the following themes: - Basic petrological processes shaping the deep Earth: magmatism and metamorphism - Fluids/melts in rocks and their geophysical effects - The interior of the Earth down to 100 km depth - The crust: oceanic vs. continental - Lithological heterogeneities in the crust - What is the composition of the lower crust? - Textural anisotropies affecting geophysical properties in the crust. - The lithospheric mantle - The low velocity zone - Textural anisotropies affecting geophysical properties in the lithospheric mantle. - Plate margins as main loci of lithospheric reworking - The interior of the Earth from 100 to 6370 km depth - The upper mantle - The transition zone - The lower mantle - The outer core - The inner core - Mineral phase transformations - Mineral physics of the deep Earth - Natural samples from the deep Earth and synthetic samples from the laboratory - Meteorites and deep Earth

Examination:
The test on the acquired knowledge will be based on two open questions on two different topics discussed during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SCQ2101459/NO

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**STRUCTURE AND COMPOSITION OF THE DEEP EARTH**

Master's degree in **GEOPHYSICS FOR NATURAL RISKS AND RESOURCES (ORD. 2020)**, Second semester

**Lecturer:** Prof. FABRIZIO NESTOLA

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge of mineralogy and petrology

**Short program:**
This course is structured to provide the fundamental knowledge of mineralogy and petrology that may be useful to a geophysicist in order to interpret observations and provide meaningful input parameters to numerical models. After recalling the main processes – magmatism and metamorphism - shaping the mineralogical and petrological structure and composition of the deep Earth, the course will describe the progressively deeper layers of the planet: crust, mantle and core. Each layer will be described in terms of mineralogical and petrological features and peculiarities, with emphasis on dynamic aspects which provide the main engine for tectonic and volcanic activity at plate margins and within lithospheric plates. The course will also address the secular changes of geodynamic style in the planet, due to warmer initial conditions. The course will also highlight some of the major issues and uncertainties in the mineralogical and petrological reconstructions of the deep Earth, and their implications for geophysics. The teaching units will cover the following themes: - Basic petrological processes shaping the deep Earth: magmatism and metamorphism - Fluids/melts in rocks and their geophysical effects - The interior of the Earth down to 100 km depth - The crust: oceanic vs. continental - Lithological heterogeneities in the crust - What is the composition of the lower crust? - Textural anisotropies affecting geophysical properties in the crust. - The lithospheric mantle - The low velocity zone - Textural anisotropies affecting geophysical properties in the lithospheric mantle. - Plate margins as main loci of lithospheric reworking - The interior of the Earth from 100 to 6370 km depth - The upper mantle - The transition zone - The lower mantle - The outer core - The inner core - Mineral phase transformations - Mineral physics of the deep Earth - Natural samples from the deep Earth and synthetic samples from the laboratory - Meteorites and deep Earth

Examination:
The test on the acquired knowledge will be based on two open questions on two different topics discussed during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SCQ2101459/NO

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**INDUSTRIAL BIOTECHNOLOGY ORD. 2014**

**METAGENOMICS AND INTERACTOMICS**

Master's degree in **INDUSTRIAL BIOTECHNOLOGY ORD. 2014**, First semester

**Lecturer:** Prof.ssa LAURA CENDRON

**Credits:** 6 ECTS

**Prerequisites:**
The Metagenomics module requires basic knowledge of molecular biology, microbiology and bioinformatics. The Interactomics module requires basic knowledge inherent in protein chemistry, covalent and non-covalent bonds, basic knowledge in biochemistry and physical chemistry.

**Short program:**
Introduction to metagenomics: application of various next-generation sequencing methods (second and third generation) including marker genes, total DNA and RNA-seq. Basic concepts related to the analysis of microbial communities’ structure, ecological indices, similarity measures. Amplicon sequencing analysis based on marker genes (16S rRNA, 18S rRNA, ITS). General discussion and use of specific software (QIIME, PICRUST). Shotgun data analysis: approaches with and without the assembly process. Procedure of “binning” of metagenomic data: the challenge of complexity and the extraction of single genomes from the microbiome. Analysis of meta-transcriptomics data to have gene expression at the community level. Case studies: structure of the microbiome in environments of interest. Anaerobic digestion: degradation of organic matter by a microbiome composed of bacteria and archaea. Aquatic and soil environment: the complexity of the microbiome as approaches have changed over the years for environmental investigations and influences on the microbiome because of contamination. The human gut: the microbiome and its role in determining pathological states. Viromics: meta-approach from
shotgun data and taxonomy. Conclusions and final remarks. Contenuti Interactomics: Introduction to Interactomics: - Fundamentals of non-covalent interactions: type of interactions, stable vs transient interactions, methods to analyze interaction determinants and surfaces in protein-protein, protein-small molecules complexes structures - Surface Chemistry, Immobilization techniques for Protein Arrays, Recombinant versus Cell-free protein synthesis approaches - Techniques to identify/study interactions: o Yeast two-hybrid (Y2H) system general overview o Protein microarrays o Co- immunoprecipitation/co-affinity purification coupled to quantitative mass spectrometry (w/o cross-linking) o Label free Proximity Ligation assays techniques - Techniques to measure interactions (HT and non-HT): o Calorimetry and Microcalorimetry- Principles and Assays o Surface Plasmon Resonance- Principles and Assays: applications in protein research, Kinetic analysis of protein-protein interaction using SPR o Interferometry techniques, Biomolecular interactions using Bio-Layer Interferometry (BLI): applications in protein research, Kinetic analysis of protein-protein interaction using BLI o Mass spectrometry - Techniques to generate novel binders by libraries screenings: o Naive, immunization vs synthetic libraries, libraries diversity, main applications o Introduction to Phage display o Introduction to Yeast display

Examination:
Final test will be based on written examination, questions will evaluate acquired knowledge, ability to summarize answers and critical discussion. Test is based on topics covered during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ0093458/NO

PLANT ENGINEERING AND PHYTOREMEDIATION

Master's degree in INDUSTRIAL BIOTECHNOLOGY ORD. 2014, First semester

Lecturer: Prof.ssa ELIDE FORMENTIN

Credits: 6 ECTS

Prerequisites: none

Short program:
Genetic engineering of plants aimed at applications in industry and agriculture - Introduction to environmental stresses with a focus on abiotic stresses. - Introduction to the transport mechanisms of water and solutes through biological membranes. - Plant responses to environmental stress: in particular the issues of water stress and oxidative stress at the molecular level will be addressed. - Molecular physiology of mineral nutrients, their absorption, transport and utilization. - Toxicity of pollutants and plant responses. - Genetic improvement for the use of plants for phytoremediation, cultivation in marginal land or the production of secondary metabolites for the pharmaceutical and cosmetic industry Phytoremediation: - Use of plants to decontaminate soils and water by containment, degradation or removal of the contaminant. - Examples of application of phytoremediation techniques.

Examination:
The exam is divided into two parts: 1. presentation and critical analysis of some works of literature (journal club). 2. written exam on the course contents.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ0093438/NO

BIOENERGY PRODUCTION

Master's degree in INDUSTRIAL BIOTECHNOLOGY ORD. 2014, First semester

Lecturer: Prof. TOMAS MOROSINOTTO

Credits: 6 ECTS

Prerequisites: No specific prerequisites. Students should have a general background in basics of chemistry, metabolism, methods for genetic modification, plant biology.

Short program:
Introduction: current energy sources and the necessity of renewable fuels. Non-renewable resources (oil, natural gas, coal) and main processes for their transformation. Biotechnology for energy production: Hydrogen production from algae and bacteria. Production of bioethanol from ligno-cellulosic biomass. Production of biodiesel from oleaginous crops. Algae as biofuels producers. Evaluation of advantages and disadvantages with respect to plants. Production of biogas. Production of bio-syngas from ligno-cellulosic biomass. The biotechnological challenges for biofuels production: the optimization of conversion of solar into chemical energy. Examples of genetic engineering for biofuels. Exploitation of unicellular algae for wastewater treatment and bioremediation. The laboratory experiments will be as follows: - Biodiesel production from spent vegetable oil - Bioethanol production from corn starch

Examination:
The evaluation consists of two parts: 1. open-question written test on the class contents. 2. optional presentation and critical analysis of some recent scientific papers.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ1098018/NO

BIOREMEDIATION
Master's degree in INDUSTRIAL BIOTECHNOLOGY ORD. 2014, First semester

**Lecturer:** Prof.ssa PAOLA VENIER  
**Credits:** 6 ECTS

**Prerequisites:**  
The course Biochemical Reactors is a prerequisite. The course Genetic toxicology and Environmental chemistry is highly recommended. This is a multidisciplinary course facilitated by notions of environmental chemistry, microbiology, biochemistry, and toxicology.

**Short program:**  
**PART A** Environmental contaminants by contamination size, hazard level and resistance to degradation. Contaminated sites of national concern in Italy. Biodeterioration and bioremediation. (0.5 CFU). Unifying features and amazing variety of microorganisms. Microbial adaptation, mixotrophy, syntrophy and extremophiles as a knowledge basis to understand biodeterioration and bioremediation processes. Gene-specific and metagenomic approaches in the study of microorganism communities in contaminated sites or ex-situ treatment plants (1 CFU). Study cases, with attention to biotransformation pathways of environmental contaminants (e.g., wastewaters and other wastes, hydrocarbons, organohalogenated compounds, plastics). What remediation strategies for metals, metalloids and radioactive materials? (1 CFU)? Limitations and perspectives in microbial bioremediation. Bioengineering of microorganisms and enzymes or selection of extremophiles inspired by nature? How to optimise bioremediation processes mediated by consortia of micro-organisms? (0.5 CFU)  

**Examination:**  
The oral exam will be an interview on Part A and Part B. The student will discuss a case or a project of bioremediation mediated by microorganisms, to be previously agreed with the two teachers and aimed at evaluating the knowledge/skills acquired by the student during the course. The exam mode may change in an emergency.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCP9088082/NO

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Master's degree in INDUSTRIAL BIOTECHNOLOGY ORD. 2014, Second semester

**Lecturer:** Prof. ALESSANDRO ALBORESI  
**Credits:** 6 ECTS

**Prerequisites:**  
Basic knowledge of Plant Physiology is recommended.

**Short program:**  
The course will provide a general introduction to the major physical phenomena associated with global climate change that threaten the survival of certain species and limit crop productivity. Main challenges for our society are related to the characteristics and speed of global climate change. The following parameters will be considered: increase in atmospheric carbon dioxide concentration and other greenhouse gases; temperature increase; acidification of water (both marine and rain); ozone and stress from UV rays. During the course, the physiological limits of living organisms will be discussed. The concepts acquired in the general part will be applied to think at biotechnological strategies to improve plant productivity and plant stress resistance. (1) In order to generate crops and specimen adapted to current global climate change, several strategies will be considered. Constant monitoring of biodiversity allows the identification of species at greater risk of extinction and species with interesting characteristics. Flowering time and control of flower development is influenced by climate change and they have an impact on plant-animal interaction. Strategies to improve carbon dioxide fixation to improve plant productivity. Seed physiology for the control of soil seed bank and plant productivity. Plant resistance to desertification, water stress and resistance of plants to global warming. The role of epigenetic control will be considered. Plant resistance to flooding. (2) In order to reduce the environmental impact of modern agricultural practices, various possibilities will be considered. Algae and plants as indicators of global climate change. Improving crop nutrient efficiency through root architecture modifications. Phosphorus acquisition efficiency. The symbiotic associations between host plants and arbuscular mycorrhiza fungi/rhizobial bacteria as additional important strategies to enhance nutrient acquisition.

**Examination:**  
Oral presentation on a relevant topic proposed by the student. Written test related to the topics covered during lectures.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ0093380/NO

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Master's degree in INDUSTRIAL BIOTECHNOLOGY ORD. 2014, Second semester

**Lecturer:** Prof.ssa PAOLA VENIER  
**Credits:** 6 ECTS

**Prerequisites:**  
Environmental contaminants by contamination size, hazard level and resistance to degradation. Contaminated sites of national concern in Italy. Biodeterioration and bioremediation. (0.5 CFU). Unifying features and amazing variety of microorganisms. Microbial adaptation, mixotrophy, syntrophy and extremophiles as a knowledge basis to understand biodeterioration and bioremediation processes. Gene-specific and metagenomic approaches in the study of microorganism communities in contaminated sites or ex-situ treatment plants (1 CFU). Study cases, with attention to biotransformation pathways of environmental contaminants (e.g., wastewaters and other wastes, hydrocarbons, organohalogenated compounds, plastics). What remediation strategies for metals, metalloids and radioactive materials? (1 CFU)? Limitations and perspectives in microbial bioremediation. Bioengineering of microorganisms and enzymes or selection of extremophiles inspired by nature? How to optimise bioremediation processes mediated by consortia of micro-organisms? (0.5 CFU)  

**Examination:**  
The oral exam will be an interview on Part A and Part B. The student will discuss a case or a project of bioremediation mediated by microorganisms, to be previously agreed with the two teachers and aimed at evaluating the knowledge/skills acquired by the student during the course. The exam mode may change in an emergency.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCP9088082/NO
Credits: 6 ECTS
Prerequisites:

Short program:

Examination:
The exam will focus on Part A (CHIM, 3 CFU) and Part B (BIO, 3 CFU). The student will also discuss a topic chosen in agreement with the teachers during the course, based on scientific literature and related to both exam parts (for part B: toxic agent or biological process intended as function and dysfunction or method of investigation). Effective illustration of biotechnological and bioremediation aspects will be positively considered. Under emergency conditions, the examination mode may change.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ1097998/NO

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Master's degree in **INDUSTRIAL BIOTECHNOLOGY ORD. 2014**, Second semester
Lecturer: Prof.ssa SABRINA ANTONELLO
Credits: 6 ECTS
Prerequisites:
B.Sc. level knowledge of Physical Chemistry and Organic Chemistry.

Short program:

Examination:
Written exam based on a series of tests, to be taken during the semester, and one final, to be taken on the first official date. Each test consists usually in four open questions that could require to draw graphs, report equations and make simple calculations.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1731/000ZZ/SCQ1097952/NO

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Master's degree in **INDUSTRIAL CHEMISTRY ORD. 2015**, First semester
Lecturer: Prof. LUCA DELL'AMICO
Credits: 6 ECTS
Prerequisites:
Good knowledge in synthetic and organic chemistry. It is strongly recommended to have passed the exam of Applied Organic Chemistry II / Organic

**Examination:**
The exam consists of a written assay, on a focused topic on process analytical control, and an oral exam with the presentation and discussion of the assay, follow by two questions on the core topics of the course. The final mark is calculated from the assessment marks of the written assay and oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCQ21011101/NO

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**ANALYTICAL CHEMISTRY OF INDUSTRIAL PROCESSES**

**Master's degree in INDUSTRIAL CHEMISTRY ORD. 2015, Second semester**

**Lecturer:** Prof. MARCO FRASCONI

**Credits:** 6 ECTS

**Prerequisites:** Knowledge of instrumental analysis: molecular spectroscopy (UV-Vis and infrared spectroscopies), electroanalytical chemistry (potentiometry and voltammetry), gas-chromatography and high-performance liquid chromatography.

**Short program:**

**Examination:**
The exam consists of a written assay, on a focused topic on process analytical control, and an oral exam with the presentation and discussion of the assay, follow by two questions on the core topics of the course. The final mark is calculated from the assessment marks of the written assay and oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCP9087648/NO

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**BIOPOLYMERS**

**Master's degree in INDUSTRIAL CHEMISTRY ORD. 2015, First semester**

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
None beyond the requisites for admission to the Master's course.

**Short program:**

Examination:
The exam is oral

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCP9087649/NO

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### BIOPOLYMERS

<table>
<thead>
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<th>Master’s degree in <strong>INDUSTRIAL CHEMISTRY ORD. 2015</strong>, First semester</th>
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<tbody>
<tr>
<td><strong>Lecturer:</strong> to be defined</td>
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<tr>
<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> None beyond the requisites for admission to the Master's course.</td>
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**Short program:**


Examination:
The exam is oral

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCP9087649/NO

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### PHYSICAL METHODS IN ORGANIC CHEMISTRY

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<tr>
<td><strong>Lecturer:</strong> Prof.ssa ESTER MAROTTA</td>
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<tr>
<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> Good understanding of organic chemistry and basic concepts of NMR spectroscopy and mass spectrometry</td>
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**Short program:**


Examination:
Written test

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCP9087647/NO
PHYSICAL METHODS IN ORGANIC CHEMISTRY

Master's degree in INDUSTRIAL CHEMISTRY ORD. 2015, First semester

Lecturer: Prof.ssa ESTER MAROTTA

Credits: 6 ECTS

Prerequisites:
Good understanding of organic chemistry and basic concepts of NMR spectroscopy and mass spectrometry

Short program:

Examination:
Written test

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1170/000ZZ/SCP9087647/NO

MARINE BIOLOGY ORD. 2021

BIODIVERSITY AND BEHAVIOUR

Master’s degree in MARINE BIOLOGY ORD. 2021, First semester

Lecturer: Prof. GIL GUASTONI ROSENTHAL

Credits: 8 ECTS

Prerequisites:
To successfully follow this course, students are recommended to have taken at least two previous courses in ecology and/or evolutionary biology.

Short program:
Microevolution: population and quantitative genetics; the key role of evolution in shaping biodiversity. Behavioral strategies; sexual selection; animal communication; cognitive mechanisms; quantitative models of decision making, optimal foraging, and game theory. Biodiversity as the web of complex interrelationships between organisms, the contribution of the study of animal behavior to understanding the concept of biodiversity. The study of reproductive behaviour, parental care, mimicry and social life, using the most modern concepts of behavioral ecology. Anthropic pressures on aquatic species and habitats. Anthropic impacts on aquatic species behavior.

Examination:
The evaluation is organized in two parts: - the oral presentation of an article relating to the topics covered in class; - a written test with 2 open questions

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093498/NO

ECOLOGY AND PHYSIOLOGY OF GLOBAL CHANGES

Master's degree in MARINE BIOLOGY ORD. 2021, Second semester

Lecturer: Prof.ssa LAURA AIROLDI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of Marine Ecology and Biochemistry and Animal Physiology.

Short program:
1st module Airoldi 1) Introduction 2) The main drivers of ocean change and their pressures on ocean ecosystems 3) The consequences of global changes
on key marine systems and human welfare 4) Unique ecological conditions of marine urban ecosystems – changes in the physical and chemical 
environment; changes in biogenic habitat cover and biodiversity; losers and winners in urban habitats and the spread of invasive species; altered 
connectivity 5) Indicators of environmental quality in urban environments (e.g. the human footprint, the Ocean health index, etc) and the challenges of 
managing multiple stressors 6) Conservation and restoration in an rapidly changing context We will elaborate on some concepts through discussion groups 
of relevant papers 2nd module Santovito Physiological responses to environmental temperature changes: thermal relationships between an animal and its 
environment; effects of temperature and thermal adaptation; body temperature and tolerance to temperature variations; thermoreception; thermoregulation 
mechanisms; homeothermia, poikilothermia and heterothermia; adaptations to extreme environmental conditions. Physiological responses to the increase 
in the environmental CO2 concentration: chemical and protein buffers; regulation of the acid-base balance of body fluids; cellular defense systems against 
hypercapnia; environmental acidosis. Physiological responses to the variation of the environmental O2 concentration: the cellular defense systems against 
hypoxia and hyperoxia.

Examination:
There will be 6 exam sessions during the year, two for each exam session. The assessment will consist in a written test with both open and closed 
questions, possibly followed by an oral evaluation. The contents presented, as well as the activities carried out during the discussion groups and practical 
sessions, will form an integral part of the study program. The exam may be taken separately for the 2 modules. The exam grade awarded may be refused 
up to a maximum of two times.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093618/NO

### EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

**Master's degree in MARINE BIOLOGY ORD. 2021, First semester**

**Lecturer:** Dott. DUC KHANH TO

**Credits:** 6 ECTS

**Prerequisites:**
No prerequisites are required to attend the course

**Short program:**
First part (2 CFU + 1 CFU practical): Focus is on testing hypotheses for cause and effect. Via examples of selected experiments, discussions of hot topic 
articles, and group self-practice students will be introduced to the methodological and design issues in planning an experiment. The aim is building the 
knowledge basis to enable students to have a fully designed experiment, which can be carried out as a thesis dissertation proposal or research paper. We 
will go through controlled experiments and field experiments, single factor experiments and factorial designs, manipulation checks, environmental impact 
assessment etc.; and walk through the steps in deciding which of these elements can be best used in the creation of each experiment. Specific topics 
include: 1) General structure of a scientific paper 2) The scientific method - a logical framework for hypothesis testing in ecology 3) components of an 
experimental test; hypothesis and statistical test; statistical population and representative sampling; variables, parameters, and frequency distributions; 
precision, accuracy and bias; 4) Experimental design: Factorial and nested designs; fixed and random factors; replication and pseudoreplication; random, 
systematic, stratified allocation of sampling units; interspersion and independence of sampling units; controls and experimental artefacts; BACI designs for 
impact assessment and other asymmetrical designs 5) Sampling: number of replicates; Sample size; how to allocate replication in space and time; 
measured response variables and sampling approaches 6) How to prepare a good data set and analyse collected data. 7) How to interpret and present the 
outcomes. Second part (2 CFU +1 CFU practical): univariate and multivariate methods to evaluate association among biotic and abiotic variables, their 
relationships and presence of structures with gradients in experimental data. Specifically: inferential methods; multiple regression; principal component 
analysis and multi dimensional scaling.

**Examination:**
The evaluation includes two parts, according to the course structure. The first part of the evaluation consists of a written exam with an open question on 
the application of the tools learnt during the course to a case study. The second part consists of a practical exam in informatics lab. The finale score is the 
weighted average of the two scores.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093518/NO

### FARMING AND FEEDING OF AQUATIC SPECIES

**Master's degree in MARINE BIOLOGY ORD. 2021, First semester**

**Lecturer:** Dott. MARCO BIROLO

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge (bacelor degree) of chemistry and biochemistry, animal biology, anatomy and physiology of aquatic species. It is suggested to have 
previously taken the exam of Production, Inspection and quality of farmed organism.
FISH REPRODUCTION IN AQUACULTURE

Master's degree in MARINE BIOLOGY ORD. 2021. First semester

Lecturer: Prof.ssa DANIELA BERTOTTO

Credits: 8 ECTS

Prerequisites: Students are required to have basic knowledge in anatomy and physiology of fishes.

Short program:
Theory lectures will focus on: Sexuality and reproductive patterns in fishes. Anatomy of fish reproductive organs. Reproductive cycles and gonadal development. Endocrinology of reproduction. Artificial fertilization. Environmental control of reproduction. Reproductive dysfunctions in captivity and hormonal therapies. Assessment of gamete quality and cryoconservation. Sex determination, sex reversal and induction of sterility in fishes. Chromosome manipulation in fish. Reproduction and stress. Hints of bony fish embryo and larval development. The reproduction of molluscs and crustaceans will also be covered in a basic way to provide essential information on the reproduction and the first breeding phases of these animals in farming conditions. Lab sessions will focus on the evaluation of pre and post fertilization gamete quality, on embryo and larval development and mating.

Examination:
The exam includes at least two open questions based on the topics covered, and aimed at assessing comprehension, critical thinking skills and the ability to identify interrelationships between issues, as well as a good command of scientific language.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093501/NO

LIFE CYCLES AND ADAPTATIONS OF MARINE ORGANISMS

Master's degree in MARINE BIOLOGY ORD. 2021. Second semester

Lecturer: Prof. GIANFRANCO SANTOVITO

Credits: 10 ECTS

Prerequisites: Knowledge of Physics (especially fluid dynamics), Biochemistry, Cell Biology, Botany, Zoology, General Physiology, Plant Physiology and General Ecology.

Short program:

Examination:
The verification will consist in a written test with open questions, eventually followed by an oral evaluation. Both the contents presented, and the activities
carried out during practical sessions, will constitute an integral part of the study program.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093579/NO

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<th>MARINE BIODIVERSITY</th>
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<tr>
<td><strong>Lecturer:</strong> Prof.ssa CARLOTTA MAZZOLDI</td>
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<td><strong>Credits:</strong> 9 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> Knowledge of zoology, comparative anatomy, botany and systematic botany.</td>
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<tr>
<td><strong>Short program:</strong> General features and phylogeny of marine photosynthetic organisms. Biodiversity of marine cyanobacteria, microalgae, and seaweeds: origin and evolution; cell structure; anatomic and morphological characteristics; biochemical and molecular features, distribution, and systematics. Marine macrophyte communities: seagrasses and mangroves. Morphological and anatomical characteristics, biodiversity, and distribution. Systematics of the Mediterranean seagrasses. Cultivation of marine photosynthetic organisms: cell isolation and setting up of algal cultures. Main marine animal taxa, their general features, and phylogenetic relationships: sponges, cnidarians, ctenophores, worms, molluscs, crustaceans, lophophorates, echinoderms, tunicates, cartilaginous and bony fish, marine reptiles, mammals and birds. Form, function, and adaptations: morphological adaptations for locomotion, feeding modes, sensorial systems, reproduction. Organisms and environment: benthos, plankton, and nekton; main adaptations to different environments, the role of organisms in the trophic webs.</td>
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<td><strong>Examination:</strong> The evaluation consists of a written exam with open questions and a multiple-choice test. The questions will be focused on the knowledge of the course topics while the multiple-choice test will allow verifying the accurateness of the acquired knowledge.</td>
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<td>More information:</td>
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<tr>
<th>MARINE CONSERVATION: PRINCIPLES AND APPLICATIONS</th>
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<td>Master's degree in <strong>MARINE BIOLOGY ORD. 2021</strong>, Second semester</td>
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<tr>
<td><strong>Lecturer:</strong> Prof. ALBERTO BARAUSSE</td>
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<td><strong>Credits:</strong> 8 ECTS</td>
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<td><strong>Prerequisites:</strong> No one.</td>
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<td><strong>Short program:</strong> The course will focus on concepts and principles of marine conservation and management as well as on how they are applied, making use of real world examples and case studies whenever possible to show the management relevance of these topics. Principles of Marine Conservation: 1) Marine conservation, management and environmental protection 2) Major threats to marine biodiversity, such as climate change, fishing, alien species invasion, eutrophication, pollution, aquaculture, as well as recently recognized sources of impact (windfarms, etc.) 3) Extinction risks and drivers 4) The Ecosystem Approach 5) MPAs and spatial protection measures 6) Quantitative and modeling tools to support marine management and conservation: single species models, multispecies and ecosystem models, etc. 7) Stakeholder participation Applications of Marine Conservation 1) UN Sustainable Development Goals 2) Common Fisheries Policy 3) The EU approach to the protection of the sea: Water Framework Directive, Birds and Habitats Directives, Marine Strategy Framework Directive, Maritime Spatial Planning Directive 4) Citizen Science and NGOs 5) Nature based solutions</td>
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<td><strong>Examination:</strong> Written exam.</td>
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<td>More information:</td>
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<tr>
<th>MARINE ECOLOGY: PATTERNS AND PROCESSES</th>
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<tr>
<td>Master's degree in <strong>MARINE BIOLOGY ORD. 2021</strong>, First semester</td>
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<tr>
<td><strong>Lecturer:</strong> Prof.ssa LAURA AIROLDI</td>
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<tr>
<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> Basic knowledge of ecology, and biology of marine organisms.</td>
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<td><strong>Short program:</strong></td>
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The lectures will cover a variety of coastal ecosystems. For each ecosystem we will analyse: • Main environmental characteristics • Main ecological processes and functioning, with emphasis on experimental work focusing on some particularly well studied processes • Human-induced threats and conservation and restoration approaches. The course is structured as follows: 1) Introduction to Marine Ecology 2) The physical environment and the marine biomes 3) Introduction to the concept of ecosystem services 4) Introduction to the concept of habitat shifts and novel ecosystems 5) Intertidal rocky bottoms - experiments on the role of competition, predator-prey interactions and bottom up effects 6) Subtidal rocky bottoms and canopy forming macroalgae & kelp forests - experiments on the role of disturbance, trophic cascades, and the effects of sedimentation 7) Estuarine environments, saltmarshes, mangroves - experiments on the role of positive interactions and of the effects of excessive nutrient loads 8) Seagrasses – focus on productivity, trophic transfer and the role of microbial communities 9) Oyster reefs, coralligenous reefs, coral reefs and other biogenic reefs 10) Soft-bottoms and deep sea ecosystems 11) Artificial man-made habitats – focus on eco-design of marine artificial structures. We will elaborate on some concepts through discussion groups of relevant papers. We will also carry out field excursions to visit coastal marine ecosystems of the region.

Examination:
The course will have 6 exam sessions during the year, two for each exam session. The exams will be written and will include about 20 questions both closed and open (the questions will cover all the topics of the course). The exam grade awarded may be refused up to a maximum of two times.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093552/NO

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**MARINE ECOTOXICOLOGY**

Master's degree in Marine Biology Ord. 2021, First semester

**Lecturer:** Dott. MARCO MUNARI

**Credits:** 6 ECTS

**Prerequisites:** None

**Short program:**
1) Introduction to Ecotoxicology: origins and evolution of an interdisciplinary science (0.25 CFU) 2) Contaminants in the marine environment: traditional and emerging contaminants (0.25 CFU) 3) Contaminants and biota. Bioavailability, bioconcentration, bioaccumulation and biomagnification; routes of intake, sites of accumulation, biotransformation, detoxification and activation processes, elimination mechanisms (0.5 CFU) 4) Bioindicators, Biomonitoring, Biomarkers (1 CFU) 5) Case studies in the laboratory and in the field on the effects of exposure to contaminants at the cellular, organism, population and community level. Toxicity tests: acute and chronic tests, tests on early stages of fish and marine invertebrates (3 CFU) 6) Omics approach in ecotoxicological studies (1 CFU).

**Examination:**
Written verification, with multiple choice and open-ended questions.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ1097379/NO

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**MARINE MICROBIOLOGY**

Master's degree in Marine Biology Ord. 2021, First semester

**Lecturer:** Prof.ssa PAOLA VENIER

**Credits:** 6 ECTS

**Prerequisites:** No prerequisites. However, notions of microbiology and biochemistry are essential.

**Short program:**
Introduction: historical development of marine microbiology; types of marine microorganisms and relative abundance, morpho-structural and habitat varieties, evolutionary peculiarities, current taxonomy (1.5 CFU). Methods to quantify, identify and characterize marine micro-organisms (0.5 CFU). Analysis "16S rRNA amplicon sequencing" in computer lab (1 CFU). Marine prokaryotes: main metabolic types; mixotrophy; syntrophy; extremophiles; variety, peculiarities and interactions in the Bacteria and Archaea domains. Marine microeukaryotes (in general) (0.5 CFU). Marine viruses: classification, structure, and replication strategies through examples (1 CFU). Marine microorganisms in the trophic network: microbial loop, viral shunt, biological pump, biogeochemical cycles (0.75 CFU). Marine microbial symbionts; microbial bioremediation in marine environment (0.75 CFU).

**Examination:**
Written examination (questionnaire) or oral examination (interview) depending on the number of participants. In emergency conditions, the examination mode may change. The student will be tested on the course contents (50%) as well as on one or two specific topics, previously agreed with the teacher and individually prepared (50%).

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093500/NO
MOLECULAR METHODS FOR MANAGEMENT AND AQUACULTURE

Master’s degree in MARINE BIOLOGY ORD. 2021, First semester

Lecturer: Prof.ssa CHIARA PAPETTI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of Ecology, Population Genetics, Botany, Zoology and Statistics. The course will be held in English, hence an understanding of written and spoken English is required

Short program:
Review of population genetics: factors that determine genetic variability. Characteristics of marine organisms and their effects at the genetic level. Effective population size. Environment and distribution of polymorphisms on a geographical and evolutionary scale. Types of molecular markers: mitochondrial markers, microsatellites, AFLP, SNPs. Laboratory methodologies. Types of data produced by molecular markers and associated analyzes. Analysis at the individual population level. Comparison between populations. Choice of markers in relation to the biological problem. Identification of individuals by genetic markers, marking and recapture with genetic methods, estimation of the historical size of the population, estimation of geographical differentiation, identification of stocks, and mixed stock assessment. During the course, examples and case studies will be presented in order to expand on some of the main themes, pointing out the sampling design, the methods and markers used, the characteristics of the species analyzed, and the data analysis. During the course, a molecular ecology laboratory will be proposed during which the main basic molecular biology techniques (e.g. DNA extraction, PCR, sequencing/genotyping) will be applied to the solution of an ecological problem. The data will be analyzed with the main molecular analysis software.

Examination:
The exam consists of three parts: two group works to be carried out during the course (presentation of molecular markers, 10 points and an interview with an expert, 10 points) and a written test (3-4 open-ended questions, 10 points) to be done during the usual exam session. Some changes to the evaluation plan and to the course general approaches may be agreed on with students. Details on the structure of the exam, subdivision of the scores between each part will be illustrated again during the first lessons and, upon request, also later. The exam rules will be made available also via moodle (descriptive slides and video recording). To facilitate understanding of the examination procedures and evaluation criteria, a simulation will take place during the course with some of the possible exam questions or by organizing study groups.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093553/NO

PATHOLOGY OF AQUATIC ORGANISMS

Master’s degree in MARINE BIOLOGY ORD. 2021, First semester

Lecturer: Dott. SANDRO MAZZARIOL

Credits: 6 ECTS

Short program:
DISEASE AND PATHOLOGY of COMMERCIAL MARINE SPECIES (FISH & SEA FOOD) - Diagnostic methodology in fish pathology: the environmental survey, anamnestic data, clinical examination, sampling, technique of necropsy, identification of organs, histopathology, laboratory analyses. - Prevention and control applied to infectious diseases in aquaculture. - Non-specific and specific defense mechanisms, vaccination of farmed fish. - Infectious fish diseases (viral, bacterial and parasitic diseases). Main diseases of crustaceans and molluscs. POST-MORTEM INVESTIGATIONS ON SEA TURTLE AND MARINE MAMMALS - Basic anatomy and physiology of sea turtles and cetaceans. - Principle of Post-mortem techniques and tissue sampling. Ancillary examinations. Detection of evidences of human interaction. - Main diseases and pathology: virus, bacteria and parasites in a changing sea. - Relevant threats associated with human activities. - The use of collected data for the implementation of EU Directives (i.e. Habitat, Marine Strategy Framework Directive) and International Agreements (i.e. ACCOBAMS, ASCOBANS, RAC/SPA, etc.)

Examination:
The students will be assessed using a written examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ1097398/NO

PHARMACOLOGY, TOXICOLOGY AND WELFARE IN AQUACULTURE

Master’s degree in MARINE BIOLOGY ORD. 2021, Second semester

Lecturer: Prof. MARCO DE LIGUORO

Credits: 8 ECTS

Prerequisites:
Basic knowledge of chemistry, biochemistry, biology, microbiology, anatomy and physiology is recommended.

Short program:
Pharmacotoxicology module (5 credits) General principles of pharmacokinetics and toxicokinetics. The use of pharmaceuticals and disinfectants in aquaculture, with particular reference to dosage forms, prescription, and administration methods. Different criteria and rules for the use of pharmaceuticals in food-producing and in ornamental fish: understanding the specific issues and the related legislation. Fate of active principles in the environment. Drug residues and contaminants from industrial and natural sources in fish products and in the aquatic compartment: risk assessment for the consumer and the environment. Laboratory activities: 1) Setting up aquatic toxicity tests on crustaceans - Acute immobilization test in Daphnia magna - Embryonic toxicity test in Daphnia magna 2) Processing of acute and chronic aquatic ecotoxicity test data - ECx calculation - Determination of LOEC and NOEC 3) Aquatic toxicity test on Rapidocelis subcapitata - Method for culturing the unicellular green alga - Algal cell count on Barker's chamber Welfare module (3 credits) Definition of animal welfare, related legislation and applicability to fish. Human interactions with fish and effects of such interactions on fish welfare. Fish physiology with particular reference to the welfare of farmed fish. The stress response and the ability to feel pain and fear in fish. The main factors affecting the welfare of farmed fish. Physiological, behavioural and health indicators for the evaluation of fish welfare in farming and related analytical methods. Laboratory activities: 1) Preparation of aquatic toxicity tests on crustaceans 2) Dissection of Sea Bass; sampling of tissue and organs for the evaluation of fish welfare; hematocrit and erythrocyte and leukocyte cells count by hemocytometer; preparation and evaluation of blood smear . 3) Radioimmunoassay, immunohistochemistry, protein assay and Western Blot analysis to evaluate fish welfare.

Examination: There is an oral examination at the end of the Course. The exam includes at least five questions based on the topics covered, and aimed at assessing comprehension, critical thinking skills and the ability to identify interrelationships between issues, as well as a good command of scientific language.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093619/NO

SEAFood Sustainability, Production and Control

Master's degree in Marine Biology Ord. 2021, Second semester

Lecturer: Prof.ssa Angela Trocino

Credits: 6 ECTS

Prerequisites: None

Short program: The module consists of two parts which refer to Production systems and product quality (40 hours, AGR/20, Prof. Angela Trocino) and hygiene and control of safety of fish products (24 hours, VET/04, Prof. Luca Fasolato). AGR/20 Aquaculture and fisheries. Fish production and consumption in Italy and all over the world, main problems and perspectives. Definition, classification and description of aquaculture systems. Water quality and management in aquaculture. Nutritional and sensorial evaluation of fish products. Factors affecting fish quality. Freshness evolution. Production and quality of fresh, frozen and transformed fish products. Seminars, Active learning, visits at commercial plants. VET/04 Inspection and control of the hygienic status of fishery products, sector problems, regulatory context and role of the Food and Business Operator (FBO). Introduction to risks in the industry, intrinsic and extrinsic factors that influence microbiological risks in products. Foodborne pathogens of fish products and parasitic disease, notes on analytical methods. Control according to the EU regulations of freshness, Edible molluscs bivalves. Harvesting, packaging and labeling of live bivalve molluscs. Food fraud in the fish sector. HACCP procedures in the fish products sector. Laboratories activities and technical visits in production plants.

Examination: The exam will consist of a written examination with open questions, multiple choices questions, and exercises.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC2596/000ZZ/SCQ0093598/NO

Material Science Ord. 2015

Physics of Disordered Materials

Master's degree in Material Science Ord. 2015, First semester

Lecturer: Prof. Giulio Monaco

Credits: 6 ECTS

Prerequisites: Notions of quantum mechanics and physics of matter.


Examination:
Oral examination and talk on a topic discussed during the course and chosen together with the student.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCQ1097162/NO
FUNDAMENTALS OF NANOSCIENCE

Master's degree in MATERIAL SCIENCE ORD. 2015, Second semester

Lecturer: Prof. GIOVANNI MATTEI

Credits: 8 ECTS

Prerequisites:
Electromagnetism, Quantum Physics (particle in a box, quantum confinement), Solid State Physics (phononic and electronic structures of solids, thermal and optical properties)

Short program:

Examination:
1) Fundamentals of NanoScience (MSc in Materials Science) The exam is written (duration 2 h) with two open questions and a set of multiple-choice questions. 2) Introduction to NanoPhysics (MSc in PHYSICS) The exam is written (duration 2 h) with an open question and an exercise with numerical applications of the learned topics. 3) Fundamentals of NanoScience (MSc in Materials Engineering) The exam is written (duration 2 h) with one open question and a set of multiple-choice questions.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC1174/000ZZ/SCQ0090018/NO

MATERIALS TECHNOLOGY

Master's degree in MATERIAL SCIENCE ORD. 2015, First semester

Lecturer: Prof. CHRISTIAN DURANTE

Credits: 6 ECTS

Prerequisites:
Knowledge of general chemistry (General and inorganic Chemistry), thermodynamics (Physical Chemistry), -ionic and electronic conduction - acid base properties - thermodynamic quantities - chemical kinetics and kinetic theories - atomic and molecular orbitals, band theory - properties of polymers, metals and gases

Short program:

Examination:
Oral examination generally based on three topics: -electrochemical kinetic theory -electrochemical techniques/ electrodeposition techniques - energy conversion and storage devices/ properties of electronic materials The possibility of carrying out the exam in written form with three intermediate tests will also be evaluated, in relation to student requests

More information:
https://en.didattica.unipd.it/off/2022/LM/SC1174/000ZZ/SCP9087651/NO

110/233
Master's degree in MATERIAL SCIENCE ORD. 2015, First semester

**Lecturer:** Prof. ALESSANDRO MARTUCCI

**Credits:** 6 ECTS

**Prerequisites:**
The course requires the knowledge of the Bachelor's Degree Fundamentals of Materials Science exam.

**Short program:**

**Examination:**
Oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCQ0090019/NO

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**NANOFABRICATION**

Master's degree in MATERIAL SCIENCE ORD. 2015, First semester

**Lecturer:** Prof. FILIPPO ROMANATO

**Credits:** 6 ECTS

**Prerequisites:**
third year courses in materials science, optics, matter structure

**Short program:**
Many of the impressive technical and scientific advances of the last two decades are based on the ability to control individual chemical-physical phenomena at the level of a few nanometers, that is, on the scale of size at which most natural phenomena occur. This control was obtained by developing micro and nano fabrication systems and processes for the realization of devices (also called lab-on-chip) capable of exchanging signals (detection and actuation) with systems of the size of a few nanometers, coining, in fact, the definition of nanotechnology. The course is aimed at students (materials sciences, physics) in view of the degree thesis for the broad correlation between physical, chemical, biochemical phenomena that nanofabrication processes require in view of the realization of nanostructures and nanodevices. Opening themes towards the research of nanosciences are discussed. The course will discuss the miniaturization process and the scale reduction process of many natural phenomena that distinguish the functioning of nanodevices. The main nanofabrication technologies will be presented and examples of applications for the realization of nanoscience devices and experiments will be presented. After a general distinction between top-down and bottom-up processes, lithography technologies (UV, electronics, X-ray, ionic, imprinting, interferential etc), deposition processes (plasma assisted, in vapor or chemical phase, will be illustrated). sol-gel etc.) and subtraction in the gas phase (reactive ion etching, milling) or liquid (chemical etching). The manufacturing technology of silicon-based electronic devices will be reviewed. Simulation exercises for the design of nanosystems are proposed. The course is completed by visits to the nanofab Padua at the LaNN laboratory and in Trieste at the CNR nanofabrication laboratories at the Elettra synchrotron. During these visits there will be practical demonstrations of the lithographic processes treated during the classroom course.

**Examination:**
Deepening of a topic, preparation of a presentation, written discussion. Oral exam, presentation of the paper and verification of the learning of the main concepts of nanolithography.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP9087654/NO

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**OPTICS AND LASER PHYSICS**

Master's degree in MATERIAL SCIENCE ORD. 2015, First semester

**Lecturer:** Prof.ssa TIZIANA CESCA

**Credits:** 6 ECTS

**Prerequisites:**
Topics learned in basic courses of Mathematics and Physics.

**Short program:**
Classical optics: - propagation of electromagnetic waves; - polarization, birefringence, interference and diffraction; - geometrical optics and matrix method; - main optical instruments; Lasers: - the laser idea and proprieties of laser beams; - absorption, spontaneous emission, stimulated emission; - gain and population inversion; - optical cavities and pumping; - cw lasers; - pulsed lasers: Q-switch and mode-locking; - examples of main different laser types: gas lasers, solid-state lasers Introduction to Quantum Optics: - Photon statistics - buching and antibuching; - weak and strong coupling: Purcell effect and Rabi splitting.

**Examination:**
111/233
The exam is written and comprises two exercises and one open question.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP7081800/NO

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**OPTICS OF MATERIALS**

Master's degree in **MATERIAL SCIENCE ORD. 2015**, First semester

**Lecturer:** Prof. MORENO MENEGHETTI  
**Credits:** 6 ECTS  
**Prerequisites:** Basic knowledge of electromagnetic wave propagation and of quantum mechanics.

**Short program:**  

**Examination:**  
Examination will be an oral test.

More information:  
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP9087655/NO

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**ORGANIC FUNCTIONAL MATERIALS**

Master's degree in **MATERIAL SCIENCE ORD. 2015**, First semester

**Lecturer:** Prof.ssa MIRIAM MBA BLAZQUEZ  
**Credits:** 6 ECTS  
**Prerequisites:** Organic Chemistry courses of the 1st cycle Degree: nomenclature of organic molecules, organic functional groups electrophile and nucleophile basicity and acidity addition reactions (alkenes) nucleophilic substitution (alcohols, halogenated compounds) Electrophilic aromatic substitution (reactions of aromatic compounds) Polymers: basic concepts

**Short program:**  

**Examination:**  
Written exam. 5 questions.

More information:  
https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP9087652/NO

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**PHYSICS AND TECHNOLOGY OF SEMICONDUCTORS**

Master's degree in **MATERIAL SCIENCE ORD. 2015**, First semester

**Lecturer:** Prof. DAVIDE DE SALVADOR  
**Credits:** 8 ECTS  


Examination: Oral exam. During the semester it will be possible to give a mid-term oral exam about the first part of the course concerning physical principles; at the end a second oral exam on the devices and processes will complete the final grade.

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP9087650/NO

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**SUPERCONDUCTING MATERIALS**

Master's degree in MATERIAL SCIENCE ORD. 2015, Second semester

**Lecturer:** Dott. CRISTIAN PIRA

**Credits:** 6 ECTS

**Prerequisites:**

Solid State Physics

**Short program:**

The Course is divided into two main parts. A first part that by using a phenomenological approach presents the main properties of superconductors and the three main theories that describe their behavior. A second part focused on the characteristics of different superconducting materials and their applications, with special attention to particle accelerators. Other applications of superconductors will be presented by international experts (if possible) and by the students themselves, who will prepare each (or in groups) a specific small seminar. COURSE DETAIL: Introduction to cryogenics (history of helium liquefaction, helium phase diagram, thermal conduction in solids, thermal shielding, cryogenic refrigeration techniques), fundamental properties of superconductors (history of the discovery of superconductivity, zero resistance, ideal conductors and superconductors, Meissner effect, type I and type II superconductors, Vortices in SCs, flux quantization, isotopic effect, thermodynamic approach to SC, pinning, Josephson effect), fundamentals of the main phenomenological and microscopic theories (London theory, Ginzburg Landau theory, BCS ter theory), superconducting materials (BCS superconductors: elements and alloys, organic compounds, high Tc superconductors), commercial superconducting materials (NbTi, Nb3Sn, MgB2, REBCO, production and characteristics), introduction to accelerator technology (superconducting magnets, accelerator cavities), fundamentals of superconductivity in radio frequency (surface resistance in SCs, contributions to residual resistance, superheating critical field, limits to the performance of SRF cavities: multipactoring, thermal breakdown, field emission, Q-diseases and possible solutions), materials for SRFs: bulk Nb and thin films, applications of superconductivity (seminars by international experts + student presentations).

**Examination:**

The evaluation exam on the knowledge and expected skills is based on an oral discussion (of about half an hour), in which open questions on the arguments of the course will be submitted

More information: https://en.didattica.unipd.it/off/2022/LM/SC/SC1174/000ZZ/SCP9087678/NO

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**SUSTAINABLE ENERGY: MATERIALS AND TECHNOLOGIES**

Master's degree in MATERIAL SCIENCE ORD. 2015, Second semester

**Lecturer:** Prof.ssa LAURA CALVILLO LAMANA

**Credits:** 6 ECTS

**Prerequisites:**

Fundamental concepts of Chemical Thermodynamics and Kinetics Fundamental concepts of Electrochemistry

**Short program:**

# MATHEMATICS ORD. 2011

## HAMILTONIAN DYNAMICAL SYSTEM

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** to be defined  
**Credits:** 6 ECTS  

## INTRODUCTION TO CELESTIAL AND HAMILTONIAN MECHANICS

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** to be defined  
**Credits:** 6 ECTS  

## INTRODUCTION TO EVOLUTION PDES

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** to be defined  
**Credits:** 6 ECTS  

## INTRODUCTION TO NON-LINEAR PDES

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** to be defined  
**Credits:** 6 ECTS  

## JUMP PROCESSES

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** to be defined
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ADVANCED ANALYSIS

Master's degree in MATHEMATICS ORD. 2011, Second semester

Lecturer: Prof. GIOVANNI COLOMBO

Credits: 8 ECTS

Prerequisites:
Basic real and functional analysis (some results will be recalled during the first lecture)

Short program:

Examination:
An oral exam on the topics covered by the course, that will include some exercises, among those that were assigned during the course.

More information:

CALCULUS OF VARIATIONS

Master's degree in MATHEMATICS ORD. 2011, Second semester

Lecturer: Prof. ROBERTO MONTI

Credits: 8 ECTS

Prerequisites:
The Analysis 1 and 2 and the Real Analysis courses

Short program:
(1) Classic functionals of the Calculus of Variations (a) Euler-Lagrange's equations (b) Du Bois-Reymon's equation (c) Indirect methods and convexity methods (d) Fermat's principle for the geometrical optics (e) Brachistochrone's problem (2) Semi-direct methods (a) Functionals depending on the gradient (b) Bounded slope condition (3) Direct method of the Calculus of Variations (4) Functional in Sobolev spaces (a) Brief review on Sobolev spaces (b) Convexity and lower-semicontinuity in W1,p (c) Existence of minimizers in W1,p (d) Examples (e) Interior Sobolev regularity (f) Schauder regularity and De Giorgi-Nash theorem (without proofs) (5) Plateau's problem (a) The parametric formulation of Douglas-Radó (b) Brief introductions to BV functions and sets with finite perimeter (c) Plateau's problem for sets with finite perimeter (6) ?-convergence and applications to phase transition (a) Relaxation and ?-limits (7) The isoperimetric property of the sphere and its applications (a) Steiner's rearrangement (b) Isoperimetric property of the sphere (c) Quantitative version of the isoperimetric inequality (d) The best shape of a drum: minimum eigenvalue for ?u = ?u2 ? 1 (7) The isoperimetric inequality (8) Problems of minimal length (a) Compactness (b) Lower semicontinuity

Examination:
Homeworks and oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0093999/NO

DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2011, Second semester

Lecturer: Prof. MARTINO BARDI

Credits: 6 ECTS

Prerequisites:
Differential and integral calculus for functions of several variables; elementary theory of ordinary differential equations; some classical results in Functional Analysis.

Short program:

Examination:
Oral exam, either on the lectures of the course, including the exercises proposed to the students, or on some additional material related to the topics of the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0093962/NO

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**DYNAMICAL SYSTEMS**

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** Prof. LUIS CONSTANTINO GARCIA NARANJO ORTIZ DE LA HUERTA

**Credits:** 7 ECTS

**Prerequisites:**
1. Basic knowledge of the theory of ordinary differential equations (ODEs) and of the qualitative theory of ODEs, at the level of, e.g., the course "Fisica Matematica" which is offered as a mandatory course at the second year of the Corso di Laurea in Matematica in this University. 2. A basic knowledge of the programming language "Mathematica" (at the level of the tutorials periodically offered by the CCS and available on the YouTube channel of the Department of Mathematics) is useful, as it will be used in the numerical part of the course.

**Short program:**

**Examination:**
Oral examination on the topics studied in the course, and with an evaluation and a discussion of the numerical assignments (which will be assigned during the course). Students will prepare the numerical assignments by working either alone or in pairs, at their choice. This examination format allows to evaluate: 1) The level of the theoretical knowledge and mathematical comprehension of the subject reached by the student. 2) The abilities reached by the student in the analysis and comprehension of the numerical results.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094084/NO

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**FUNCTIONS THEORY**

Master's degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** Prof. DAVIDE VITTONE

**Credits:** 8 ECTS

**Prerequisites:**
Besides the courses of Analysis 1 and 2, the courses of Real Analysis and Functional Analysis 1

**Short program:**
Between brackets we denote topics that might be skipped or exposed without proofs according to time availability and/or audience interests. THEORY OF DISTRIBUTIONS Definitions, derivatives in the sense of distributions, order of a distribution, compactly supported distributions, convolutions, tempered distributions, Fourier transform, applications. SOBOLEV SPACES Definition and elementary properties, approximation theorems, boundary trace and extension results, Sobolev-Gagliardo-Nirenberg, Poincaré and Morrey inequalities, compactness theorems. ELEMENTS OF GEOMETRIC MEASURE THEORY Recap of some measure theoretical tools, covering theorems and differentiation of measures, Hausdorff measure and dimension, Lipschitz functions and Rademacher theorem, rectifiable sets, approximate tangent space. [area and coarea formulae]. FUNCTIONS WITH BOUNDED VARIATION Definition, approximation and compactness results, trace and extension theorems, coarea formula, sets with finite perimeter, isoperimetric inequalities, reduced boundary and structure theorem for sets with finite perimeter, [fine properties and decomposability of the derivative of a BV function]

**Examination:**
Home exercises (one exercises sheet for each of the four parts of the course), according to which a mark will be proposed to the student. Alternatively: written examination. An oral examination is optional.
HARMONIC ANALYSIS

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: Prof. PAOLO CIATTI

Credits: 6 ECTS

Prerequisites:
Calculus and Advanced Calculus, and, possibly, basics in real and complex analysis. A basic knowledge of Lebesgue integration and Lebesgue spaces, together with the basics in Hilbert space theory is highly recommended. Some knowledge of holomorphic function theory would be also helpful.

Short program:

Examination:
The final exam will be a take-home exam, consisting of roughly eight questions, and a discussion of the topics considered during the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094119/NO

INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: Prof.ssa LAURA CARAVENNA

Credits: 8 ECTS

Prerequisites:
Differential and integral calculus: basis on integration and differentiation, explicit integrals and derivatives of elementary functions, the fundamental theorem of calculus, basics on curves and surfaces. Green-Gauss-Stokes theorems and the theorems concerning limiting procedures in integrals are important but they will be revised at an essential level. Elementary theory of ordinary differential equations and on the Cauchy problem. Gronwall estimates and classical well posedness for ODEs will be recalled at an essential level. Basic theory of complex analysis: what are functions of complex variables, holomorphic and analytic functions, very essential properties as Cauchy–Riemann equations.

Short program:

Examination:
The exam consists of a final oral examination on the topics treated in class. There will be both theoretical questions and the discussion of some exercise to solve. The final exam could be reduced via in itinere activities.

More information:

INTRODUCTION TO STOCHASTIC PROCESSES

Master's degree in MATHEMATICS ORD. 2011, Second semester

Lecturer: Prof. BERNARDO D’AURIA

Credits: 8 ECTS

Prerequisites:
A basic course in Probability.

Short program:

Examination:
To be defined

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0093964/NO

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**NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS**

Master’s degree in **MATHEMATICS ORD. 2011**, Second semester

**Lecturer:** Prof. MARIO PUTTI

**Credits:** 7 ECTS

**Prerequisites:**
Mathematical Analysis 1 and 2, with elements of Differential Equations and functional analysis. Numerical Analysis and linear algebra. The lab projects require some knowledge of Matlab programming.

**Short program:**

**Examination:**
Oral examination with discussion on the lab projects.

**More information:**

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**STOCHASTIC ANALYSIS**

Master’s degree in **MATHEMATICS ORD. 2011**, First semester

**Lecturer:** Prof. DAVID BARBATO

**Credits:** 7 ECTS

**Prerequisites:**
Basic probability theory, basic analysis (differential calculus in \( \mathbb{R}^d \), ordinary differential equations), measure theory.

**Short program:**

**Examination:**
Th exam consists of two partial part, a written test and oral test.

**More information:**

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**STOCHASTIC METHODS FOR FINANCE**

Master’s degree in **MATHEMATICS ORD. 2011**, Second semester

**Lecturer:** Prof. MARTINO GRASSELLI

**Credits:** 7 ECTS
### Prerequisites:
Stochastic analysis

### Short program:

### Examination:
Final examination based on: Written and oral examination.

### More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094085/NO

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### SYMPLECTIC MECHANICS

**Master's degree in MATHEMATICS ORD. 2011, Second semester**  

**Lecturer:** Prof. FRANCESCO FASSO`  

**Credits:** 6 ECTS  

**Prerequisites:**  
Basic notions of Differential Geometry (manifolds, differential forms, vector fields), at the level at which they are treated in the course "Differential Geometry" at the first semester. Some knowledge of Lagrangian and Hamiltonian mechanics (at the level of the course "Fisica Matematica" of the II year of the Laurea Triennale) is useful but not strictly necessary.

**Short program:**  

**Examination:**  
Oral examination on the topics treated in the course.

### More information:

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### HAMILTONIAN DYNAMICAL SYSTEM

**Master's degree in MATHEMATICS ORD. 2011, First semester**  

**Lecturer:** to be defined  

**Credits:** 6 ECTS  

**More information:**  

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### INTRODUCTION TO CELESTIAL AND HAMILTONIAN MECHANICS

**Master's degree in MATHEMATICS ORD. 2011, First semester**  

**Lecturer:** to be defined  

**Credits:** 6 ECTS  

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INTRODUCTION TO EVOLUTION PDES

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094154/NO

INTRODUCTION TO NON-LINEAR PDES

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:

JUMP PROCESSES

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094156/NO

MONTE-CARLO AND DETERMINISTIC METHODS FOR PARABOLIC EQUATIONS

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:

NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS AND CONTROL

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1172/011PD/SCQ0094152/NO

STOCHASTIC CALCULUS
Master's degree in MATHEMATICS ORD. 2011, First semester

**STOCHASTIC CONTROL**

Master's degree in MATHEMATICS ORD. 2011, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:

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**MATHEMATICS ORD. 2022**

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**ALGEBRAIC GEOMETRY 1**

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. REMKE NANNE KLOOSTERMAN

Credits: 8 ECTS

Prerequisites:
Basic knowledge of commutative algebra (first half of the commutative algebra course).

Short program:
This course is intended as a introductory course in algebraic geometry, starting from the basics of the subject and progressing to more advanced techniques such as the study of sheaves and schemes. Contents: Affine varieties. The Zariski topology. The sheaf of regular functions on a variety. Morphisms of varieties. Projective varieties. Dimension of a variety. Introduction to schemes.

Examination:
Written exam, possibly taking homework assignments into account.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094306/NO

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**ALGEBRAIC GEOMETRY 2**

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. ERNESTO CARLO MISTRETTA

Credits: 6 ECTS

Prerequisites:
Basics in topology and differential geometry. It is recommended to have some knowledge on the theory of Riemann Surfaces.
Short program:
The course is thought about as a continuation in higher dimension of the ideas developed in the theory of Riemann Surfaces. - Preliminaries: holomorphic functions in complex variables, the difference with holomorphic functions in one complex variable. - Complex manifolds: definitions and first properties. - Complex tangent space, and complex differential calculus. - Vector Bundles: complex, hermitian, holomorphic vector bundles. Connections and curvature, the Chern connection. The example of line bundles. Chern forms. - Divisors, line bundles, and Picard group. Weil Divisors and Cartier divisors. - Kaehler manifolds: examples, volume form. Fubini-Study metric, smooth projective varieties as Kaehler manifolds. Examples of non-Kaehler varieties. - Introduction to cohomology: de Rham cohomology, Dolbeault cohomology. Short overview on singular cohomology and sheaf cohomology. The computation of some cohomology groups will be shown, this will serve as a motivation for more general theories (to be studied in other classes). - Analytic tools: integration, $L^2$ metric, operators on Kaehler manifolds, Laplacian. - Hodge identities, Hodge decomposition, Hodge symmetry. - Hodge decomposition in the algebraic case (projective varieties), Hodge conjecture. - 2 important theorems: Kodaira embedding theorem, Torelli's theorem.

Examination:
Seminar with questions.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094305/NO

COMMUTATIVE ALGEBRA

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof.ssa ORSOLA TOMMASI

Credits: 8 ECTS

Prerequisites:
Basic algebra notions (groups, rings, ideals, fields, quotients, etc.), as acquired in the "Algebra 1" course.

Short program:

Examination:
Written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094309/NO

COMPLEX ANALYSIS

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. MASSIMO LANZA DE CRISTOFORIS

Credits: 6 ECTS

Prerequisites:
Analysis courses of the first two years, and preferably the following courses Mathematical Methods Functional Analysis 1

Short program:
Real and complex differentiability in finite and infinite dimension. Complexification of a real problem The Riemann Mapping Theorem, integral representation of holomorphic functions, boundary behaviour and applications to the solution of boundary value problems

Examination:
Partial tests and final oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094308/NO
CRYPTOGRAPHY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ALESSANDRO LANGUASCO

Credits: 6 ECTS

Prerequisites:
For the first part (Prof. Languasco; 6 credits): The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): OS, Programming.

Short program:

Examination:
For the first part (Prof. Languasco; 6 credits): Written exam in class; if, due to the pandemic situation, this will not be possible the written exam will be done using the available videoconferencing tools. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): Written Exam, Homeworks, oral test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0093658/NO

HOMOLOGY AND COHOMOLOGY

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. JAKOB SCHOLBACH

Credits: 6 ECTS

Prerequisites:
we expect the student knows that it is possible to associate some invariants (fundamental group..), basic commutative algebra.

Short program:
Starting from the basic definition of the algebraic topology we will introduce the definition of homology and cohomology for a topological space. Singular, simplicial, cellular, relative, excisin, Mayer-vietoris. Tor and Ext: universal coefficients theorem. Cup and cap product: teh ring structure on the cohomology of a projective space and some other particular topological spaces. Eventually Poincare' duality.

Examination:
taylored on the basis of the students attitudes: written and homeworks during the semester.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094302/NO

INTRODUCTION TO GROUP THEORY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ANDREA LUCCHINI

Credits: 8 ECTS

Prerequisites:
Basic knowedges in general algebra
Short program:
General introduction to group theory: actions of groups, solvable and nilpotent groups, finitely presented groups. A short history of the classification of finite simple groups. Topological groups, pro-finite groups (characterizations, pro-finite completion, countable based pro-finite groups, arithmetical properties, subgroups of finite index in pro-finite groups, Galois groups of an infinite dimensional extension). Probabilistic methods in group theory.

Examination:
Oral. The candidate will be asked to present the most important arguments presented in the course, proving the more significant results and solving some related exercise.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094303/NO

INTRODUCTION TO RING THEORY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ALBERTO TONOLO

Credits: 8 ECTS

Prerequisites:
Algebra 1 and Algebra 2 courses

Short program:

Examination:
Written exam and possibly an oral one

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094304/NO

NUMBER THEORY 1

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. MATTEO LONGO

Credits: 8 ECTS

Prerequisites:
Standard basic courses in Algebra, Calculus, Topology, Linear Algebra. Galois Theory. Commutative Algebra may be useful.

Short program:

Examination:
Written examination.

More information:

NUMBER THEORY 2

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. ADRIAN IOVITA

Credits: 6 ECTS

Prerequisites:
Number Theory 1.

Short program:
The course will develop the theory of local fields following J.-P. Serre's book: Local fields. We will study: valuation rings, completions of valuation rings, complete discrete valuation fields of mixed characteristic and their finite extensions, the ramification filtration of the the Galois group of a finite, Galois extension of a local field. As an application we will study p-adic modular forms.

Examination:
Homework exercises will be handed in weekly, there will be a midterm exam and written final.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094300/NO

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**REPRESENTATION THEORY OF GROUPS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof.ssa GIOVANNA CARNOVALE

**Credits:** 6 ECTS

**Prerequisites:**
Basic notions in linear algebra and group theory.

**Short program:**
Representations, irreducible representations, Maschke's theorem, orthogonality of characters, induced representations, Frobenius reciprocity, representation indotte, formule di Mackey, reciprocity of Frobenius, Frobenius-Scur indicator, compact groups, linear algebraic groups and their Lie algebras, solvable, nilpotent and semisimple Lie algebras, Cartan's criterion, Killing form, Weyl's theorem, root space decomposition, root systems, classification of semisimple Lie algebras, universal enveloping algebras, finite dimensional irreducible representations of a semisimple Lie algebra.

**Examination:**
Unless sanitary emergency situation forces to do otherwise, the exam will be written, based on a series of exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094299/NO

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**RINGS AND MODULES**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. JORGE NUNO DOS SANTOS VITORIA

**Credits:** 6 ECTS

**Prerequisites:**
Notions from the Algebra courses of the first two years of the degree in Mathematics and basic notions on module theory over arbitrary rings.

**Short program:**
Categories, functors and natural transformations. Adjoint functors. additive and abelian categories. functor categories. limits and colimits. pullbacks and pushouts. left and right exact functors. projective, injective and flat modules. Examples for path algebras of quivers over a field. Categories of chain complexes and the homotopy category of an additive category. left and right derived functors. the functors Tor and Ext, Yoneda extensions. flat, projective and injective dimensions of modules and their characterisation in terms of derived functors. Global dimension. the homotopy category of projective modules over rings of global dimension at most 1.

**Examination:**
Written exam. An optional oral exam will be available in addition to the written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094307/NO

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**SYMPLECTIC MECHANICS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. FRANCESCO FASSO

**Credits:** 6 ECTS

**Prerequisites:**
Basic notions of Differential Geometry (manifolds, differential forms, vector fields), at the level at which they are treated in the course "Differential Geometry" at the first semester. Some knowledge of Lagrangian and Hamiltonian mechanics (at the level of the course "Fisica Matematica" of the II year of the Laurea Triennale) is useful but not strictly necessary.

**Short program:**

Examination:
Oral examination on the topics treated in the course.

More information:

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**TOPOLOGY 2**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. ANDREA D'AGNOLO

**Credits:** 6 ECTS

**Short program:**
Algebraic Topology is usually approached via the study of the fundamental group and of homology, defined using chain complexes, whereas, here, the accent is put on the language of categories and sheaves, with particular attention to locally constant sheaves. Sheaves on topological spaces were invented by Jean Leray as a tool to deduce global properties from local ones. This tool turned out to be extremely powerful, and applies to many areas of Mathematics, from Algebraic Geometry to Quantum Field Theory. On a topological space, the functor associating to a sheaf the space of its global sections is left exact, but not right exact in general. The derived functors are cohomology groups that encode the obstructions to pass from local to global. The cohomology groups of the constant sheaf are topological (and even homotopical) invariants of the space, and we shall explain how to calculate them in various situations.

**Examination:**
traditional

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/001PD/SCQ0094298/NO

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**ADVANCED ANALYSIS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. GIOVANNI COLOMBO

**Credits:** 8 ECTS

**Prerequisites:**
Basic real and functional analysis (some results will be recalled during the first lecture)

**Short program:**

**Examination:**
An oral exam on the topics covered by the course, that will include some exercises, among those that were assigned during the course.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093998/NO

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**ADVANCED STOCHASTIC PROCESSES**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof.ssa ALESSANDRA BIANCHI
Credits: 7 ECTS

Prerequisites:

Short program:

Examination:
Exam consisting of two partial tests, one written (carrying out exercises), one oral (theoretical).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ2101559/NO

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CALCULUS OF VARIATIONS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. ROBERTO MONTI

Credits: 8 ECTS

Prerequisites:
The Analysis 1 and 2 and the Real Analysis courses

Short program:
(1) Classic functionals of the Calculus of Variations (a) Euler-Lagrange’s equations (b) Du Bois-Reymond’s equation (c) Indirect methods and convexity methods (d) Fermat’s principle for the geometrical optics (e) Brachistochrone’s problem (2) Semi-direct methods (a) Functionals depending on the gradient (b) Bounded slope condition (3) Direct method of the Calculus of Variations (4) Functional in Sobolev spaces (a) Brief review on Sobolev spaces (b) Convexity and lower-semicontinuity in W1,p (c) Existence of minimizers in W1,p (d) Examples (e) Interior Sobolev regularity (f) Schauder regularity and De Giorgi-Nash theorem (without proofs) (5) Plateau’s problem (a) The parametric formulation of Douglas-Radó (b) Brief introductions to BV functions and sets with finite perimeter (c) Plateau’s problem for sets with finite perimeter (6) ?-convergence and applications to phase transition (a) Relaxation and ?-limits (b) Convergence of minima and minimizers (c) Applications: Modica-Mortola functional and perimeter (d) De Giorgi’s conjecture on the equation ?u = ?u(2 ? 1) (7) The isoperimetric property of the sphere and its applications (a) Steiner’s rearrangement (b) Isoperimetric property of the sphere (c) Quantitative version of the isoperimetric inequality (d) The best shape of a drum: minimum eigenvalue for ?u = ?u (e) Schwarz’s rearrangement and sharp Sobolev inequalities (f) The Yamabe’s equation (8) Introduction to the theory of optimal transportation (a) Monge’s problem (b) Kantorovic’s formulation (c) Brenier’s theorem (d) Another proof of the isoperimetric inequality (9) Problems of minimal length (a) Compactness (b) Lower semicontinuity

Examination:
Homeworks and oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093999/NO

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DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. MARTINO BARDI

Credits: 6 ECTS

Prerequisites:
Differential and integral calculus for functions of several variables; elementary theory of ordinary differential equations; some classical results in Functional Analysis.

Short program:

Examination:
Oral exam, either on the lectures of the course, including the exercises proposed to the students, or on some additional material related to the topics of the course.
DIFFERENTIAL GEOMETRY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. DAVIDE BARILARI

Credits: 8 ECTS

Prerequisites:
The course requires notions of Linear Algebra (vector spaces, linear maps, matrices, bilinear forms, and more in general multilinear forms) and Analysis (differential and integral calculus for real functions of one or more variables). Some knowledge of general topology is also required (open and closed sets, connectedness, compactness and main properties).

Short program:

Examination:
The exam is based on a written test and an oral test. During written test the student is asked to solve some exercises where he must be able to apply theoretical notions studied during the course. The student who is admitted to the oral test will be asked to answer to some questions on the main notions and results about the course. The final mark is based on the results of both the written test and the oral test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2651/003PD/SCQ0093963/NO

DYNAMICAL SISTEMS

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. LUIS CONSTANTINO GARCIA NARANJO ORTIZ DE LA HUERTA

Credits: 7 ECTS

Prerequisites:
1. Basic knowledge of the theory of ordinary differential equations (ODEs) and of the qualitative theory of ODEs, at the level of, e.g., the course "Fisica Matematica" which is offered as a a mandatory course at the second year of the Corso di Laurea in Matematica in this University. 2. A basic knowledge of the programming language "Mathematica" (at the level of the tutorials periodically offered by the CCs and available on the YouTube channel of the Department of Mathematics) is useful, as it will be used in the numerical part of the course.

Short program:

Examination:
Oral examination on the topics studied in the course, and with an evaluation and a discussion of the numerical assignments (which will be assigned during the course). Students will prepare the numerical assignments by working either alone or in pairs, at their choice. This examination format allows to evaluate: 1) The level of the theoretical knowledge and mathematical comprehension of the subject reached by the student. 2) The abilities reached by the student in the analysis and comprehension of the numerical results.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2651/003PD/SCQ0094084/NO

FUNCTIONS THEORY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. DAVIDE VITTONE

Credits: 8 ECTS

Prerequisites:
Besides the courses of Analysis 1 and 2, the courses of Real Analysis and Functional Analysis 1

Short program:
Between brackets we denote topics that might be skipped or exposed without proofs according to time availability and/or audience interests. THEORY OF DISTRIBUTIONS Definitions, derivatives in the sense of distributions, order of a distribution, compactly supported distributions, convolutions, tempered distributions, Fourier transform, applications. SOBOLEV SPACES Definition and elementary properties, approximation theorems, boundary trace and extension results, Sobolev-Gagliardo-Nirenberg, Poincaré and Morrey inequalities, compactness theorems. ELEMENTS OF GEOMETRIC MEASURE THEORY Recap of some measure theoretical tools, covering theorems and differentiation of measures, Hausdorff measure and dimension. Lipschitz functions and Rademacher theorem, rectifiable sets, approximate tangent space, [area and coarea formulae]. FUNCTIONS WITH BOUNDED VARIATION Definition, approximation and compactness results, trace and extension theorems, coarea formula, sets with finite perimeter, isoperimetric inequalities, reduced boundary and structure theorem for sets with finite perimeter, [fine properties and decomposability of the derivative of a BV function]

Examination:
Home exercises (one exercises sheet for each of the four parts of the course), according to which a mark will be proposed to the student. Alternatively: written examination. An oral examination is optional.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094119/NO

HARMONIC ANALYSIS

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. PAOLO CIATTI

Credits: 6 ECTS

Prerequisites:
Calculus and Advanced Calculus, and, possibly, basics in real and complex analysis. A basic knowledge of Lebesgue integration and Lebesgue spaces, together with the basics in Hilbert space theory is highly recommended. Some knowledge of holomorphic function theory would be also helpful.

Short program:

Examination:
The final exam will be a take-home exam, consisting of roughly eight questions, and a discussion of the topics considered during the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093960/NO

INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof.ssa LAURA CARAVENNA

Credits: 8 ECTS

Prerequisites:
Differential and integral calculus: basis on integration and differentiation, explicit integrals and derivatives of elementary functions, the fundamental theorem of calculus, basics on curves and surfaces. Green-Gauss-Stokes theorems and the theorems concerning limiting procedures in integrals are important but they will be revised at an essential level. Elementary theory of ordinary differential equations and on the Cauchy problem. Gronwall estimates and classical well posedness for ODEs will be recalled at an essential level. Basic theory of complex analysis: what are functions of complex variables, holomorphic and analytic functions, very essential properties as Cauchy–Riemann equations.

Short program:

Examination:
The exam consists of a final oral examination on the topics treated in class. There will be both theoretical questions and the discussion of some exercise to solve. The final exam could be reduced via in itinere activities.
**INTRODUCTION TO STOCHASTIC PROCESSES**

Master’s degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. BERNARDO D’AURIA

**Credits:** 8 ECTS

**Prerequisites:** A basic course in Probability.

**Short program:**

**Examination:** To be defined

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094080/NO

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**NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS**

Master’s degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. MARIO PUTTI

**Credits:** 7 ECTS

**Prerequisites:** Mathematical Analysis 1 and 2, with elements of Differential Equations and functional analysis. Numerical Analysis and linear algebra. The lab projects require some knowledge of Matlab programming.

**Short program:**

**Examination:** Oral examination with discussion on the lab projects.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094083/NO

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**STOCHASTIC ANALYSIS**

Master’s degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. DAVID BARBATO

**Credits:** 7 ECTS

**Prerequisites:** Basic probability theory, basic analysis (differential calculus in $\mathbb{R}^d$, ordinary differential equations), measure theory.

**Short program:**

**Examination:**

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The exam consists of two partial parts, a written test and oral test.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093961/NO

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**STOCHASTIC METHODS FOR FINANCE**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. MARTINO GRASSELLI

**Credits:** 7 ECTS

**Prerequisites:**
Stochastic analysis

**Short program:**
- Contenuti: The pricing problem in the binomial models
- Risk neutral pricing in the discrete time world
- European and American options in the binomial model
- Arbitrage and risk neutral pricing in continuous time.
- Pricing of contingent claims in continuous time: the Black&Scholes formula.
- Feynman-Kac formula and risk neutral pricing in continuous time.
- Pur Call parity, dividends and static vs dynamic hedging.
- Quanto option pricing in the Black&Scholes model.
- Multi asset markets, pricing and hedging.
- Exchange options pricing in the multi-asset Black&Scholes model.
- Incomplete markets: quadratic hedging.
- Smile and skew stylized facts. Beyond the Black&Scholes model: stochastic volatility.
- The Heston model.
- Bonds and interest rates.
- Pre-crisis and multiple-curve frameworks.
- Short rate models, Vasicek, CIR, Hull-White models, affine models. Cap&Floor pricing in the short rate approaches.

**Examination:**
- Final examination based on: Written and oral examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094085/NO

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**SYMPLECTIC MECHANICS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. FRANCESCO FASSO

**Credits:** 6 ECTS

**Prerequisites:**
- Basic notions of Differential Geometry (manifolds, differential forms, vector fields), at the level at which they are treated in the course "Differential Geometry" at the first semester. Some knowledge of Lagrangian and Hamiltonian mechanics (at the level of the course "Fisica Matematica" of the II year of the Laurea Triennale) is useful but not strictly necessary.

**Short program:**

**Examination:**
- Oral examination on the topics treated in the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094082/NO

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**BROWNIAN MOTION AND ASSET PRICING**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined

**Credits:** 4 ECTS

More information:
CONTINUOUS PROCESSES - ADVANCED

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined Course not activated for the a.y. 2022/2023

Credits: 4 ECTS

Prerequisites:

Short program:

Examination:

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094143/NO

CONTROL OF MARKOV CHAINES

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094093/NO

CONVEX ANALYSIS - ADVANCED

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined Course not activated for the a.y. 2022/2023

Credits: 4 ECTS

Prerequisites:

Short program:

Examination:

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094144/NO

DISCRETE PROCESSES

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094092/NO
FUNCTIONAL ANALYSIS

Master’s degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 8 ECTS


GEOMETRY AND DIFFERENTIAL EQUATIONS

Master’s degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS


GERMAN 1 AND 2

Master’s degree in MATHEMATICS ORD. 2022, First and Second semester

Lecturer: to be defined Course not activated for the a.y. 2022/2023

Credits: 4 ECTS

Prerequisites: -

Short program: -

Examination: -


MONTE-CARLO

Master’s degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS


NON-PARAMETRIC STATISTICS

Master’s degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: to be defined Course not activated for the a.y. 2022/2023

Credits: 4 ECTS

Prerequisites: -

Short program:
NUMERICAL METHODS FOR TIME-DEPENDENT PROBLEMS

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** to be defined Course not activated for the a.y. 2022/2023

**Credits:** 4 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094148/NO

OPTIMIZATION

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined Course not activated for the a.y. 2022/2023

**Credits:** 4 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094091/NO

POISSON PROCESS

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined Course not activated for the a.y. 2022/2023

**Credits:** 4 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094145/NO
STATISTICAL LEARNING

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** to be defined Course not activated for the a.y. 2022/2023

**Credits:** 4 ECTS

**Prerequisites:**

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**Short program:**

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**Examination:**

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**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094146/NO

ADVANCED ANALYSIS

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. GIOVANNI COLOMBO

**Credits:** 8 ECTS

**Prerequisites:**

Basic real and functional analysis (some results will be recalled during the first lecture)

**Short program:**


**Examination:**

An oral exam on the topics covered by the course, that will include some exercises, among those that were assigned during the course.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093998/NO

CALCULUS OF VARIATIONS

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. ROBERTO MONTI

**Credits:** 8 ECTS

**Prerequisites:**

The Analysis 1 and 2 and the Real Analysis courses
Short program:
(1) Classic functionals of the Calculus of Variations (a) Euler-Lagrange’s equations (b) Du Bois-Reymond’s equation (c) Indirect methods and convexity
methods (d) Fermat’s principle for the geometrical optics (e) Brachistochrone’s problem (2) Semi-direct methods (a) Functionals depending on the gradient
(b) Bounded slope condition (3) Direct method of the Calculus of Variations (4) Functional in Sobolev spaces (a) Brief review on Sobolev spaces (b)
Convexity and lower-semicontinuity in W1,p (c) Existence of minimizers in W1,p (d) Examples (e) Interior Sobolev regularity (f) Schauder regularity and De
Giorgi-Nash theorem (without proofs) (5) Plateau’s problem (a) The parametric formulation of Douglas-Rad’o (b) Brief introductions to BV functions and sets
with finite perimeter (c) Plateau’s problem for sets with finite perimeter (6) ?-convergence and applications to phase transition (a) Relaxation and ?-limits (b)
Convergence of minima and minimizers (c) Applications: Modica-Mortola functional and perimeter (d) De Giorgi’s conjecture on the equation ?u = ?u(2 ?
1) (7) The isoperimetric property of the sphere and its applications (a) Steiner’s rearrangement (b) Isoperimetric property of the sphere (c) Quantitative
version of the isoperimetric inequality (d) The best shape of a drum: minimum eigenvalue for ?u = ?u (e) Schwarz’s rearrangement and sharp Sobolev
inequalities (f) The Yamabe’s equation (8) Introduction to the theory of optimal transportation (a) Monge’s problem (b) Kantorovic’s formulation (c) Brenier’s
theorem (d) Another proof of the isoperimetric inequality (9) Problems of minimal length (a) Compactness (b) Lower semicontinuity

Examination:
Homeworks and oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093999/NO

CONTROL OF MARKOV CHAINES

Master’s degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094093/NO

DIFFERENTIAL EQUATIONS

Master’s degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. MARTINO BARDI

Credits: 6 ECTS

Prerequisites:
Differential and integral calculus for functions of several variables; elementary theory of ordinary differential equations; some classical results in Functional
Analysis.

Short program:
Part 1: - Classical examples of Hamilton-Jacobi equations; the method of characteristics and the onset of singularities. - The Hopf-Lax formula. - Viscosity
solutions: motivations and basic theory. - The Comparison Principle and some consequences. - Introduction to optimal control and the Dynamic
games: the min-max theorem and its consequences. - Games with N players: Nash equilibria. - Two-person differential games: verification theorems and
feedback Nash equilibria. - Zero-sum differential games: causal strategies and the definitions of value; Dynamic Programming and the H-J-Isaacs equation;
existence of the value. - Deterministic Mean Field Games: motivations of the theory, derivation of the system of Partial Differential Equations; uniqueness
of the solution; some results about existence, with examples.

Examination:
Oral exam, either on the lectures of the course, including the exercises proposed to the students, or on some additional material related to the topics of the
course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093962/NO

DISCRETE PROCESSES

Master’s degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS
**DYNAMICAL SYSTEMS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. LUIS CONSTANTINO GARCIA NARANJO ORTIZ DE LA HUERTA

**Credits:** 7 ECTS

**Prerequisites:**
1. Basic knowledge of the theory of ordinary differential equations (ODEs) and of the qualitative theory of ODEs, at the level of, e.g., the course “Fisica Matematica” which is offered as a mandatory course at the second year of the Corso di Laurea in Matematica in this University. 2. A basic knowledge of the programming language “Mathematica” (at the level of the tutorials periodically offered by the CCS and available on the YouTube channel of the Department of Mathematics) is useful, as it will be used in the numerical part of the course.

**Short program:**

**Examination:**
Oral examination on the topics studied in the course, and with an evaluation and a discussion of the numerical assignments (which will be assigned during the course). Students will prepare the numerical assignments by working either alone or in pairs, at their choice. This examination format allows to evaluate: 1) The level of the theoretical knowledge and mathematical comprehension of the subject reached by the student. 2) The abilities reached by the student in the analysis and comprehension of the numerical results.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094092/NO

**FUNCTIONAL ANALYSIS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined

**Credits:** 8 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094084/NO

**GEOMETRY AND DIFFERENTIAL EQUATIONS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined

**Credits:** 4 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094088/NO

**HARMONIC ANALYSIS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. PAOLO CIATTI

**Credits:** 6 ECTS

**Prerequisites:**
Calculus and Advanced Calculus, and, possibly, basics in real and complex analysis. A basic knowledge of Lebesgue integration and Lebesgue spaces, together with the basics in Hilbert space theory is highly recommended. Some knowledge of holomorphic function theory would be also helpful.

**Short program:**

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Examination:
The final exam will be a take-home exam, consisting of roughly eight questions, and a discussion of the topics considered during the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093960/NO

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INTRODUCTION TO STOCHASTIC PROCESSES

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. BERNARDO D'AURIA

Credits: 8 ECTS

Prerequisites:
A basic course in Probability.

Short program:

Examination:
To be defined

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0093964/NO

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MONTE-CARLO

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: to be defined

Credits: 4 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094094/NO

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NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. MARIO PUTTI

Credits: 7 ECTS

Prerequisites:
Mathematical Analysis 1 and 2, with elements of Differential Equations and functional analysis. Numerical Analysis and linear algebra. The lab projects require some knowledge of Matlab programming.

Short program:

Examination:
Oral examination with discussion on the lab projects.
### OPTIMIZATION

**Master's degree in MATHEMATICS ORD. 2022**, First semester

**Lecturer:** to be defined  
**Course not activated for the a.y. 2022/2023**

**Credits:** 4 ECTS  
**Prerequisites:**  
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**Short program:**  
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**Examination:**  
-  
**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094083/NO

### STOCHASTIC METHODS FOR FINANCE

**Master's degree in MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. MARTINO GRASSELLI

**Credits:** 7 ECTS  
**Prerequisites:**  
- Stochastic analysis  
**Short program:**  

**Examination:**  
Final examination based on: Written and oral examination.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/003PD/SCQ0094091/NO

### ADVANCED ANALYSIS

**Master's degree in MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. GIOVANNI COLOMBO  
**Credits:** 8 ECTS  
**Prerequisites:**  
- Basic real and functional analysis (some results will be recalled during the first lecture)
Short program:

Examination:
An oral exam on the topics covered by the course, that will include some exercises, among those that were assigned during the course.

More information:

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ADVANCED STOCHASTIC PROCESSES

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof.ssa ALESSANDRA BIANCHI

Credits: 7 ECTS

Prerequisites:

Short program:

Examination:
Exam consisting of two partial tests, one written (carrying out exercises), one oral (theoretical).

More information:

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ALGEBRAIC GEOMETRY 1

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. REMKE NANNE KLOOSTERMAN

Credits: 8 ECTS

Prerequisites:
Basic knowledge of commutative algebra (first half of the commutative algebra course).

Short program:
This course is intended as a introductory course in algebraic geometry, starting from the basics of the subject and progressing to more advanced techniques such as the study of sheaves and schemes. Contents: Affine varieties. The Zariski topology. The sheaf of regular functions on a variety. Morphisms of varieties. Projective varieties. Dimension of a variety. Introduction to schemes.

Examination:
Written exam, possibly taking homework assignments into account.

More information:

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ALGEBRAIC GEOMETRY 2

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. ERNESTO CARLO MISTRETTA

Credits: 6 ECTS

Prerequisites:
Basics in topology and differential geometry. It is recommended to have some knowledge on the theory of Riemann Surfaces.

Short program:
The course is thought about as a continuation in higher dimension of the ideas developed in the theory of Riemann Surfaces. - Preliminaries: holomorphic functions in complex variables, the difference with holomorphic functions in one complex variable. - Complex manifolds: definitions and first properties. - Complex tangent space, and complex differential calculus. - Vector Bundles: complex, hermitian, holomorphic vector bundles. Connections and curvature, the Chern connection. The example of line bundles. Chern forms. - Divisors, line bundles, and Picard group. Weil Divisors and Cartier divisors. - Kaehler manifolds: examples, volume form. Fubini-Study metric, smooth projective varieties as Kaehler manifolds. Examples of non-Kaehler varieties. - Introduction to cohomology: de Rham cohomology, Dolbeault cohomology. Short overview on singular cohomology and sheaf cohomology. The computation of some cohomology groups will be shown, this will serve as a motivation for more general theories (to be studied in other classes). - Analytic tools: integration, $L^2$ metric, operators on Kaehler manifolds, Laplacian. - Hodge identities, Hodge decomposition, Hodge symmetry. - Hodge decomposition in the algebraic case (projective varieties), Hodge conjecture. - 2 important theorems: Kodaira embedding theorem, Torelli’s theorem.

Examination:
Seminar with questions.

More information:

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**CALCULUS OF VARIATIONS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. ROBERTO MONTI

**Credits:** 8 ECTS

**Prerequisites:**
The Analysis 1 and 2 and the Real Analysis courses

**Short program:**
(1) Classic functionals of the Calculus of Variations (a) Euler-Lagrange’s equations (b) Du Bois-Reymond’s equation (c) Indirect methods and convexity methods (d) Fermat’s principle for the geometrical optics (e) Brachistochrone’s problem (2) Semi-direct methods (a) Functionals depending on the gradient (b) Bounded slope condition (3) Direct method of the Calculus of Variations (d) Functional in Sobolev spaces (a) Brief review on Sobolev spaces (b) Convexity and lower-semicontinuity in W^{1,p} (c) Existence of minimizers in W^{1,p} (d) Examples (e) Interior Sobolev regularity (f) Schauder regularity and De Giorgi-Nash theorem (without proofs) (5) Plateau's problem (a) The parametric formulation of Douglas-Radó (b) Brief introductions to BV functions and sets with finite perimeter (c) Plateau’s problem for sets with finite perimeter (6) $\gamma$-convergence and applications to phase transition (a) Relaxation and $\gamma$-limits (b) Convergence of minima and minimizers (c) Applications: Modica-Mortola functional and perimeter (d) De Giorgi’s conjecture on the equation $\Delta u = \Delta(u^2)$ (7) The isoperimetric property of the sphere and its applications (a) Steiner’s rearrangement (b) Isoperimetric property of the sphere (c) Quantitative version of the isoperimetric inequality (d) The best shape of a drum: minimum eigenvalue for $\Delta u = \Delta(u^2)$ (e) Schwarz’s rearrangement and sharp Sobolev inequalities (f) The Yamabe’s equation (8) Introduction to the theory of optimal transportation (a) Monge’s problem (b) Kantorovic’s formulation (c) Brenier’s theorem (d) Another proof of the isoperimetric inequality (9) Problems of minimal length (a) Compactness (b) Lower semicontinuity

**Examination:**
Homeworks and oral exam

More information:

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**COMMUTATIVE ALGEBRA**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof.ssa ORSOLA TOMMASI

**Credits:** 8 ECTS

**Prerequisites:**
Basic algebra notions (groups, rings, ideals, fields, quotients, etc.), as acquired in the “Algebra 1” course.

**Short program:**

**Examination:**
**COMPLEX ANALYSIS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. MASSIMO LANZA DE CRISTOFORIS

**Credits:** 6 ECTS

**Prerequisites:**
Analysis courses of the first two years, and preferably the following courses Mathematical Methods Functional Analysis 1

**Short program:**
Real and complex differentiability in finite and infinite dimension. Complexification of a real problem The Riemann Mapping Theorem, integral representation of holomorphic functions, boundary behaviour and applications to the solution of boundary value problems

**Examination:**
Partial tests and final oral exam

More information:

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**CRYPTOGRAPHY**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. ALESSANDRO LANGUASCO

**Credits:** 6 ECTS

**Prerequisites:**
For the first part (Prof. Languasco; 6 credits): The topics of the following courses: Algebra (congruences, groups and cyclic groups, finite fields), Calculus (differential and integral calculus, numerical series) both for the BA in Mathematics. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): OS, Programming.

**Short program:**

**Examination:**
For the first part (Prof. Languasco; 6 credits): Written exam in class; if, due to the pandemic situation, this will not be possible the written exam will be done using the available videoconferencing tools. For the second part (Prof. Conti and Prof. (to be determined); 6 credits): Written Exam, Homeworks, oral test.

More information:

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**DIFFERENTIAL EQUATIONS**

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. MARTINO BARDI

**Credits:** 6 ECTS

**Prerequisites:**
Differential and integral calculus for functions of several variables; elementary theory of ordinary differential equations; some classical results in Functional Analysis.

**Short program:**

Examination:
Oral exam, either on the lectures of the course, including the exercises proposed to the students, or on some additional material related to the topics of the course.

More information:

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**DIFFERENTIAL GEOMETRY**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. DAVIDE BARILARI

**Credits:** 8 ECTS

**Prerequisites:**
The course requires notions of Linear Algebra (vector spaces, linear maps, matrices, bilinear forms, and more in general multilinear forms) and Analysis (differential and integral calculus for real functions of one or more variables). Some knowledge of general topology is also required (open and closed sets, connectedness, compactness and main properties).

**Short program:**

**Examination:**
The exam is based on a written test and an oral test. During written test the student is asked to solve some exercises where he must be able to apply theoretical notions studied during the course. The student who is admitted to the oral test will be asked to answer to some questions on the main notions and results about the course. The final mark is based on the results of both the written test and the oral test.

**More information:**

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**DYNAMICAL SISTEMS**

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. FRANCESCO FASSO`

**Credits:** 7 ECTS

**Prerequisites:**
1. Basic knowledge of the theory of ordinary differential equations (ODEs) and of the qualitative theory of ODEs, at the level of, e.g., the course “Fisica Matematica” which is offered as a a mandatory course at the second year of the Corso di Laurea in Matematica in this University. 2. A basic knowledge of the programming language “Mathematica” (at the level of the tutorials periodically offered by the CCS and available on the YouTube channel of the Department of Mathematics) is useful, as it will be used in the numerical part of the course.

**Short program:**

**Examination:**
Oral examination on the topics studied in the course, and with an evaluation and a discussion of the numerical assignments (which will be assigned during the course). Students will prepare the numerical assignments by working either alone or in pairs, at their choice. This examination format allows to evaluate: 1) The level of the theoretical knowledge and mathematical comprehension of the subject reached by the student. 2) The abilities reached by the student in the analysis and comprehension of the numerical results.
ELEMENTARY MATHEMATICS FROM A SUPERIOR POINT OF VIEW

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. LUIGI TOMASI

Credits: 6 ECTS

Prerequisites:
The mathematical prerequisites are those covered by basic courses of the Bachelor's Degree in Mathematics, in particular Algebra, Geometry, Mathematical Analysis, Probability and Foundations of Mathematics.

Short program:
The course will discuss, from an epistemological, historical and didactic point of view, those topics and ideas of basic mathematics that constitute the fundamental themes of the Mathematics curriculum in secondary school: - Arithmetic and Algebra - Geometry - Relations and functions (in particular, Mathematical Analysis) - Data and Forecasting (in particular, Probability). In particular, the following topics will be specifically developed (some will be requested in the students’ reports): - Solution of algebraic equations in radicals, with hints on the history of classical algebra - Straightedge and compass constructions: the classical problems of geometry; points of the plan that can be constructed with straightedge and compass; constructible numbers; constructible regular polygons, with historical notes. - Elementary number theory topics: Pythagorean triples, prime numbers, fundamental theorem of arithmetic, congruence relation, Euclid's algorithm for the gcd, divisibility criteria; the Euler functions d(n), sigma(n), phi(n); decimal fractions and period of a fraction. The principle of mathematical induction. - Definitions, theorems and proofs in mathematics teaching (in secondary school); types of proofs; indirect proofs; proofs by contradiction; proofs by induction. - Axiomatic systems for geometry (Euclid, Hilbert, Choquet,…) and teaching of geometry in secondary school; some approaches to teaching geometry in secondary school. "Paths" for the teaching of geometry in secondary school. - Sequences and functions; the definition of limit; definition of derivative and definition of definite integral; epistemological, historical and didactic considerations. - Probability; the definitions of probability; basic theorems of probability. These elementary mathematics topics will be presented "from a superior point of view", that is, with critical attention to their foundations, their history and their current teaching (in secondary school). During the course, the use of technological tools for teaching and learning mathematics in secondary school will also be proposed, underlining their methodological value, with frequent examples of use of mathematical software (in particular, the use of the GeoGebra software will be proposed).

Examination:
Oral exam plus an in-depth written report on a fundamental topic (assigned by the teacher) covered in the course. The report will be presented in the last part of the course or, alternatively, in the first part of the exam.

FUNCTIONS THEORY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. DAVIDE VITTONE

Credits: 8 ECTS

Prerequisites:
Besides the courses of Analysis 1 and 2, the courses of Real Analysis and Functional Analysis 1

Short program:
Between brackets we denote topics that might be skipped or exposed without proofs according to time availability and/or audience interests. THEORY OF DISTRIBUTIONS Definitions, derivatives in the sense of distributions, order of a distribution, compactly supported distributions, convolutions, tempered distributions, Fourier transform, applications. SOBOLEV SPACES Definition and elementary properties, approximation theorems, boundary trace and extension results, Sobolev-Gagliardo-Nirenberg, Poincaré and Morrey inequalities, compactness theorems. ELEMENTS OF GEOMETRIC MEASURE THEORY Recap of some measure theoretical tools, covering theorems and differentiation of measures, Hausdorff measure and dimension, Lipschitz functions and Rademacher theorem, rectifiable sets, approximate tangent space, [area and coarea formulae]. FUNCTIONS WITH BOUNDED VARIATION Definition, approximation and compactness results, trace and extension theorems, coarea formula, sets with finite perimeter, isoperimetric inequalities, reduced boundary and structure theorem for sets with finite perimeter, [fine properties and decomposability of the derivative of a BV function]

Examination:
Home exercises (one exercises sheet for each of the four parts of the course), according to which a mark will be proposed to the student. Alternatively: written examination. An oral examination is optional.

HAMLETANION MECHANICS
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<td><em>Master’s degree in MATHEMATICS ORD. 2022, First semester</em></td>
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<td><strong>Lecturer:</strong> Prof. PAOLO CIATTI</td>
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<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> Calculus and Advanced Calculus, and, possibly, basics in real and complex analysis. A basic knowledge of Lebesgue integration and Lebesgue spaces, together with the basics in Hilbert space theory is highly recommended. Some knowledge of holomorphic function theory would be also helpful.</td>
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<td><strong>Examination:</strong> The final exam will be a take-home exam, consisting of roughly eight questions, and a discussion of the topics considered during the lectures.</td>
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<td><strong>More information:</strong> <a href="https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0093960/NO">https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0093960/NO</a></td>
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<tr>
<td><strong>HOMOLOGY AND COHOMOLOGY</strong></td>
<td><em>Master’s degree in MATHEMATICS ORD. 2022, Second semester</em></td>
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<tr>
<td><strong>Lecturer:</strong> Prof. JAKOB SCHOLBACH</td>
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<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> we expect the student knows that it is possible to associate some invariants (fundamental group..), basic commutative algebra.</td>
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<td><strong>Short program:</strong> Starting from the basic definition of the algebraic topology we will introduce the definition of homology and cohomology for a topological space. Singular, simplicial, cellular, relative, excisin, mayer-vietoris. Tor and Ext: universal coefficients theorem. Cup and cap product: teh ring structure on the cohomology of a projective space and some other particular topological spaces. Eventually Poincare’ duality.</td>
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<td><strong>Examination:</strong> taiyored on the basis of the students attitudes: written and homeworks during the semester.</td>
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<td><strong>More information:</strong> <a href="https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0094302/NO">https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0094302/NO</a></td>
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<tr>
<td><strong>INTRODUCTION TO GROUP THEORY</strong></td>
<td><em>Master’s degree in MATHEMATICS ORD. 2022, Second semester</em></td>
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<td><strong>Lecturer:</strong> Prof. PAOLO ROSSI</td>
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<tr>
<td><strong>Credits:</strong> 6 ECTS</td>
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<tr>
<td><strong>Prerequisites:</strong> Basics of algebra and differential geometry.</td>
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<tr>
<td><strong>Short program:</strong> Smooth bundles on smooth manifolds (general definitions, local description, sections, examples) Vector bundles (definitions local description, sections, linear connections, parallel transport, covariant derivative, examples) Principal bundles (short reminder on Lie groups, their representations and actions on manifolds, general definitions, local description, sections, principal connections, associated vector bundles, examples) Characteristic classes (time permitting, Chern-Weil approach to Stiefel-Whitney and Chern classes) Applications (gauge theories of various origin)</td>
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<td><strong>Examination:</strong> To be decided depending also on the number of students. Either a traditional oral exam on the entire program, or a written exam containing both simple exercises and questions on theory.</td>
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<td><strong>More information:</strong> <a href="https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0094081/NO">https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0094081/NO</a></td>
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Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ANDREA LUCCHINI

Credits: 8 ECTS

Prerequisites:
Basic knowledges in general algebra

Short program:
General introduction to group theory: actions of groups, solvable and nilpotent groups, finitely presented groups. A short history of the classification of finite simple groups. Topological groups, profinite groups (characterizations, profinite completion, countable based profinite groups, arithmetical properties, subgroups of profinite index in profinite groups, Galois groups of ifinite dimensional extension). Probabilistic methods in group theory.

Examination:
Oral. The candidate will be asked to present the most important arguments presented in the course, proving the more significant results and solving some related exercise.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2651/002PD/SCQ0094303/NO

INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof.ssa LAURA CARAVENNA

Credits: 8 ECTS

Prerequisites:
Differential and integral calculus: basis on integration and differentiation, explicit integrals and derivatives of elementary functions, the fundamental theorem of calculus, basics on curves and surfaces. Green-Gauss-Stokes theorems and the theorems concerning limiting procedures in integrals are important but they will be revised at an essential level. Elementary theory of ordinary differential equations and on the Cauchy problem. Gronwall estimates and classical well posedness for ODEs will be recalled at an essential level. Basic theory of complex analysis: what are functions of complex variables, holomorphic and analytic functions, very essential properties as Cauchy–Riemann equations.

Short program:

Examination:
The exam consists of a final oral examination on the topics treated in class. There will be both theoretical questions and the discussion of some exercise to solve. The final exam could be reduced via itinerne activities.

More information:

INTRODUCTION TO RING THEORY

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ALBERTO TONOLO

Credits: 8 ECTS

Prerequisites:
Algebra 1 and Algebra 2 courses

Short program:

Examination:
Written exam and possibly an oral one
INTRODUCTION TO STOCHASTIC PROCESSES

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. BERNARDO D'AURIA

Credits: 8 ECTS

Prerequisites:
A basic course in Probability.

Short program:

Examination:
To be defined

More information:

MATHEMATICAL LOGIC 2

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Dott. SAMUELE MASCHIO

Credits: 6 ECTS

Prerequisites:
Basic notions of algebra, geometry and analysis. The knowledge of axiomatic methods and basics of set theory is preferable, but not necessary.

Short program:

Examination:
Oral exam.

More information:

MODERN PHYSICS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: to be defined

Credits: 8 ECTS

Prerequisites:
The student should know the fundamentals of Classical Physics related to the fields of Mechanics, Mathematical Physics, Electromagnetism and Thermodynamics.

Short program:

Examination:
Oral examination.

More information:

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**NUMBER THEORY 1**

Master's degree in MATHEMATICS ORD. 2022, First semester

**Lecturer:** Prof. MATTEO LONGO

**Credits:** 8 ECTS

**Prerequisites:**
Standard basic courses in Algebra, Calculus, Topology, Linear Algebra. Galois Theory. Commutative Algebra may be useful.

**Short program:**

**Examination:**
Written examination.

More information:

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**NUMBER THEORY 2**

Master's degree in MATHEMATICS ORD. 2022, Second semester

**Lecturer:** Prof. ADRIAN IOVITA

**Credits:** 6 ECTS

**Prerequisites:**
Number Theory 1.

**Short program:**
The course will develop the theory of local fields following J.-P. Serre's book: Local fields. We will study: valuation rings, completions of valuation rings, complete discrete valuation fields of mixed characteristic and their finite extensions, the ramification filtration of the the Galois group of a finite, Galois extension of a local field. As an application we will study p-adic modular forms.

**Examination:**
Homework exercises will be handed in weekly, there will be a midterm exam and written final.

More information:

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**NUMERICAL LINEAR ALGEBRA AND LEARNING FROM DATA**

Master's degree in MATHEMATICS ORD. 2022, First semester

**Lecturer:** Dott. FABIO MARCUZZI
NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. MARIO PUTTI

Credits: 7 ECTS

Prerequisites: Mathematical Analysis 1 and 2, with elements of Differential Equations and functional analysis. Numerical Analysis and linear algebra. The lab projects require some knowledge of Matlab programming.


Examination: Oral examination with discussion on the lab projects.


OPERATIONS RESEARCH

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. FRANCESCO RINALDI

Credits: 8 ECTS

Prerequisites: Basic Knowledge of Linear Algebra and Calculus.


Examination: The exam is divided into two parts: Written Test and Project The final grade is determined by two elements: 1) Project (max score 10 points): must be requested by email and delivered within 3 days from the date of the exam. 2) Written exam (max score 24 points). NOTES: - Students interested in studying specific aspects of the subject can ask for an integrative project (theoretical / practical) that partially replaces the written test (max score 12 points). - The exam is passed if the final score for the project is at least 6 points and for the written test is at least 12 points. - The project grades have no expiration date.

OPTIMIZATION

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: to be defined Course not activated for the a.y. 2022/2023

Credits: 6 ECTS

Prerequisites:
-

Short program:
-

Examination:
-


REPRESENTATION THEORY OF GROUPS

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof.ssa GIOVANNA CARNOVALE

Credits: 6 ECTS

Prerequisites:
Basic notions in linear algebra and group theory.

Short program:

Examination:
Unless sanitary emergency situation forces to do otherwise, the exam will be written, based on a series of exercises.


RINGS AND MODULES

Master's degree in MATHEMATICS ORD. 2022, Second semester

Lecturer: Prof. JORGE NUNO DOS SANTOS VITORIA

Credits: 6 ECTS

Prerequisites:
Notions from the Algebra courses of the first two years of the degree in Mathematics and basic notions on module theory over arbitrary rings.

Short program:

Examination:
Written exam. An optional oral exam will be available in addition to the written exam.

STOCHASTIC ANALYSIS

Master's degree in **MATHEMATICS ORD. 2022**, First semester

**Lecturer:** Prof. DAVID BARBATO

**Credits:** 7 ECTS

**Prerequisites:**
Basic probability theory, basic analysis (differential calculus in $\mathbb{R}^d$, ordinary differential equations), measure theory.

**Short program:**

**Examination:**
Th exam consists of two partial part, a written test and oral test.

**More information:**

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STOCHASTIC METHODS FOR FINANCE

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. MARTINO GRASSELLI

**Credits:** 7 ECTS

**Prerequisites:**
Stochastic analysis

**Short program:**

**Examination:**
Final examination based on: Written and oral examination.

**More information:**

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SYMPLECTIC MECHANICS

Master's degree in **MATHEMATICS ORD. 2022**, Second semester

**Lecturer:** Prof. LUIS CONSTANTINO GARCIA NARANJO ORTIZ DE LA HUERTA

**Credits:** 6 ECTS

**Prerequisites:**
Basic notions of Differential Geometry (manifolds, differential forms, vector fields), at the level at which they are treated in the course "Differential Geometry" at the first semester. Some knowledge of Lagrangian and Hamiltonian mechanics (at the level of the course "Fisica Matematica" of the II year of the Laurea Triennale) is useful but not strictly necessary.

**Short program:**

Examination:
Oral examination on the topics treated in the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2651/002PD/SCQ0094082/NO

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TOPOLOGY 2

Master's degree in MATHEMATICS ORD. 2022, First semester

Lecturer: Prof. ANDREA D'AGNOLO

Credits: 6 ECTS

Short program:
Algebraic Topology is usually approached via the study of the fundamental group and of homology, defined using chain complexes, whereas, here, the accent is put on the language of categories and sheaves, with particular attention to locally constant sheaves. Sheaves on topological spaces were invented by Jean Leray as a tool to deduce global properties from local ones. This tool turned out to be extremely powerful, and applies to many areas of Mathematics, from Algebraic Geometry to Quantum Field Theory. On a topological space, the functor associating to a sheaf the space of its global sections is left exact, but not right exact in general. The derived functors are cohomology groups that encode the obstructions to pass from local to global. The cohomology groups of the constant sheaf are topological (and even homotopical) invariants of the space, and we shall explain how to calculate them in various situations.

Examination:
traditional

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2651/002PD/SCQ0094298/NO

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MOLECULAR BIOLOGY (ORD. 2020)

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APPLIED STATISTICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. DAVIDE RISSO

Credits: 6 ECTS

Prerequisites:
The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.

Short program:

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2445/007PD/SCP8085059/NO

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BEHAVIOURAL GENETICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. MAURO AGOSTINO ZORDAN
**Prerequisites:**
Basic Genetics and possibly also Population Genetics. Ideally some background in programming with R (Rstudio)

**Short program:**
- Introduction to behavioural genetics: - Historical introduction: - Francis Galton, eugenics, racial laws and Nazism, behaviourism, birth of behavioural genetics: - Behaviour as gene-environment interaction (nature-nurture): Studies on human families - MZ and DZ twins and adoptive children; - Model organisms in behavioural genetics: Caenorhabditis, Drosophila, Zebrafish, mammals: rat, mouse, dog (behaviour and domestication). - Genetics of quantitative characters in the study of behaviour (behavioural quantitative traits) - Types of quantitative characters - Similarity between relatives and the concept of heritability - Artificial selection and realized heritability - Equation for the prediction of individual selection - Genetic models for quantitative characters - Components of phenotypic variation - Sources of genetic and environmental variation - Components of genetic variation - Covariance between relatives - Studies on twins and inferences on human heritability - Norm of reaction, threshold characters and genetic correlation - Norm of reaction and phenotypic plasticity - Threshold characters: Genes as risk factors in disease - Genetic correlation and correlated response - How to identify genes? Single genes or multiple genes? - Genes which influence quantitative characters - The number of genes which influence quantitative traits - Methods for mapping (Quantitative Trait Loci) QTL - Candidate genes - Genome Wide Association (GWA) - Single Nucleotide Polymorphisms (SNP) - Physiological behaviour and it's variations, considering also pathological aspects of selected behaviours. - circadian rhythms, sleep - learning and memory - socialization, aggressiveness - locomotion - orientation and navigation - sexual orientation - seeking novelties - Description of the molecular mechanisms and the neuronal circuits involved in the control of some of the behavioural patterns described in the preceding section. - Practicals: Methods to study behaviour in animal models (partly taught class, partly laboratory simulations) - Design of equipment, computer hardware and software, numerical and statistical analysis of data (i.e. videos, movement tracking).

**Examination:**
Written exam, at the end of the course, using the Moodle platform.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCQ1097221/NO

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**CELL BIOLOGY**

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

**Lecturer:** Prof.ssa CHIARA RAMPAZZO

**Credits:** 9 ECTS

**Prerequisites:**
Basic level of Cell Biology, Molecular Biology and Genetics

**Short program:**
The 9 CFU course is organized in about 7 CFU of frontal lectures and 2 CFU dedicated to the presentation and discussion of recent articles on specific topics. The discussion of the articles is an integral part of the program. Lectures will cover 7 main topics: 1) Physical principles behind the most common microscopy techniques (1 CFU). 2) Chromatin Biology and nuclear organization to address fundamental questions about cellular differentiation and nuclear reprogramming. Chromosome territories and subdomains. Nucleoli and nuclear lamina (2CFU) 3) Centromeric and telomeric chromatin (1 CFU). 4) polycomb complexes, facultative heterochromatin and bivalent chromatin in pluripotent stem cells (1 CFU) 5) Symmetric / asymmetric cell division and cell polarity (1 CFU) 6) Main principles of autophagy and related diseases 7) Quiescence and senescence in mammalian cells. Abnormal signal transduction pathways in cancer development. Immortalization and transformation, role of telomeres. Cancer stem cells (2CFU).

**Examination:**
The knowledge acquired by the student will be evaluated with a written exam organized in two parts. First part (1 CFU) described in the course contents at section 1 will be assessed with one open question that include a long answer. the second part (6 CFU) described in the course content at section 2 to 4 will be assessed with open questions that include short or longer answer. The final grade is expressed as a weighted average between the two parties.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP8085218/NO

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**COMPUTATIONAL ANTHROPOLOGY**

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

**Lecturer:** Prof. LUCA PAGANI

**Credits:** 6 ECTS

**Prerequisites:**
Prior knowledge needed for the classes in Computational Anthropology is that normally provided for students at the final class of the first degree in Molecular Biology. Particularly, the basic understanding of Genetics, Statistics, Phylogeny, and Evolutionary Biology in their fundamental principles and processes, is required. Students must also be familiar with the Unix/Shell environment. No prior knowledge is requested about specific contents in Population Genetics and Genomics, however scientific contents of the "Anthropology" course may be of great help during this course.

**Short program:**
The course aims at blending basic knowledge within the fields of Molecular Anthropology and Human Population Genetics with practical (bioinformatic) skills, transferable to the expanding occupational sectors of Personal Genomics and Ancestry analyses. The following topics will be explored from a
theoretical and a practical/applicative angle: 1) Genetic admixture and local ancestry; 2) Ancestry deconvolution and ancestry-specific analyses; 3) Population differentiation among human groups, both at a genome-wide and at a locus-specific level; 4) Effect on the genome of natural selection events; 5) Introgression events between Homo sapiens and Archaic humans; These general objectives are addressed through critical discussion of case-studies taken from primary scientific literature on Molecular Anthropology, and through extensive hands on exercise in a computer lab.

Examination:
Examination will be based on a practical exercise of approximately 3 hours, to be carried out in the computer room. The exercise will include the main topics of the course and will be comparable to what already experienced during the hands on lectures. Final evaluation will be based upon the obtained results and will follow a discussion with the teacher about the information and procedures carried out to solve the exercise.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP8085072/NO

### EPIGENETICS AND EPIGENOMICS

**Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester**

**Lecturer:** Prof. CARLO FIORE VISCOMI

**Credits:** 6 ECTS

**Prerequisites:**
Knowledge of the fundamental principles of Genetics, Biochemistry, and Molecular Biology. The course aims at providing the students of the master's degree in Molecular Biology with advanced knowledge of the most up-to-date concepts in epigenetics and epigenomics, with a particular focus on their role in human diseases.

**Short program:**
Introduction: What is epigenetics? (0.2 CFU) The composition of chromatin: the epigenome and molecules involved in chromatin regulation (0.8 CFU) Technologies for analysing the nuclear transcriptional activity: (e.g.: high-resolution FISH of genes in transcription factories, 3C, 4C, 5C and HiC of chromatin for resolving co-localized and co-transcribed sequences, genome-wide Mapping of DNAse I hypersensitive sites) (0.5 CFU) Proximal and distant DNA regions involved in genome regulation: DNA and chromatin modifications and regulation of genome expression (internal and external factors)(0.5 CFU) Examples of dynamic changes in the three-dimensional architecture of chromatin and gene regulation. (0.5 CFU) The protein non-coding part of the genome with its principal products: Micro RNAs: biogenesis, regulation and activities; specific examples of miRNA actions; interactions with other epigenetic molecules; network of interactions between miRNA and mRNAs (with original papers, e.g: miRNA 27a and 142 and metabolism modulation; miR-208b and miR-499 and muscle performance) (0.5 CFU) Long non-coding RNAs (LncRNAs): the discovery (ENCODE project, full-length mapping) biogenesis, evolution, regulation and activities by illustrating examples (original papers) of specific actions of LncRNAs (e.g. g as GASS as decay, HOTAIR as scaffold, PVT1 as protein modifier, MD-1 and as microRNA sponge); circular RNAs (e.g.: CDR1as as cytoplasmic sponge), other non-coding RNA classes (0.5 CFU) Heritability of DNA modifications: global role during early development and gametogenesis, X-chromosome inactivation. (0.5 CFU) Reversibility of epigenetic patterns: approaches for epigenome reprogramming (nuclear transfer, cell fusion, cell extracts, cloned genes or proteins, mRNAs) (0.5 CFU) The epigenetic basis of gene imprinting: genomic imprinting, differential expression of paternal and maternal alleles, control of monoallelic expression of imprinted genes; examples of imprinting; establishing differentially methylated genomic regions; disorders & imprinting. (0.5 CFU) Epigenetic regulation in Mendelian disorders: chromatin diseases and gene modifiers (e.g. FSHD, Duchenne MD, Rett syndrome, mitochondrial diseases), diseases caused by heterochromatin dysregulation (inappropriate gene silencing, heterochromatin reduction). (0.4 CFU) Epigenetic modifications and multifactorial syndromes.(0.2 CFU) Regulating the epigenome in the therapy of human diseases (0.2 CFU) Epigenetic control of the mitotic cell cycle (0.2 CFU) Epigenetics of cancer: uncontrolled replication, epigenetic changes leading to transformation, abnormal patterns of methylation, histone modifications and cancer, epigenetics of tumour metastasis. (0.2 CFU)

**Examination:**
written final exam (open questions) in presence or online (only in the presence of the conditions accepted by the University).

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP9087941/NO

### FUNDAMENTALS OF INFORMATION SYSTEMS

**Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester**

**Lecturer:** Prof. GIORGIO MARIA DI NUNZIO

**Credits:** 12 ECTS

**Prerequisites:**
The student should have basic knowledge of computer programming and problem solving skills.

**Short program:**
The course is structured into 3 submodules: - Python Programming (for Data Science) This submodule provides students with the foundational coding skills they need as data scientists. First, the basics of the Python programming language are covered (i.e., built-in data types, functions, I/O, etc.) along with the environment which is used throughout the class (i.e., Jupyter Notebook). Afterwards, students will dig into a set of the most up-to-date data science Python packages; those are: numpy/scipy (for numerical/scientific computing), pandas (for data manipulation), matplotlib/seaborn (for data visualization), and finally scikit-learn (for learning from data). - Databases This submodule is dedicated to data storage, and it covers the following topics: Relational databases, Logical and Physical Design of a Relational Database. SQL Language: Data Definition and Data Manipulation Language, Database Query The Postgre/SQL database: Creation and Definition of a Database, SQL Queries. Non Relational databases, graph databases, Cypher query language. Neo4J database: Creation and Definition of a Database, Graph Query Language. - Algorithmic Methods: Preliminaries; definition of problem, instance, solution, algorithm. Models of computation. Analysis of algorithms: correctness and running time. Asymptotic analysis. Basic data structures: lists, stacks, queues.

155/233
Trees and their properties. Dictionaries and their implementation. Priority queues. Graphs: representation of graphs. Basic properties. Graph searches and applications. Divide and Conquer paradigm: the use of recursion. Case study: sorting. Eventually, at the end all the modules, students will be able to implement all the stages of a typical machine learning pipeline: from collecting data to building predictive models for solving efficiently a data analysis/prediction problem.

Examination:
Written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP7078720/NO

<table>
<thead>
<tr>
<th>GENOMICS AND NGS DATA ANALYSIS</th>
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<tbody>
<tr>
<td>Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester</td>
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<tr>
<td>Lecturer: Prof. GABRIELE SALES</td>
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<tr>
<td>Credits: 9 ECTS</td>
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<tr>
<td>Prerequisites: Bioinformatics fundamentals (courses “Informatica e Bioinformatica” and “Bioinformatica II”). Solid knowledge of molecular biology, genetics and biochemistry.</td>
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<tr>
<td>Short program:</td>
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<tr>
<td>1. The statistical programming system R (1.5 CFU) - Basic commands and the interface to the operating system - Package installation; using BioConductor - The graphical environment RStudio - Using notebooks for analysis and reporting - Transformation of tabular data - Plot generation 2. Sequence alignment for NGS (1.5 CFU) - Burrows–Weeler transform, genome indexing - Using alignment programs: Bowtie, TopHat and STAR - Quality control - Computing quality metrics with FastQC and CoRTs - Expression quantification - Practical abundance estimation with RSEM and STAR 3. Transcriptomic assembly (1 CFU) - Software methods for short reads: the Trinity software. - Combining multiple assemblies with EvidentialGene. - Annotation methods: BLAST, InterproScan. 4. Introduction to omic and open data (0.5 CFU) - Programmatic access to databanks: BioMart. 5. Gene expression analysis (1 CFU) - Data normalization - Exploratory analyses - Differential expression tests - Functional analysis for the interpretation of results 6. DNA variant analysis (1 CFU) - Quality filters - Statistical tests - Main variants DB: use and analysis - Software for variant germinal variant calling: VarScan, DeepVar. 7. Introduction to single cell data analysis (0.5 CFU) - Seurat workflow</td>
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<td>Examination:</td>
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</table>
The evaluation of the acquired knowledge will be based on a written exam based on open questions. The final evaluation will also keep into account the activity of the student in the analysis of a case study and the preparation of a report on his findings. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures. |
| More information: |
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCQ0094199/NO

<table>
<thead>
<tr>
<th>INTEGRATIVE BIOLOGY AND NETWORK ANALYSIS</th>
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<tbody>
<tr>
<td>Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester</td>
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<tr>
<td>Lecturer: Dott.ssa ENRICA CALURA</td>
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<td>Credits: 6 ECTS</td>
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<tr>
<td>Prerequisites: Notions of molecular biology and genomics techniques, notions of programming and knowledge of the first year course topics.</td>
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<td>Short program:</td>
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<tr>
<td>Course Introduction: (4 ore – 0.5 CFU) • What is integrative biology? • Big Data in biology • Digital DNA: practical, high-capacity, low-maintenance information storage in synthesized DNA • Why modern biology is integrative: history and evolution of bioinformatics • Summary and recall of RNA-sequencing: (4 ore – 0.5 CFU) • Experimental design of omic experiments: types of experimental design; how to choose the right experimental setting according to the biological questions. • Microarrays - RNAseq vocabulary and NGS technologies • Transcriptomic data analysis: brief recall of RNAseq differential expression. • Long-read human genome sequencing and its applications: The omic data integration in cancers (2 ore – 0.25 CFU) • Basis of cancer genomics and molecular biology of cancers • Omics and multi-omics in cancer • Computational resources for the integration of biological data (2 ore – 0.25 CFU) • Types of tools, utilities and functions • Tips for evaluation of computational resource R programming base (4 ore – 0.5 CFU) • Introduction to R (data types and data structures, basic commands) • The R world useful for biology (RStudio, R packages, Bioconductor, quick GitHub detour, R markdown) Integrating microRNA and gene expression: (6 ore – 0.75 CFU) • Biogenesis and mechanisms of microRNA • System biology of microRNA: the miRNAome complexity • miRNA bioinformatics tools • Computational principles and practice of circulating microRNA trafficking and regulation • Pathways and networks for biologic data integration (8 ore – 1 CFU) • Gene set and analysis • Biological networks: the pathway model • Pathway types, graphical notation and data formats • Evolution, drawbacks and challenges in knowledge representation of metabolic pathway • Evolution, drawbacks and challenges of cell signaling pathway • Multi-omic data integration in pathway analyses Transcriptome regulation (4 ore – 0.5 CFU) • Transcription factor and computational motif finding • Chromatin Immuno Precipitation (ChIP-seq) data analysis • ChIP-seq motif analysis and TF interactions Epigenomics data integration (6 ore – 0.75 CFU) • DNA-Methylation (MeDip-seq, MRE-seq, WG and RR bisulfite seq, SMRT sequencing) • Nucleosome position (MNase-seq) • Histone modification (H3K4me3) Chromatin accessibility (DNAase-Seq, ATAC-Seq) • Higher order chromatin interactions (H-C) Spatial Transcriptomics (2 ore – 0.25 CFU) ESERCITAZIONI (16 ore – 1 CFU) 1. Surfing and evaluation of Multi-omic Cancer Data 2. Surfing and evaluation of Multi-omic Cancer Webtools 3. Pathway analyses with R programming 4. ChIP-seq case study with R programming</td>
</tr>
<tr>
<td>Examination:</td>
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</table>
The evaluation of the acquired knowledge will be based on a written exam based on open questions. The final evaluation will also keep into account the activity of the student in the analysis of a case study and the preparation of a report on his findings. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures. |
| More information: |
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP7078720/NO
**MICROBIAL METAGENOMICS**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. STEFANO CAMPANARO

**Credits:** 6 ECTS

**Prerequisites:**
The course requests basic knowledge regarding molecular biology, microbiology and bioinformatics.

**Short program:**
Introduction to metagenomics. First part - Methods
Next generation sequencing for metagenomics. Second generation sequencing (Illumina) and third generation sequencing (Nanopore/PacBio) deeply influenced the metagenomic field. Amplicon libraries, shotgun DNA libraries, RNA-seq for metatranscriptomics (0.4 CFU). Basic concepts regarding microbial community analysis. Structure of the microbial communities, ecological indices, similarity measures (0.2 CFU). Marker genes based analysis. Amplicon sequencing analysis using different marker genes (16S rRNA, 18S rRNA, ITS, viral markers, other examples) (0.4 CFU). Video lessons Rob Knight - 16S amplicon sequencing. Genari resume regardin marker gene analysis and the use of specific software (QIIME, Mothur) (0.1 CFU). Metagenomic inference. How to infer the genetic composition of a microbiome starting from amplicon sequencing data using PICRUSt (0.3 CFU). Analysis of shotgun metagenomic reads. Approaches and software used for analyzing shotgun sequence data without performing the assembly process (0.2 CFU). Metagenomic assembly and binning. Approaches to the assembly of shotgun reads, the challenge of the microbial communities. Extraction of single genomes from the metagenome: the binning approach (0.6 CFU). Metatranscriptomics. Analysis of RNA-seq data to analyze the gene expression at community-level (0.6 CFU). Video lessons Rob Knight - Statistical analyses. Statistical approaches to the study of metagenomics (0.2 CFU). Metabolic flux balance analysis. Methods to the investigation of metabolic fluxes in complex microbial populations (0.4 CFU). Second part – Structure of the microbiome in some selected environments. Anaerobic digestion metagenomics. Degradation of complex organic matter is performed by a multi-layer microbiome composed by Bacteria and Archaea (0.3 CFU). Marine metagenomics. The structure of the marine microbiome, how approaches changed during the years for the investigation of this complex microbial community (0.3 CFU). Soil metagenomics. The composition of the soil microbiome described from a number of examples (0.3 CFU). Human gut metagenomics. The human gut microbiome, its role in determining specific diseases (0.3 CFU). Viruses metagenomics. The metagenomics of viruses performed from shotgun sequencing data (0.2 CFU). Conclusions and final remarks (0.1 CFU). Journal club. Students will select a paper and will present in critical way methods and findings (0.1 CFU).

**Examination:**
Final test will be based on written examination, questions will evaluate acquired knowledge, ability to summarize answers and critical discussion. Test is based on topics covered during the course.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCQ0094218/NO

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**MODELS IN GENETIC DISEASE RESEARCH**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. MAURO AGOSTINO ZORDAN

**Credits:** 4 ECTS

**Prerequisites:**
The course consists in a series of specific seminars dealing with the general topic of genetic diseases and the model organisms employed to study the molecular mechanisms involved in the physiopathology of the diseases. Consequently, all of the courses entailed by the Master's degree are considered preparatory to this course.

**Short program:**
The course is organized as a series of one-hour seminars on topics dealing mainly with genetic diseases and the use of model organisms in genetic disease research. Topics typically touch upon molecular aspects of select genetic diseases and on the application of models such as in vitro mammalian cells, yeast, Drosophila, zebrafish and mouse to study the pathogenetic mechanisms of specific genetic defects.

**Examination:**
The final exam will be written and consists in reading a scientific paper dealing with the subject exposed in one of the seminars and, on the basis of the paper's content, writing an abstract, which for the occasion, will have been concealed from the original paper.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP9087942/NO
## MOLECULAR BIOLOGY OF DEVELOPMENT

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. FRANCESCO ARGENTON  
**Credits:** 8 ECTS  
**Prerequisites:** The students should have already acquired the fundamentals on eukariotic cellular biology, on control of gene expression, differentiation, histology and developmental biology.

**Short program:**
1. Presentation of the course, history and principles of developmental genetics (1.5 CFU): cell fate analysis, organizers and transplants, mutagenesis, cellular asymmetry, chemoaffectivity hypothesis, sex determination, lateral inhibition, somitogenesis.  
2. Cellular Developmental Mechanisms (0.5 CFU): Survival, Apoptosis, Shape, Movement, Differentiation, Gene Expression  
3. Morphogenetic theory (0.5 CFU): Wnt, TGFβ, BMP, HH, Notch  
4. Genetic pathways controlling development, their function and visualization (1.5 CFU): JAK/STAT and FGF pathways.  
5. germ layers induction and regionalization of the main axes (DV, AP, LR) in vertebrates and Drosophila, Examples of organ formation.  
6. Adult stem cells.  
7. Early mouse and human development from zygote to gastrulation (0.5 CFU)  
8. Reprogramming (0.5 CFU)

**Examination:**
Three essay on open questions on theoretical, practical and critical topics of the class. For the laboratory experience, students must prepare a written report of their practicals on whole mount analysis of development. Students are also asked during the progress of the class to present a developmental genetic topic.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCP8085061/NO

## STRUCTURAL BIOCHEMISTRY AND BIOPHYSICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa LAURA CENDRON  
**Credits:** 9 ECTS  
**Prerequisites:** General Biochemistry concepts. Basic Mathematics and Physics courses.

**Short program:**
The course will be divided in two parts. The first will be devoted to the introduction of basic principles of Biophysical techniques focused on structural and functional characterization of biological macromolecules, supramolecular assemblies and cells. In the second part, three recently described paradigms in the analysis of sensorial system study will be introduced. Such examples will be proposed mainly focusing on the Biophysical Methods that allowed disclosing important links between structure and function of macromolecules. First part A. Basic principles about protein structure B. Protein sequences analysis, alignment and structure prediction C. X-ray crystallography 1. Crystallization techniques in biochemistry. 2. Crystals, mathematical lattice, symmetry in crystals, space groups. 3. Production of X-rays; 4. Diffraction of X-rays (waves, interference); 5. Single crystal X-rays diffraction; Bragg’s law; X-rays diffraction pattern; structure factors; the concept of Resolution 7. X-ray data collection, indexing and processing. 8. From diffraction data to the protein model 9. The phase problem and solution methods, MIR, MAD, MR 10. Structure refinement; The R index; Treatment and analysis of structural data; D. Single particle CryoElectron Microscopy (CRYO-EM): basic concepts and applications of electron microscopy on single particle specimens 1. Basic concepts 2. Instruments 3. Sample preparation 4. Data collection and treatment. 5. From 2D projections to 3D reconstruction E. Nuclear magnetic resonance (NMR) NMR spectroscopy applied to protein studies: Basic concepts and technique introduction; F. Examples of structural data usage in the investigation of relevant questions in biochemistry as well as for purposes related to applied research; Second part: 1. Energy transformation in biology: from the physiological mechanisms to the biophysical methods used to study physiology, which are based on the interaction between energy and matter 2. Sound energy and the molecular mechanisms of the perception of different frequencies. 3. Visual perception and the molecular basis of photoreception. Leading from physiology to exploit light as a tool to investigate the molecular mechanisms of biology, 4. Advanced optical microscopy methods: technology beyond human eye 5. Non-visible electromagnetic radiation: (patho)physiological mechanisms and biophysical methods in biology that exploit these light wavelenghts 6. Heart as a fluidic pump: from the electric signal (and its molecular mechanisms) to the mechanic work 7. The use of the magnetic properties of the matter to investigate the biomolecules: protein NMR in physiology and comparison with other structural biology methods 8. Magnetoreception in nature and its molecular mechanisms: how can the earth magnetic field be detected by live being? 9. The problem of signal to noise ratio in physiology and in the measuring instruments.

**Examination:**
Written or oral examination. Both general and specific questions for each of the two parts of the course will be proposed.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCQ0094201/NO

## SYSTEMS BIOLOGY
### Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. GABRIELE SALES

**Credits:** 6 ECTS

**Prerequisites:**
The basic knowledge deriving from the subjects of the first year of the Master Degree

**Short program:**
Introduction to Systems Biology. (0.25 CFU) Basics of Derivatives, Integrals and Differential Equations Mathematical Modeling. (0.25 CFU) Static Network Models. (0.5 CFU) Markov Models. (0.5 CFU) Mutual Information, Relevance Networks and Bayesian Networks. (0.5 CFU) The Mathematics of Biological Systems. (0.5 CFU) Parameter Estimation from Noisy Data: Grid Searches, Hill Climbing, Genetic Algorithms. (0.5 CFU) Signaling Systems. (0.5 CFU) Population Systems. (0.5 CFU) SIR Model Simulation. (0.5 CFU)

**Examination:**
The evaluation of the acquired knowledge will be based on a written exam based on 4 open questions. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/007PD/SCQ0094202/NO

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### APPLIED STATISTICS FOR GENETICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. DAVIDE RISSO

**Credits:** 6 ECTS

**More information:**

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### BIOCHEMISTRY FOR GENETICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa ILDIKO SZABO

**Credits:** 8 ECTS

**More information:**

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### BIOCHEMISTRY OF DISEASES

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. LUCA SCORRANO

**Credits:** 8 ECTS

**Prerequisites:**
Biochemistry, Physiology and Pathology

**Short program:**
Introduction to class. Course organization. Distribution of material. designing and interpreting an experiment in biology how to critically read a research paper (w/example) Metabolic flexibility Interorganellar contact sites angiogenesis adipocyte biology neurodegeneration Design and analysis of a conditional knockout mouse Introduction to the lab rotation experiments Presentation of the lab rotation experiments by students Critical presentation of a paper by students course wrap up: questions, doubts, answers

**Examination:**
Evaluation of the overall active participation to classes and tutorials (30%) Evaluation of the lab report (30%) Evaluation of the final public presentation (40%)
COMPUTATIONAL ANTHROPOLOGY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. LUCA PAGANI

**Credits:** 6 ECTS

More information:

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EPIGENETICS AND EPIGENOMICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. CARLO FIORE VISCOMI

**Credits:** 6 ECTS

More information:

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HUMAN PHYSIOLOGY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 9 ECTS

More information:

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INTEGRATIVE BIOLOGY AND NETWORK ANALYSIS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Dott.ssa ENRICA CALURA

**Credits:** 6 ECTS

More information:

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MATHEMATICAL MODELING FOR BIOLOGISTS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** to be defined

**Credits:** 2 ECTS

More information:

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MODELS IN GENETIC DISEASE RESEARCH
Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. MAURO AGOSTINO ZORDAN

**Credits:** 4 ECTS

**More information:**

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Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. LUCA PAGANI

**Credits:** 8 ECTS

**More information:**

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Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa MILENA BELLIN

**Credits:** 6 ECTS

**More information:**

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Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. GABRIELE SALES

**Credits:** 6 ECTS

**More information:**

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Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. DAVIDE RISSO

**Credits:** 6 ECTS

**Prerequisites:**
The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.

**Short program:**

**Examination:**
Written exam
**CELL BIOLOGY**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa CHIARA RAMPAZZO

**Credits:** 9 ECTS

**More information:**

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**COMPUTATIONAL ANTHROPOLOGY**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. LUCA PAGANI

**Credits:** 6 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/006PD/SCP8085218/NO

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**FUNDAMENTALS OF INFORMATION SYSTEMS**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. GIORGIO MARIA DI NUNZIO

**Credits:** 12 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/006PD/SCP7078720/NO

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**GENOMICS AND NGS DATA ANALYSIS**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. GABRIELE SALES

**Credits:** 9 ECTS

**More information:**

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**MICROBIAL METAGENOMICS**

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. STEFANO CAMPANARO

**Credits:** 6 ECTS

**More information:**

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**MODELS IN GENETIC DISEASE RESEARCH**
MOLECULAR BIOLOGY OF DEVELOPMENT

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

Lecturer: Prof. FRANCESCO ARGENTON

Credits: 8 ECTS

More information:

APPLIED STATISTICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. DAVIDE RISSO

Credits: 6 ECTS

Prerequisites:
The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.

Short program:

Examination:
Written exam

More information:

BIOCHEMISTRY

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof.ssa ILDIKO SZABO

Credits: 8 ECTS

More information:

CELL BIOLOGY

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof.ssa CHIARA RAMPAZZO

Credits: 9 ECTS
GENOMICS AND NGS DATA ANALYSIS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

Lecturer: Prof. GABRIELE SALES

Credits: 9 ECTS

MODELS IN GENETIC DISEASE RESEARCH

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. MAURO AGOSTINO ZORDAN

Credits: 4 ECTS

MOLECULAR AND CELL BIOLOGY OF PLANTS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof.ssa BARBARA BALDAN

Credits: 9 ECTS

Prerequisites:
Students should have already acquired a basic knowledge of Cell Biology, Plant Biology, Biochemistry and Molecular Biology.

Short program:
Ca²⁺-mediated signal transduction in response to biotic and abiotic stresses in plants: Ca²⁺ as intracellular messenger; methods of measuring intracellular Ca²⁺ concentration; calcium transients and calcium signatures (1 CFU). Plant hormones (auxins, gibberellins, cytokinins, ethylene, abscisic acid): biosynthesis, actions, transport and developmental effects; signal transduction pathways (2 CFU). Growth and development: Shoot and root apical meristems: their establishment and maintenance. Determination of the developmental axes and the involved genes. Molecular aspects of lateral organ formation (0.5 CFU). Blue light and red light responses: light perception, signal transduction and plant responses to light environmental conditions (0.5 CFU). Plant reproductive development: floral meristem development, floral organ identity genes, ABCDE model to explain the flower development; the control of flowering (1 CFU). Molecular aspects in micro and macro-gametogenesis; self-incompatibility during the pollen-pistil interactions; genes involved in control of double fertilization; embryo, seed and fruit development (2 CFU). Plant–microorganism interactions: cellular and molecular surveys about mycorrhiza, Rhizobium-Leguminosae symbiosis and plant-Agrobacterium interaction (1 CFU). 1 CFU (16 h) of practical work on the following topics: 1) Somatic embryogenesis in the model system Daucus carota, tobacco micropropagation; 2) Isolation of protoplasts from cell suspension cultures of Arabidopsis thaliana transgenic lines; fluorescence imaging of intracellular compartments; 3) Beneficial plant-microbe interactions: staining and observation of arbuscules in Lotus japonicus roots; 4) Visit to the Botanical Garden of the University of Padova.

Examination:
To verify the acquired knowledge, the exam will be in written form, with open questions on theoretical topics dealt with during the course, as well as questions concerning the practical activity carried out in the laboratory. The active participation to the discussions proposed during teaching classrooms will also be considered.

MOLECULAR BIOLOGY OF DEVELOPMENT

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

Lecturer: Prof. FRANCESCO ARGENTON

Credits: 8 ECTS
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</tr>
</tbody>
</table>
BIODEMOGRAPHY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

- 

**Short program:**

- 

**Examination:**

- 

**More information:**


BIOOTHERAPY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

- 

**Short program:**

- 

**Examination:**

- 

**More information:**


CELL IMAGING

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

- 

**Short program:**

- 

**Examination:**

- 

**More information:**

CELLULAR ASPECTS OF DEVELOPMENT

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**


CELLULAR BIOLOGY OF CANCER

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**


CELLULAR NEUROBIOLOGY AND DEVELOPMENT

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**


EPIDEMIOLOGY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester
Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -


EVOLUTION AND DEVELOPMENT

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -


GENETIC PREDISPOSITION TO CANCER

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -


GENETICS AND EPIGENETICS OF MULTIFACTORIAL DISEASES

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -
GENOMIC ANALYSIS OF CANCERS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:

Short program:

Examination:

More information:

GENOMICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:

Short program:

Examination:

More information:

HUMAN EVOLUTIONARY GENETICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:

Short program:

Examination:

More information:

HUMAN GENETICS AND HEMATOLOGY
HUMAN GENETICS AND NEUROBIOLOGY

Master's degree in MOLECULAR BIOLOGY (ORD. 2020). First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:
-

Short program:
-

Examination:
-

More information:

MICROBIOLOGY: HOST-PATHOGENS INTERACTIONS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020). First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:
-

Short program:
-

Examination:
-

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/006PD/SCQ0094456/NO

MOLECULAR GENETICS OF HUMAN DISEASES

Master's degree in MOLECULAR BIOLOGY (ORD. 2020). First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites:
-

Short program:
NEURODEVELOPMENT, PREMATURITY, HOMEOSTASIS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**

NORMAL AND PATHOLOGICAL INTRACELLULAR SIGNALISATION

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**

OPTOGENETICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** to be defined

**Credits:** 3 ECTS

**Prerequisites:**

**Short program:**

**Examination:**

**More information:**
RNASEQ ANALYSIS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -

More information:

SOMATIC GENETIC IN CANCER

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -

More information:

STEM CELLS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined

Credits: 3 ECTS

Prerequisites: -

Short program: -

Examination: -

More information:

VERTEBRATE DEVELOPMENT AND RELATED HUMAN PATHTOLOGIES

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: to be defined
### APPLIED STATISTICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. DAVIDE RISSO  
**Credits:** 6 ECTS

**Prerequisites:**  
- Basic level of biochemistry, cellular biology and physiology

**Short program:**  
- Introduction to behavioural genetics:  
- Historical introduction:  
- Francis Galton, eugenics, racial laws and Naziism, behaviourism, birth of behavioural genetics:  
- Behaviour as gene-environment interaction (nature-nurture): Studies on human families - MZ and DZ twins and adoptive children:  
- Model organisms in behavioural genetics: Caenorhabditis, Drosophila, Zebrafish, mammals: rat, mouse, dog (behaviour and domestication):  
- Genetics of quantitative characters in the study of behaviour (behavioural quantitative traits):  
- Types of quantitative characters - Similarity between relatives and the concept of heritability:  
- Artificial selection and realized heritability:  
- Equation for the prediction of individual selection:  
- Genetic models for quantitative characters:  
- Components of phenotypic variation - Sources of genetic and environmental variation:  
- Components of genetic variation:  
- Covariance between relatives - Studies on twins and inferences on human heritability:  
- Norm of reaction, threshold characters and genetic correlation:  
- Norm of reaction and phenotypic plasticity:  
- Threshold characters: Genes as risk factors in disease:  
- Genetic correlation and correlated response:  
- How to identify genes? Single genes or multiple genes?:  
- Genes which influence quantitative characters:  
- The number of genes which influence quantitative traits:  
- Methods for mapping (Quantitative Trait Loci) QTL:  
- Candidate genes - Genome Wide Association (GWA):  
- Single Nucleotide Polymorphisms (SNP):  
- Physiological behaviour and its' variations, considering also pathological aspects of selected behaviours:  
- circadian rhythms, sleep - learning and memory - socialization, aggressiveness - locomotion - orientation and navigation - sexual orientation - seeking novelties:  
- Description of the molecular mechanisms and the neuronal circuits involved in the control of some of the behavioural patterns described in the preceding section:  
- Practicals: Methods to study behaviour in animal models (partly taught class, partly laboratory simulations):  
- Design of equipment, computer hardware and software, numerical and statistical analysis of data (i.e. videos, movement tracking).

**Examination:**  
Written exam, at the end of the course, using the Moodle platform.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085059/NO

### BEHAVIOURAL GENETICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof. MAURO AGOSTINO ZORDAN  
**Credits:** 6 ECTS

**Prerequisites:**  
Basic Genetics and possibly also Population Genetics. Ideally some background in programming with R (Rstudio)

**Short program:**  
- Introduction to behavioural genetics:  
- Historical introduction:  
- Francis Galton, eugenics, racial laws and Nazism, behaviourism, birth of behavioural genetics:  
- Behaviour as gene-environment interaction (nature-nurture): Studies on human families - MZ and DZ twins and adoptive children:  
- Model organisms in behavioural genetics: Caenorhabditis, Drosophila, Zebrafish, mammals: rat, mouse, dog (behaviour and domestication):  
- Genetics of quantitative characters in the study of behaviour (behavioural quantitative traits):  
- Types of quantitative characters - Similarity between relatives and the concept of heritability:  
- Artificial selection and realized heritability:  
- Equation for the prediction of individual selection:  
- Genetic models for quantitative characters:  
- Components of phenotypic variation - Sources of genetic and environmental variation:  
- Components of genetic variation:  
- Covariance between relatives - Studies on twins and inferences on human heritability:  
- Norm of reaction, threshold characters and genetic correlation:  
- Norm of reaction and phenotypic plasticity:  
- Threshold characters: Genes as risk factors in disease:  
- Genetic correlation and correlated response:  
- How to identify genes? Single genes or multiple genes?:  
- Genes which influence quantitative characters:  
- The number of genes which influence quantitative traits:  
- Methods for mapping (Quantitative Trait Loci) QTL:  
- Candidate genes - Genome Wide Association (GWA):  
- Single Nucleotide Polymorphisms (SNP):  
- Physiological behaviour and its' variations, considering also pathological aspects of selected behaviours:  
- circadian rhythms, sleep - learning and memory - socialization, aggressiveness - locomotion - orientation and navigation - sexual orientation - seeking novelties:  
- Description of the molecular mechanisms and the neuronal circuits involved in the control of some of the behavioural patterns described in the preceding section:  
- Practicals: Methods to study behaviour in animal models (partly taught class, partly laboratory simulations):  
- Design of equipment, computer hardware and software, numerical and statistical analysis of data (i.e. videos, movement tracking).

**Examination:**  
Written exam, at the end of the course, using the Moodle platform.

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085059/NO

### BIOCHEMISTRY

Master’s degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa ILDIKO SZABO  
**Credits:** 8 ECTS

**Prerequisites:**  
Basic level of biochemistry, cellular biology and physiology

**Short program:**
The course will give an in depth knowledge of some aspects of modern, advanced biochemistry regarding protein import mechanisms into organelles (mitochondria, chloroplasts and peroxisomes) including illustration of the importance of the above processes in plant and animal physiology. Connected to these themes, mechanisms of photoprotection in higher plants will be discussed. In addition, the study of membrane proteins (topology, structure,structure/function relationship) will be discussed with illustration of advanced techniques, with particular reference to ion channels. In addition, the most important aspects of tumor metabolism will be discussed.

Examination:
Written exam comprising open questions.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085067/NO

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**BIOCHEMISTRY OF DISEASES**

Master's degree in [MOLECULAR BIOLOGY (ORD. 2020)](https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085067/NO), First semester

**Lecturer:** Prof. LUCA SCORRANO

**Credits:** 8 ECTS

**Prerequisites:** Biochemistry, Physiology and Pathology

**Short program:**
Introduction to class. Course organization. Distribution of material. designing and interpreting an experiment in biology how to critically read a research paper (w/example) Metabolic flexibility Interorganellar contact sites angiogenesis adipocyte biology neurodegeneration Design and analysis of a conditional knockout mouse Introduction to the lab rotation experiments Presentation of the lab rotation experiments by students Critical presentation of a paper by students course wrap up: questions, doubts, answers

**Examination:**
Evaluation of the overall active participation to classes and tutorials (30%) Evaluation of the lab report (30%) Evaluation of the final public presentation (40%)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085083/NO

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**CELL BIOLOGY**

Master's degree in [MOLECULAR BIOLOGY (ORD. 2020)](https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085067/NO), First semester

**Lecturer:** Prof.ssa CHIARA RAMPASSO

**Credits:** 9 ECTS

**Prerequisites:** Basic level of Cell Biology, Molecular Biology and Genetics

**Short program:**
The 9 CFU course is organized in about 7 CFU of frontal lectures and 2 CFU dedicated to the presentation and discussion of recent articles on specific topics. The discussion of the articles is an integral part of the program. Lectures will cover 7 main topics: 1) Physical principles behind the most common microscopy techniques (1 CFU). 2) Chromatin Biology and nuclear organization to address fundamental questions about cellular differentiation and nuclear reprogramming. Chromosomal territories and subdomains. Nucleolus and nuclear lamina (2CFU) 3) Centromeric and telomeric chromatin (1 CFU). 4) polycomb complexes, facultative heterochromatin and bivalent chromatin in pluripotent stem cells (1 CFU) 5) Symmetric / asymmetric cell division and cell polarity (1 CFU) 6) Main principles of autophagy and related diseases 7) Quiescence and senescence in mammalian cells. Abnormal signal transduction pathways in cancer development. Immunization and transformation, role of telomeres. Cancer stem cells (2CFU).

**Examination:**
The knowledge acquired by the student will be evaluated with a written exam organized in two parts. First part (1 CFU) described in the course contents at section 1 will be assessed with one open question that include a long answer, the second part (6 CFU) described in the course content at section 2 to 4 will be assessed with open questions that include short or longer answer. The final grade is expressed as a weighted average between the two parts.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085218/NO

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**COMPUTATIONAL ANTHROPOLOGY**

Master's degree in [MOLECULAR BIOLOGY (ORD. 2020)](https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085067/NO), Second semester

**Lecturer:** Prof. LUCA PAGANI

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EPIGENETICS AND EPIGENOMICS

Master’s degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. CARLO FIORE VISCOMI

Credits: 6 ECTS

Prerequisites:
Knowledge of the fundamental principles of Genetics, Biochemistry, and Molecular Biology. The course aims at providing the students of the master’s degree in Molecular Biology with advanced knowledge of the most up-to-date concepts in epigenetics and epigenomics, with a particular focus on their role in human diseases.

Short program:
Introduction: What is epigenetics? (0.2 CFU) The composition of chromatin: the epigenome and molecules involved in chromatin regulation (0.8 CFU) Technologies for analysing the nuclear genome transcriptional activity: (e.g.: high-resolution FISH of genes in transcription factories, 3C, 4C, 5C and HiC of chromatin for resolving co-localized and co-transcribed sequences, genome-wide Mapping of DNAse I hypersensitive sites) (0.5 CFU) Proximal and distant DNA regions involved in genome regulation: DNA and chromatin modifications and regulation of genome expression (internal and external factors) (0.5 CFU) Examples of dynamic changes in the three-dimensional architecture of chromatin and gene regulation (0.5 CFU) The protein non-coding part of the genome with its principal products. Micro RNAs: biogenesis, regulation and activities; specific examples of miRNA actions; interactions with other epigenetic molecules; network of interactions between miRNA and mRNAs (with original papers, e.g: miRNA 27a and 142 and metabolism modulation; miR-208b and miR-499 and muscle performance) (0.5 CFU) Long non-coding RNAs (LncRNAs): the discovery (ENCODE project, full-length mapping) biogenesis, evolution, regulation and activities by illustrating examples (original papers) of specific actions of LncRNAs (e.g. as GASS as decoy, HOXAIR as scaffold, PVT1 as protein modifier, MD-1 and as microRNA sponge); circular RNAs (e.g.: CDR1as as cytoplasmic sponge), other non-coding RNA classes (0.5 CFU) Heritability of DNA modifications: global role during early development and gametogenesis, X-chromosome inactivation. (0.5 CFU) Reversibility of epigenetic patterns: approaches for epigenome reprogramming (nuclear transfer, cell fusion, cell extracts, cloned genes or proteins, mRNAs) (0.5 CFU) Epigenetic regulation in Mendelian disorders: chromatin diseases and gene modifiers (e.g. FSHD, Duchenne MD, Rett syndrome, mitochondrial diseases), diseases caused by heterochromatin dysregulation (inappropriate gene silencing, heterochromatin reduction). (0.4 CFU) Epigenetic modifications and multifactorial syndromes. (0.2 CFU) Regulating the epigenome in the therapy of human diseases (0.2 CFU) Epigenetic control of the mitotic cell cycle (0.2 CFU) Epigenetics of cancer: uncontrolled replication, epigenetic changes leading to transformation, abnormal patterns of methylation, histone modifications and cancer, epigenetics of tumour metastasis. (0.2 CFU)

Examination:
written final exam (open questions) in presence or online (only in the presence of the conditions accepted by the University).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP9085072/NO

GENOMICS AND NGS DATA ANALYSIS

Master’s degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

Lecturer: Prof. GABRIELE SALES

Credits: 9 ECTS

Prerequisites:
Prior knowledge needed for the classes in Computational Anthropology is that normally provided for students at the final class of the first degree in Molecular Biology. Particularly, the basic understanding of Genetics, Statistics, Phylogeny, and Evolutionary Biology in their fundamental principles and processes, is required. Students must also be familiar with the Unix/Shell environment. No prior knowledge is requested about specific contents in Population Genetics and Genomics, however scientific contents of the “Anthropology” course may be of great help during this course.

Short program:
The course aims at blending basic knowledge within the fields of Molecular Anthropology and Human Population Genetics with practical (bioinformatic) skills, transferable to the expanding occupational sectors of Personal Genomics and Ancestry analyses. The following topics will be explored from a theoretical and a practical/applicative angle: 1) Genetic admixture and local ancestry; 2) Ancestry deconvolution and ancestry-specific analyses; 3) Population differentiation among human groups, both at a genome-wide and at a locus-specific level; 4) Effect on the genome of natural selection events; 5) Introgression events between Homo sapiens and Archaic humans; These general objectives are addressed through critical discussion of case-studies taken from primary scientific literature on Molecular Anthropology, and through extensive hands on exercise in a computer lab.

Examination:
Examination will be based on a practical exercise of approximately 3 hours, to be carried out in the computer room. The exercise will include the main topics of the course and will be comparable to what already experienced during the hands on lectures. Final evaluation will be based upon the obtained results and will follow a discussion with the teacher about the information and procedures carried out to solve the exercise.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP9087941/NO
Bioinformatics fundamentals (courses “Informatica e Bioinformatica” and “Bioinformatica II”). Solid knowledge of molecular biology, genetics and biochemistry.

Short program:
1. The statistical programming system R (1.5 CFU) - Basic commands and the interface to the operating system - Package installation; using BioConductor - The graphical environment RStudio - Using notebooks for analysis and reporting - Transformation of tabular data - Plot generation 2. Sequence alignment for NGS (1.5 CFU) - Burrows–Wheeler transform, genome indexing - Using alignment programs: Bowtie, TopHat and STAR - Quality control - Computing quality metrics with FastQC and QoRTs - Expression quantification - Practical abundance estimation with RSEM and STAR 3. Transcriptomic assembly (1 CFU) - Software methods for short reads: the Trinity software. - Combining multiple assemblies with EvidentialGene. - Annotation methods: BLAST, InterproScan. 4. Introduction to omic and open data (0.5 CFU) - Programmatic access to databanks: BioMart. 5. Gene expression analysis (1 CFU) - Data normalization - Exploratory analyses - Differential expression tests - Functional analysis for the interpretation of results 6. DNA variant analysis (1 CFU) - Quality filters - Statistical tests - Main variants DB: use and analysis - Software for variant germinal variant calling: VarScan, DeepVar 7. Introduction to single cell data analysis (0.5 CFU) - Seurat workflow

Examination:
The evaluation of the acquired knowledge will be based on a written exam based on open questions. The final evaluation will also keep into account the activity of the student in the analysis of a case study and the preparation of a report on his findings. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP9087942/NO

MICROBIAL METAGENOMICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), Second semester

Lecturer: Prof. STEFANO CAMPANARO

Credits: 6 ECTS

Prerequisites:
The course requests basic knowledge regarding molecular biology, microbiology and bioinformatics.

Short program:
Introduction to metagenomics. First part -Methods Next generation sequencing for metagenomics. Second generation sequencing (Illumina) and third generation sequencing (Nanopore/PacBio) deeply influenced the metagenomic field. Amplicon libraries, shotgun DNA libraries, RNA-seq for metatranscriptomics (0.4 CFU). Basic concepts regarding microbial community analysis. Structure of the microbial communities, ecological indices, similarity measures (0.2 CFU). Marker genes based analysis. Amplicon sequencing analysis using different marker genes (16S rRNA, 18S rRNA, ITS, viral markers, other examples) (0.4 CFU). Video lessons Rob Knight - 16S amplicon sequencing. Genarl resume regardin marker gene analysis and the use of specific software (QiIME, Mothur) (0.1 CFU). Metagenomic inference. How to infer the genetic composition of a microbe using amplicon sequencing data using PICRUST (0.3 CFU). Analysis of shotgun metagenomic reads. Approaches and software used for analyzing shotgun sequence data without performing the assembly process (0.2 CFU). Metagenomic assembly and binning. Approaches to the assembly of shotgun reads, the challenge of the microbial communities. Extraction of single genomes from the metagenome: the binning approach (0.6 CFU). Metatranscriptomics. Analysis of RNA-seq data to analyze the gene expression at community-level (0.6 CFU). Video lessons Rob Knight - Statistical analyses. Statistical approaches to the study of metagenomics (0.2 CFU). Metabolic flux balance analysis. Methods to the investigation of metabolic fluxes in complex microbial populations (0.4 CFU). Second part – Structure of the microbiome in some selected environments. Anaerobic digestion metagenomics. Degradation of complex organic matter is performed by a multi-layer microbiome composed by Bacteria and Archaea (0.3 CFU). Marine metagenomics. The structure of the marine microbiome, how approaches changed during the years for the investigation of this complex microbial community (0.3 CFU). Soil metagenomics. The composition of the soil microbiome described from a number of examples (0.3 CFU). Human gut metagenomics. The human gut microbiome, its role in determining specific diseases (0.3 CFU). Viruses metagenomics. The metagenomics of viruses performed from shotgun sequencing data (0.2 CFU). Conclusions and final remarks (0.1 CFU). Journal club. Students will select a paper and will present in critical way methods and findings (0.1 CFU). Laboratory. The practical laboratory is composed of two sections, the first is based on analysis of 16S rRNA amplicon sequences using QIIME, and the second on the analysis of shotgun sequencing data using metagenomic assembly and binning (1 CFU).

Examination:
Final test will be based on written examination, questions will evaluate acquired knowledge, ability to summarize answers and critical discussion. Test is based on topics covered during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP9087942/NO

MODELS IN GENETIC DISEASE RESEARCH

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof. MAURO AGOSTINO ZORDAN

Credits: 4 ECTS

Prerequisites:
The course consists in a series of specific seminars dealing with the general topic of genetic diseases and the model organisms employed to study the molecular mechanisms involved in the physiopathology of the diseases. Consequently, all of the courses entailed by the Master's degree are considered preparatory to this course.

Short program:
1. The statistical programming system R (1.5 CFU) - Basic commands and the interface to the operating system - Package installation; using BioConductor - The graphical environment RStudio - Using notebooks for analysis and reporting - Transformation of tabular data - Plot generation 2. Sequence alignment for NGS (1.5 CFU) - Burrows–Wheeler transform, genome indexing - Using alignment programs: Bowtie, TopHat and STAR - Quality control - Computing quality metrics with FastQC and QoRTs - Expression quantification - Practical abundance estimation with RSEM and STAR 3. Transcriptomic assembly (1 CFU) - Software methods for short reads: the Trinity software. - Combining multiple assemblies with EvidentialGene. - Annotation methods: BLAST, InterproScan. 4. Introduction to omic and open data (0.5 CFU) - Programmatic access to databanks: BioMart. 5. Gene expression analysis (1 CFU) - Data normalization - Exploratory analyses - Differential expression tests - Functional analysis for the interpretation of results 6. DNA variant analysis (1 CFU) - Quality filters - Statistical tests - Main variants DB: use and analysis - Software for variant germinal variant calling: VarScan, DeepVar 7. Introduction to single cell data analysis (0.5 CFU) - Seurat workflow

Examination:
The evaluation of the acquired knowledge will be based on a written exam based on open questions. The final evaluation will also keep into account the activity of the student in the analysis of a case study and the preparation of a report on his findings. This will gauge the establishment of the proper knowledge, the scientific lexicon, the ability to discuss critically and to summarize the topics discussed in the lectures.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP9087942/NO
The course is organized as a series of one-hour seminars on topics dealing mainly with genetic diseases and the use of model organisms in genetic disease research. Topics typically touch upon molecular aspects of select genetic diseases and on the application of models such as in vitro mammalian cells, yeast, Drosophila, zebrafish and mouse to study the pathogenetic mechanisms of specific genetic defects.

Examination:
The final exam will be written and consists in reading a scientific paper dealing with the subject exposed in one of the seminars and, on the basis of the paper's content, writing an abstract, which for the occasion, will have been concealed from the original paper.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085071/NO

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MOLECULAR AND CELL BIOLOGY OF PLANTS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020). First semester

Lecturer: Prof.ssa BARBARA BALDAN

Credits: 9 ECTS

Prerequisites:
Students should have already acquired a basic knowledge of Cell Biology, Plant Biology, Biochemistry and Molecular Biology.

Short program:
- Ca2+-mediated signal transduction in response to biotic and abiotic stresses in plants: Ca2+ as intracellular messenger; methods of measuring intracellular Ca2+ concentration; calcium transients and calcium signatures (1 CFU). Plant hormones (auxins, gibberellins, cytokinins, ethylene, abscisic acid): biosynthesis, actions, transport and developmental effects; signal transduction pathways (2 CFU). Growth and development: Shoot and root apical meristems: their establishment and maintenance. Determination of the developmental axes and the involved genes. Molecular aspects of lateral organ formation (0.5 CFU). Blue light and red light responses: light perception, signal transduction and plant responses to light environmental conditions (0.5 CFU). Plant reproductive development: floral meristem development, floral organ identity genes, ABCDE model to explain the flower development: the control of flowering (1 CFU). Molecular aspects in micro and macro-gametogenesis; self-incompatibility during the pollen-pistil interactions; genes involved in control of double fertilization; embryo, seed and fruit development (2 CFU). Plant–microorganism interactions: cellular and molecular surveys about mycorrhiza, Rhizobium-Leguminosae symbiosis and plant-Agro bacterium interaction (1 CFU). 1 CFU (16 h) of practical work on the following topics: 1) Somatic embryogenesis in the model system Daucus carota, tobacco micropropagation; 2) Isolation of protoplasts from cell suspension cultures of Arabidopsis thaliana transgenic lines; fluorescence imaging of intracellular compartments; 3) Beneficial plant-microbe interactions: staining and observation of arbuscules in Lotus japonicus roots; 4) Visit to the Botanical Garden of the University of Padova.

Examination:
To verify the acquired knowledge, the exam will be in written form, with open questions on theoretical topics dealt with during the course, as well as questions concerning the practical activity carried out in the laboratory. The active participation to the discussions proposed during teaching classrooms will also be considered.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085062/NO

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MOLECULAR ANTHROPOLOGY

Master's degree in MOLECULAR BIOLOGY (ORD. 2020). First semester

Lecturer: Prof. LUCA PAGANI

Credits: 8 ECTS

Prerequisites:
Prior knowledge needed for the classes in Anthropology is that normally provided for students at the final class of the first degree in Natural Sciences. Particularly, the basic understanding of Genetics, Statistics, Phylogeny, and Evolutionary Biology in their fundamental principles and processes, is required. Students should also have sufficient and basic capacities for argumentation and expression, enabling them to defend a thesis and grasp the contents of a scientific debate, actively participating in the discussion of case-studies. No prior knowledge is requested about specific contents in Population Genetics and Genomics.

Short program:
The course aims at deepening the fundamental concepts, principles and analytical methods of Molecular Anthropology within a broader international context. Particularly: - multidisciplinary interaction and early phases of human evolution with an overview on the available fossil remains (1 CFU); - genetic characterization of archaic humans (Neanderthals and Denisova) (0.5 CFU); - human expansions out of Africa and interactions with pre-existing archaic humans (0.5 CFU); - genetic adaptation and evidences of adaptive introgressions (genetic advantages derived from archaic genetic material) (1 CFU); - peopling of the continents (Eurasia, America, Oceania) (1.5 CFU); - how structured is the genetic diversity of our species (0.5 CFU); - demographic growth and expansion/admixtural events following technological revolutions (i.e. Neolithic) (1 CFU); - brief overview on the DNA sequencing and genotyping techniques and analyses - introduction to the ground-breaking consequences of ancient DNA (aDNA) in the field of Molecular Anthropology; - succinct exploration of satellite topics introduced by the students themselves through Journal Clubs on recently published articles (2 CFU) These general objectives are addressed through critical discussion of case-studies taken from primary scientific literature on Molecular Anthropology.

Examination:
Examination is oral and aims at evaluating the scientific skills acquired, through open-ended questions and requests for argumentation and comparison of different theses and models. The suggested reference books are meant to provide a general basis of knowledge which must be integrated with the material examined during the lectures as well as with the most recent scientific papers in the field of Molecular Anthropology (introduced during the lectures).
chosen by the candidate, the exam may start with the discussion of a specific scientific paper among the ones suggested by the teacher, followed by a discussion and additional questions on various topics from the lectures. Attendance is strongly recommended, due to the teaching by interactive methods and case-studies. Students unable to attend a sizeable number of classes must get in touch with the teacher before to discuss an adequate examination mode.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCQ2101381/NO

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### MOLECULAR BIOLOGY OF DEVELOPMENT

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof. FRANCESCO ARGENTON  

**Credits:** 8 ECTS

**Prerequisites:**  
The students should have already acquired the fundamentals on eukariotic cellular biology, on control of gene expression, differentiation, histology and developmental biology.

**Short program:**

1) Presentation of the course, history and principles of developmental genetics (1.5 CFU): cell fate analysis, organizers and transplants, mutagenesis, cellular asymmetry, chemoaffinity hypothesis, sex determination, lateral inhibition, somitogenesis.  
2) Cellular Developmental Mechanisms (0.5 CFU): Survival, Apoptosis, Shape, Movement, Differentiation, Gene Expression  
3) Morphogenetic theory (0.5 CFU): reaction-diffusion theory, French flag theory.  
4) Genetic pathways controlling development, their function and visualization (1.5 CFU): Wnt, TGFβ, BMP, HH, Notch  
5) germ layers induction and regionalization of the main axes (DV, AP, LR) in vertebrates and Drosophila, Examples of organ formation.  
6) Basic concepts of stem cell biology and techniques. Adults stem cells.  
7) Early mouse and human development from zygote to gastrulation (0.5 CFU)  
8) Murine and human pluripotent stem cells. JAK/STAT and FGF pathways (0.5 CFU)  
9) Reprogramming (0.5 CFU)

**Examination:**  
Three essay on open questions on theoretical, practical and critical topics of the class. For the laboratory experience, students must prepare a written report of their practicals on whole mount analysis of development. Students are also asked during the progress of the class to present a developmental genetic topic.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085061/NO

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### MOLECULAR GENETICS

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, First semester

**Lecturer:** Prof.ssa MILENA BELLIN  

**Credits:** 6 ECTS

**Prerequisites:**  
Knowledge of the fundamental principles of Genetics and Molecular Biology. The course aims at providing the students of the Master’s degree in Molecular Biology with advanced knowledge of the most up-to-date concepts in molecular genetics, with a particular focus on their role in human diseases.

**Short program:**

1) Basic aspects of early mammalian development, cell differentiation, and stem cells  
2) Understanding genomes: - core DNA technologies - analysing the structure of genes and genome - principles of genetic manipulation of mammalian genome - uncovering the architecture and function of the human genome  
3) Genetic variation between individuals - human genetic variation - human evolution  
4) Human genetic disease - Chromosomal abnormalities and structural variants - Molecular pathology: linking genotype and phenotype - Mapping and identifying genes for monogenic disorders - Complex diseases - Cancer genetics  
5) Applied human molecular genetics - Genetic testing and ethical implications - Disease models of human disease - Genetic approaches to treating diseases

**Examination:**  
The final examination is written with a combination of open questions and multiple choice questions.

More information:

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### NEUROBIOLOGY

Master's degree in **MOLECULAR BIOLOGY (ORD. 2020)**, Second semester

**Lecturer:** Prof.ssa DANIELA PIETROBON  

**Credits:** 10 ECTS

**Prerequisites:**  
...
The course will be divided in two parts. The first will be devoted to the introduction of basic principles of Biophysical techniques focused on structural and functional characterization of biological macromolecules, supramolecular assemblies and cells. In the second part, three recently described paradigms in the analysis of sensorial system study will be introduced. Such examples will be proposed mainly focusing on the Biophysical Methods that allowed disclosing important links between structure and function of macromolecules. First part A. Basic principles about protein structure B. Protein sequences analysis, alignment and structure prediction C. X-ray crystallography 1. Crystallization techniques in biochemistry. 2. Crystals, mathematical lattice, symmetry in crystals, space groups. 3. Production of X-rays; 4. Diffraction of X-rays (waves, interference); 5. Single crystal X-rays diffraction; Bragg's law; X-rays diffraction pattern; structure factors; the concept of Resolution 7. X-ray data collection, indexing and processing 8. From diffraction data to the protein symmetry in crystals, space groups. 3. Production of X-rays; 4. Diffraction of X-rays (waves, interference); 5. Single crystal X-rays diffraction; Bragg's law; X-rays diffraction pattern; structure factors; the concept of Resolution 7. X-ray data collection, indexing and processing 8. From diffraction data to the protein structure 6. Single particle CryoElectron Microscopy (CRYO-EM): basic concepts and applications of electron microscopy on single particle specimens 1. Basic concepts 2. Instruments 3. Sample preparation 4. Data collection and treatment 5. From 2D projections to 3D reconstruction E. Nuclear magnetic resonance (NMR) NMR spectroscopy applied to protein studies: Basic concepts and technique introduction; F. Examples of structural data usage in the investigation of relevant questions in biochemistry as well as for purposes related to applied research; Second part: 1. Energy transformation in biology: from the physiological mechanisms to the biophysical methods used to study physiology, which are based on the interaction between energy and matter 2. Sound energy and the molecular mechanisms of the perception of different frequencies. 3. Visual perception and the molecular basis of photoreception. Leading from physiology to exploit light as a tool to investigate the molecular mechanisms of biology, 4. Advanced optical microscopy methods: technology beyond human eye 5. Non-visible electromagnetic radiation: (patho)physiological mechanisms and biophysical methods in biology that exploit these light wavelenghts 6. Heart as a fluidic pump: from the electric signal (and its molecular mechanisms) to the mechanic work 7. The use of the magnetic properties of the matter to investigate the biomolecules: protein NMR in physiology and comparison with other structural biology methods 8. Magnetoreception in nature and its molecular mechanisms: how can the earth magnetic field be detected by live being? 9. The problem of signal to noise ratio in physiology and in the measuring instruments.

Examination:
Written examination with three open questions, which aim to verify, besides the acquired knowledge on relevant topics, the ability of critical discussion and reasoning. The individual report on the practical experience maturated during the laboratory training is also evaluated.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCP8085065/NO

STRUCTURAL BIOCHEMISTRY AND BIOPHYSICS

Master's degree in MOLECULAR BIOLOGY (ORD. 2020), First semester

Lecturer: Prof.ssa LAURA CENDRON

Credits: 8 ECTS

Prerequisites:
General Biochemistry concepts. Basic Mathematics and Physics courses.

Short program:
The course will be divided in two parts. The first will be devoted to the introduction of basic principles of Biophysical techniques focused on structural and functional characterization of biological macromolecules, supramolecular assemblies and cells. In the second part, three recently described paradigms in the analysis of sensorial system study will be introduced. Such examples will be proposed mainly focusing on the Biophysical Methods that allowed disclosing important links between structure and function of macromolecules. First part A. Basic principles about protein structure B. Protein sequences analysis, alignment and structure prediction C. X-ray crystallography 1. Crystallization techniques in biochemistry. 2. Crystals, mathematical lattice, symmetry in crystals, space groups. 3. Production of X-rays; 4. Diffraction of X-rays (waves, interference); 5. Single crystal X-rays diffraction; Bragg's law; X-rays diffraction pattern; structure factors; the concept of Resolution 7. X-ray data collection, indexing and processing 8. From diffraction data to the protein structure 6. Single particle CryoElectron Microscopy (CRYO-EM): basic concepts and applications of electron microscopy on single particle specimens 1. Basic concepts 2. Instruments 3. Sample preparation 4. Data collection and treatment 5. From 2D projections to 3D reconstruction E. Nuclear magnetic resonance (NMR) NMR spectroscopy applied to protein studies: Basic concepts and technique introduction; F. Examples of structural data usage in the investigation of relevant questions in biochemistry as well as for purposes related to applied research; Second part: 1. Energy transformation in biology: from the physiological mechanisms to the biophysical methods used to study physiology, which are based on the interaction between energy and matter 2. Sound energy and the molecular mechanisms of the perception of different frequencies. 3. Visual perception and the molecular basis of photoreception. Leading from physiology to exploit light as a tool to investigate the molecular mechanisms of biology, 4. Advanced optical microscopy methods: technology beyond human eye 5. Non-visible electromagnetic radiation: (patho)physiological mechanisms and biophysical methods in biology that exploit these light wavelenghts 6. Heart as a fluidic pump: from the electric signal (and its molecular mechanisms) to the mechanic work 7. The use of the magnetic properties of the matter to investigate the biomolecules: protein NMR in physiology and comparison with other structural biology methods 8. Magnetoreception in nature and its molecular mechanisms: how can the earth magnetic field be detected by live being? 9. The problem of signal to noise ratio in physiology and in the measuring instruments.

Examination:
Written or oral examination. Both general and specific questions for each of the two parts of the course will be proposed.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2445/005PD/SCC0094201/NO

NATURAL SCIENCE ORD. 2014

ENVIRONMENTAL IMPACT ASSESSMENT
Master’s degree in NATURAL SCIENCE ORD. 2014, First semester

**Lecturer:** Dott. UMBERTO DE MARCHI

**Credits:** 6 ECTS

**Prerequisites:**
Ecology and environmental law

**Short program:**
- The role and need for evaluation - Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA): regulations, procedures, case studies, European and International comparisons - Art. 6 of Habitats directive and assessment of implications on Natura 2000 sites: procedures and case studies - Social Impact Assessment and interaction with environmental assessment: key case studies - Ecosystem services approach in environmental assessment - GIS techniques and Multi Criteria Models for environmental assessments - Accounting methods for environmental good and services: Contingent Evaluation, Cost/Benefits Analysis - The management of participation inside environmental assessment procedures

**Examination:**
Working group evaluation report plus oral examination

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1178/000ZZ/SCP4063900/NO

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ENVIRONMENTAL MINERALOGY

Master’s degree in NATURAL SCIENCE ORD. 2014, Second semester

**Lecturer:** Prof. FABRIZIO NESTOLA

**Credits:** 8 ECTS

**Prerequisites:**
Basic chemistry and chemical thermodynamics. Essentials of mineralogy and geology.

**Short program:**
- The internal structure of the Earth and its most abundant elements; definition of mineral; introduction to crystallography (periodicity, symmetry, unit cell, crystallographic axes, the seven crystal systems). - Isomorphism and polymorphism; physical properties of minerals: habit, density, hardness, fracture and cleavage, lustre, colour, reactivity with acids, magnetism, radioactivity. - Systematic mineralogy: composition, symmetry, physical properties, environments of formation for the most common Earth’s minerals, which could have impacts on the environment: quartz and cristobalite, asbestos and asbestiform minerals (not regulated by the Italian law), radioactive minerals, clay minerals, zeolites, iron hydroxides, arsenic and sulphur minerals. - Further minerals and elements of economic and environment interest (Fe, Mn, Cr, Ni, Si, Co, Mo, V, W, Ni and coltan, Al, Mg, Ti, Cu, Pb, Zn, Sn, Sb, As, Be, Bi, Cd, Cs, Ga, Ge, In, Li, Hg, REE, Sc, Y, Re, Se, Ta, Te, Ti, Zr, Hf, Au, Ag, PGE, diamond, beryl, corundum). - Mineralogical technical analyses: X-ray diffraction (X-ray radiation, crystal-radiation interaction, Bragg equation, powder diffraction, comparison with single crystal); electron diffraction microscopy (TEM) and electron diffraction; examples of neutron diffraction and synchrotron diffraction; X-ray fluorescence; electron microprobe (EMPA); scansion electron microscopy (SEM); ion microprobe (SIMS); micro-Raman spectroscopy. - Laboratories. Laboratory of hand mineral identification of a few common minerals of environment interest; examples of chemical formula calculations for a mineral; single-crystal X-ray diffraction (video laboratory); powder-X-ray diffraction (video laboratory); micro Raman spectroscopy (video laboratory); scanning Electron Microscopy (video laboratory); XRF (video laboratory)

**Examination:**
The test will be written and will focus on: a) one open question on the the description of an important mineral or mineral family for environment; b) one open question on the description of one analytical technique discussed during the course. This will allow to highlight the scientific knowledge, the scientific language and the ability to summarize a problem. The test is based on topics discussed during the course.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC1178/000ZZ/SCP4065427/NO

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PHYSICS OF DATA ORD. 2018

ADVANCED STATISTICS FOR PHYSICS ANALYSIS

Master’s degree in PHYSICS OF DATA ORD. 2018, Second semester

**Lecturer:** Prof. ALBERTO GARFAGNINI

**Credits:** 6 ECTS

**Prerequisites:**
None

**Short program:**
180/233
- review of basic concepts: probability, odds and rules, updating probabilities, uncertain numbers (probability functions) - from Bernoulli trials to Poisson processes and related distributions - Bernoulli theorem and Central Limit Theorem - Inference of the Bernoulli p; inference of lambda of the Poisson distribution. Inference of the Gaussian mu. Simultaneous inference of mu and sigma from a sample: general ideas and asymptotic results (large sample size). - fits as special case of parametric inference - Monte Carlo methods: rejection sampling, inversion of cumulative distributions, importance sampling. Metropolis algorithm as example of Markov Chain Monte Carlo. Simulated annealing - the R framework and language for applied statistics.

Examination:
Written exam on the topics covered during the course, oral exam about a project to be carried out by students in groups

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082557/NO

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**ASTRO-STATISTICS AND COSMOLOGY**

Master's degree in **PHYSICS OF DATA ORD. 2018**, First semester

**Lecturer:** Dott. ALESSANDRO RENZI

**Credits:** 6 ECTS

**Prerequisites:**
Probability and statistics: definition of probability, probability distributions, mean value, variance and covariance, Bayes Theorem, basics of statistical estimation theory, maximum likelihood, confidence intervals, hypothesis testing. Cosmology: Hubble law, Robertson-Walker metric, Friedmann-Robertson-Walker equations. Cosmological perturbations: Jeans instability, power spectrum, growth factor.

**Short program:**

**Examination:**
The exam is comprised of two phases. 1) Resolution of assigned homework during the course, eventually to undertake in group. 2) Oral examination with discussion of the course topics.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082722/NO

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**BIOLOGICAL DATASETS FOR COMPUTATIONAL PHYSICS**

Master's degree in **PHYSICS OF DATA ORD. 2018**, Second semester

**Lecturer:** Prof.ssa MONIKA FUXREITER

**Credits:** 6 ECTS

**Prerequisites:**
Basic statistical mechanics, statistics, programming. Chemistry and biology at high-school level.

**Short program:**

Examination:
The evaluation will be based on a project, which requires an integration of the knowledge gained in lectures and practicals. The project for each student will be different and have to be solved individually. The evaluation projects will be ‘real-life’ problems, linked to clinical data or biomedical research by research groups at the University of Padova, simplified to the extent that the students can solve them. Each project have to be completed with a written summary, which specifically includes i) the definition of the problem for the computer ii) reasons for method selection iii) concise description of the method, iv) brief description of the algorithm or flow-chart , v) results, vi) interpretation of results and vii) concluding section and future work. The projects evaluates the overall understanding of applying computational approaches to bio-problems. The projects require independent thinking and application of the lecture and practical materials. There is ample time to solve them and consultation opportunities are provided. The projects are presented as a written summary and possibly a short oral presentation.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ0093478/NO

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COMPUTATIONAL ASTROPHYSICS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof.ssa MICHELA MAPELLI

Credits: 6 ECTS

Prerequisites:
Basics of a programming language. Basics of Mathematical Analysis I and II. Basics of Kinematics and Dynamics (General Physics I), in particular Newton's theory of gravitation. Previous experience in the field of astrophysics is not requested, but is welcome.

Short program:
--- TOPIC nr. 1: Evolution of binary stars and the formation of binary compact objects --- 1.1- General introduction to the evolution of binary stars in astrophysics (mass transfer, common envelope, tidal forces). The formation of binary black holes and double neutron stars. 1.2- Population-synthesis and stellar evolution codes: simulating single and binary stellar populations. 1.3- Discussion of possible projects for topic nr. 1 --- TOPIC Nr. 2: N-body simulations, dynamics of stellar systems and the formation of binary black holes --- 2.1- General introduction to the astrophysical N-body problem. 2.2- N-body simulations: definition of an N-body simulation; concept of computational complexity; N-body units. 2.3- Examples of numerical algorithms to solve the astrophysical N-body problem: Euler, Leapfrog schemes. 2.4- Generation of the initial conditions for an N-body simulation (position, velocities, masses) via Monte Carlo methods. 2.5- Direct N-body codes for collisional systems: Hermite scheme, block time-step algorithm, regularization algorithms. 2.6- How to interface population synthesis with direct N-body codes. 2.7- Special purpose hardware, graphics processing units and high-performance computing in astrophysics. 2.8- Tree codes, softening. 2.9- Algorithms for gas dynamics: smoothed particle hydrodynamics, mesh codes, adaptive mesh refinement codes, hybrid moving mesh codes. 2.10- Sub-grid physics: star formation, sink particles, supernovae, radiative transfer. 2.11- General introduction to star cluster dynamics. 2.12- Binary black hole formation/disruption through close dynamical encounters. 2.13- Discussion of possible projects for topic nr. 2. --- TOPIC Nr. 3: Semi-analytic codes for binary black hole dynamics and cosmic evolution --- 3.1- Limitations of N-body simulations. 3.2- Semi-analytic codes for black-hole dynamics. 3.3- Semi-analytic codes for cosmic evolution of stars, galaxies, black holes. 3.4- Discussion of possible projects for topic nr. 3.

Examination:
Oral exam to discuss the final project, considering both its numerical and scientific aspects. In addition, each student will produce a report about the project and will make the scripts developed during the project available at least three days before the oral examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP9087518/NO

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FINAL EXAMINATION

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: to be defined

Credits: 22 ECTS

Short program:
The exam yielding the master title consists in the discussion of written document describing critically the scientific work produced by the candidate. Such document must be original in its essence and include an appropriate bibliography. The title is received once the candidate gathers at least 120 CFU's, respecting the maximum number of exams as indicated in the didactic regulations. The candidate shall also pass the final test which consist in the discussion in front of a committee of a thesis. The final test envisages an internship in a research center or a private company where the student will work on tasks compatible with the educational path of the master program. The committee judging the final test will be nominated by the Director of the Physics and Astronomy department. English is the language to be used for both the thesis and final test. The final grade expressed as a fraction of 110 will be based on the sum of: a) the weighted average of the grades gathered for the exams. The weight is determined by the CFU associated to each exam, b. the grade of the final test itself c. a possible grade granted to the student in recognition to her educational career. The specific contribution of each of these elements is determined by the Physics and Astronomy department upon advice from the faculty members affiliated to the master program. A “Laude” will be added to a final grade so computed exceeding 110 by a sufficient amount.
FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. SABINO MATARRESE

Credits: 6 ECTS

Prerequisites:
Fundamental concepts of quantum mechanics and special relativity

Short program:

Examination:
Oral interview.

GAME THEORY

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: ELVINA GINDULLINA

Credits: 6 ECTS

Prerequisites:
A course, even a basic one, on probability theory.

Short program:

Examination:
For all the students, in any event the exam includes a mandatory open-book written test, containing problems of game theory focusing on different topics of the course. Every exercise involves multiple questions, typically three. For the students with regular attendance to the course, the exam may also involve, if they want so, the development of a project in 1-3 person groups, on course-related topics applied to ICT. This is agreed half-way through the course together with the lecturer. If the written test is sufficient, students can directly finalize the passing score. Projects can be discussed with an oral exam after the written test. Oral exams are scheduled in the same day of written tests (even though students can decide to give the two parts on separate days). The project discussion integrates the mark of the written test.
GENERAL RELATIVITY

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. MARCO PELOSO

Credits: 6 ECTS

Prerequisites:
Knowledge of Special Relativity

Short program:

Examination:
Questions on the topics presented during the course and solution of a simple / medium problem.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7079401/NO

INFORMATION THEORY AND INFERENCE

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Dott. MICHELE ALLEGRA

Credits: 6 ECTS

Prerequisites:
The participants of the course should have a basic knowledge of statistics and statistical mechanics. It is also expected that participants are familiar with elementary programming.

Short program:
The main goal of the course is learning how to achieve probabilistic models of complex data. The course will give an introduction to information theory and its usage to constrain and explore a space of models. It will then give an introduction to Bayesian model inference, with a focus on the wide array of methods available for sampling. All concepts will be explored with hands-on applications to real data. COURSE PROGRAM Information Theory o Basics of information theory: entropy, mutual information, coding o Data Compression and Noisy Channel Coding o Comparing probability distributions: From KL divergence to information geometry o Maximum entropy models o Statistical mechanics and Information theory Inference o Example inference problems: density estimation, clustering, intrinsic dimension estimation o Bayesian Statistics: prior, likelihood, posterior. o Conjugate Priors o The Monte Carlo Paradigm: noise vs. bias. o Basic building blocks of samplers: transformations, weighting (importance sampling), acceptance/rejection. o The Metropolis algorithm (Markov Chain Monte Carlo) o Gibbs sampling: local interactions. o Hamiltonian Monte Carlo (HMC) o Approximate Bayesian Computation (ABC) o Variational Bayes o Neural Networks and Bayesian Inference o An introduction to model selection

Examination:
The evaluation of the acquired knowledge will be based partly on a report summarizing the results of a small data analysis project, and partly on an oral presentation with open questions where students will show their command of the relevant theory and vocabulary.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ0093479/NO

LABORATORY OF COMPUTATIONAL PHYSICS (C.I.)

Lecturer: Prof. MARCO ZANETTI

Prerequisites:
184/233
Even though not strictly required, the development of the class assumes the attendance of at least two physics laboratory classes during the bachelor degree.

Examination:
To verify the proficiency of the students in the subjects covered by this course, the written reports on the lab experiences will be evaluated; such evaluation will have to be confirmed by an oral exam, during which the students will also be interviewed about what is thought during the lectures. The oral exam will be split into two parts, each relevant to one of the two modules the class consists of.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082524/NO

Moduli del C.I.:
LABORATORY OF COMPUTATIONAL PHYSICS
LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)

LABORATORY OF COMPUTATIONAL PHYSICS

Lecturer: Prof. MARCO ZANETTI

Master's degree in PHYSICS OF DATA ORD. 2018, First and Second semester

Credits: 12 ECTS

Short program:
- Number representation, algorithmic complexity, data and memory management - The python programming language, from the bases to the advance programming for scientific computing; review of the modern libraries for the data management and analysis (numpy, scipy, pandas, sciit-leam, etc.) - Linear Algebra and related methods (SVD, PCA) - Monte Carlo methods for the simulation of physics phenomena - Techniques to assess and extract the statistical features of a physics datasets and comparison with model predictions - Visualisation and graphical representation of datasets and their properties

LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)

Lecturer: Prof. MARCO BAIESI

Master's degree in PHYSICS OF DATA ORD. 2018, First and Second semester

Credits: 12 ECTS

Short program:
* Gradient descent methods * Ridge and LASSO regularization * Supervised learning and unsupervised learning * Deep neural networks and convolutional version * Clustering * Data visualization * Energy-based models * Restricted Boltzmann machines * Combination of models: bagging, random forests, boosting, XGBoost

LIFE DATA EPIDEMIOLOGY

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof.ssa CHIARA POLETTO

Credits: 6 ECTS

Prerequisites:
The course requires some previous knowledge on: - Probability theory. - Differential equations.

Short program:
Epidemics: motivation and applications (both to life sciences and ICT) Epidemics through compartmental models Solutions of epidemic models through differential equations Demography and equilibria Extended models and complex contagions Time-variable trends and temporal networks Network epidemics Metapopulation for spatial diffusion Data-driven models and integration in computational epidemiology Epidemiology data: surveillance, problems, and biases Statistical and mechanical methods Maximum likelihood fit Public health scenarios: analysis and forecasts

Examination:
Written exam on the topics covered during the course, oral exam about a project to be carried out by students in groups

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082719/NO

MACHINE LEARNING (NUMEROSITA’ CANALE 1)

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Dott. FEDERICO CHIARIOTTI
MACHINE LEARNING (NUMEROSITA’ CANALE 2)

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. PIETRO ZANUTTIGH

Credits: 6 ECTS

Short program:

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082660/NO

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (C.I.)

Lecturer: Dott. JACOPO PAZZINI

Prerequisites:
Basic programming elements Basics of Unix Shell scripting, Python, Git

Examination:
There will be two separate exams related to modules A and B For Module A, the knowledge and skills expected will be checked: - through a written exam that will focus on the elements of digital electronics and computer architecture acquired during lectures - through the development of a project assigned at the end of the course and concerning the laboratory activities with the subsequent presentation and oral discussion of the report Regarding Module B, the exam will consist of two parts, related to two modules of data management and data processing respectively. - The students’ data management competencies will be assessed with a dedicated written/oral test. - For the data processing component of the exam, students will be required to carry out projects (in small groups of 3-4 people) regarding the processing and analysis topics covered in the course, and to discuss the adopted solutions and the results obtained.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082533/NO

Moduli del C.I.:
MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)
MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)

Lecturer: Dott. ANDREA TRIOSSI

Master's degree in PHYSICS OF DATA ORD. 2018, First and Second semester

Credits: 12 ECTS

Short program:

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)
Short program:
Part 1) Data Management Introduction to data structures Storage Models Reliability Authentication, Authorization Local and Distributed File systems Databases Part 2) Data processing Introduction to parallel processing Distributed Computing Systems Containerization Hadoop as a paradigm for big data processing Data processing with Spark Data processing with Dask Kafka as a distributed streaming platform

MODELS OF THEORETICAL PHYSICS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. AMOS MARITAN

Credits: 6 ECTS

Prerequisites:
Good knowledge of mathematical analysis, calculus, elementary quantum mechanics and basic physics.

Short program:

Examination:
The first part of the verification of the acquired knowledge will evaluate the weekly exercises and the participation of the students in the class discussions The second part is oral, and it will be based on a discussion on the various topics of the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8083597/NO

MOLECULAR SIMULATIONS

Master's degree in PHYSICS OF DATA ORD. 2018, Second semester

Lecturer: Dott. JACOPO PAZZINI

Credits: 12 ECTS

Prerequisites:
Statistical mechanics, unix, programming experience, high-school level chemistry.

Short program:
Examination:
The evaluation will be based on a research project, which have to be solved individually. The students can choose a biomolecular problem from a list, so the projects will be different for each student. The project is a computer simulation study, which involves: i) the definition of the problem for the computer ii) method selection with justification iii) performing the simulation (including the preparatory steps), iv) assessing the simulation quality vi) analysis and interpretation of the results vii) presentation of the project. The presentation is a written summary (ca 10 pages) according to the guidelines provided. The projects require independent thinking and application of the lecture and practical materials. There is ample time to solve them and consultation opportunities are provided. Finally the projects are presented as a written summary and possibly a short oral presentation.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ1098979/NO

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**NETWORK SCIENCE**

Master's degree in **PHYSICS OF DATA ORD. 2018**, First semester

**Lecturer:** Prof. TOMASO ERSEGHE

**Credits:** 6 ECTS

**Prerequisites:**
This course has the following prerequisites: knowledge in Probability Theory, and Computer Programming in any language which is appropriate for network analysis (Python preferred, but MatLab, R, C, or Java would do); knowledge in Calculus and Linear Algebra; any further knowledge of networking processes in economics, biology, telecommunications, semantics, etc. might be useful.

**Short program:**
The module will cover the following topics: 1. Basic network properties - graphs, adjacency matrix, degree distribution, connectivity, distance and diameter, clustering coefficient. 2. Network models - Erdos-Renyi model; Random graphs with general degree distribution; Power laws and scale free networks; Small world phenomena; Hubs; Network generation and expansion; Barabasi-Albert model; Preferential attachment. 3. Centrality measures: Hubs and authorities; Pagerank: teleportation, topic specific ranking, proximity measures, trust rank; betweenness, closeness, eigenvector and Katz centralities. 4. Other analytics: homophily ( assortativity), polarisation, innovation, clustering, robustness, link prediction. 5. Community detection - Girvan Newman method and betweenness; Louvain modularity optimisation; Spectral clustering; Consensus clustering; Model-driven algorithms; Algorithms for overlapping communities. 6. Network representation - Gephi and R/Python graphical functions; rationale of force directed graph layout algorithms. 7. Twitter Lab - How to extract a semantic network from Twitter data.

**Examination:**
The verification of the expected knowledge and skills is carried out with the DEVELOPMENT OF A PROJECT aimed at verifying the ability to apply theory in interdisciplinary contexts, and which requires: the choice, the collection of data, and the analysis of a different network for each student; computer implementation (in any programming language known to the student) of the algorithms required for the analysis; the drafting of an essay; the oral presentation of the main project outcomes. A bonus of up to 3 points is available for attending students that take part to an INTERDISCIPLINARY PROJECT with social science students attending the twin course on SOCIAL NETWORK ANALYSIS.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082723/NO

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**NEURAL NETWORKS AND DEEP LEARNING**

Master's degree in **PHYSICS OF DATA ORD. 2018**, First semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
CONTENT NOT PRESENT

**Short program:**
CONTENT NOT PRESENT

**Examination:**
CONTENT NOT PRESENT

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP9087899/NO

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**NUCLEAR PHYSICS**

Master's degree in **PHYSICS OF DATA ORD. 2018**, First semester

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Lecturer: Prof.ssa SILVIA MONICA LENZI

Credits: 6 ECTS

Prerequisites: Quantum mechanics

Short program:
Program of Nuclear Physics 2021/2022 First part: Nuclear Structure and Nuclear Models • Introduction: The nucleus as a laboratory of Quantum Mechanics • Symmetries and the Nuclear Force • Theoretical Models: 1) Collective Models: The nuclear deformation, Surface vibrations, Rotating nuclei 2) Microscopic Models: Mean-field Models, Interacting Shell Model The Nilsson Model • Experimental tools in nuclear structure Second part: Nuclear reactions Introduction • Nucleon-Nucleon Scattering • Nuclear Reactions • Interactions between heavy ions • Direct nuclear reactions between heavy ions • Multi-nucleon transfer reactions between heavy ions • Compound nuclear reactions • Fusion reactions below the Coulomb barrier • Superheavy nuclei • Reactions of astrophysical interest

Examination:
The exam consists on an oral examination that includes the discussion of the exercises proposed during the course, and eventual presentation of a research work on one of the several subjects proposed by the professors.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7081658/NO

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Lecturer: Prof. SAMIR SIMON SUWEIS

Credits: 6 ECTS

Prerequisites:
Basics of Stochastic processes and Statistical Mechanics. If you never attended the class “Statistical Mechanics of Complex Systems” or “Models of Theoretical Physics” you will need to work a little to recover some topics through personal additional study guided by the professor

Short program:

Examination:
The first part of the verification of the acquired knowledge will evaluated be through homework exercises (to do in groups) and the participation of the students in the class discussions The second part will takes place through, a common written test with 1-2 exercises to be solved and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The third facultative part of the exam will be oral and will be based on a discussion on the various topics discussed during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ1097938/NO

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Lecturer: Prof. MANLIO DE DOMENICO

Credits: 6 ECTS

Prerequisites:
The course will introduce, from the point of view of statistical physics, complex networks and how they can be used to model and analyze a variety of empirical systems across scales, from cells to societies. We will consider applications ranging from quantum communication to classical socio-technical systems and their behavior in physical and digital space, using networks to unravel ubiquitous and recurring mechanisms building complex physical systems. The course will be articulated in two parts: theoretical (36h) and lab (12h). The knowledge of Calculus, Linear Algebra, basics of Probability and statistics, fundamentals of python/R programming, fundamentals of quantum mechanics is required. Knowledge of basics of statistical mechanics might be useful.

Short program:
0. Presentation of the course (2h) 1. Physics of networks (12h) - Representation and fundamentals of network theory (2) - Network ensembles: ER models; stochastic block model (6) - Maximum-entropy derivation (2) - Spectral analysis and linear response (2) 2. Dynamics on complex networks (11h) - Basics of dynamical systems (2) - Diffusive process and classical/quantum walks (3) - Reaction-diffusion dynamics (2) - Application to human mobility (2) - Application to online social systems (2) 3. Structural analysis (11h) - Centrality (1) - Motifs (1) - Meso-scale organization; integration vs segregation (2) - Percollation and cascade failures; entanglement percolation (4) - Application to quantum networks (quantum
Examination:
The assessment of knowledge is aimed at verifying the fact that the expected learning outcomes are actually acquired by the students. A crucial element of the exams will therefore be the assessment of knowledge and skills achieved. The exam consists of a lab project and an oral test. The methods of carrying out this eventual test will naturally depend on the legislation on the conduct of teaching that will be adopted in relation to the coronavirus. In general, the exam will aim to verify the knowledge (facts, principles, theories and practices that characterize the teaching) and the skills of the student. In particular: - ability to understand and discuss problems related to the program carried out; - understanding of the theoretical bases illustrated during the course; - ability to show the results of the exercises and the applications.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ2101383/NO

PHYSICS OF COMPLEX SYSTEMS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. ANTONIO TROVATO

Credits: 6 ECTS

Prerequisites:
Students are expected to already know the main concepts of equilibrium statistical mechanics, including phase transition, critical exponents and the renormalization group.

Short program:

Examination:
Examination based on the choice and on the oral presentation of a specific topic related to the ones taught during the course. During the oral presentation, possible connections with other parts of the program will be the subject of further questions. The presentation will focus either on a book chapter or on a scientific research paper, generally but non necessarily a review. It is also possible to focus on a computational mini-project related to the topics taught in the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7081763/NO

QUANTUM INFORMATION AND COMPUTING

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. SIMONE MONTANGERO

Credits: 6 ECTS

Prerequisites:
Quantum mechanics and elements of programming.

Short program:

Examination:
The exam will be a final project composed of programming, data acquisition, and analysis, which will be discussed orally.
QUANTUM INFORMATION WITH ATOMS AND PHOTONS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Dott. PIETRO SILVI

Credits: 6 ECTS

Prerequisites:
Quantum Mechanics foundations Structure of Matter

Short program:

Examination:
One of the three following exam types: (A) Oral exam on the contents of the course. (B) Talk on a scientific publication pertaining the contents of the course. (C) Shorter talk followed by shorter oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ2101439/NO

STAGE

Master's degree in PHYSICS OF DATA ORD. 2018, Second semester

Lecturer: Prof. MARCO ZANETTI

Credits: 8 ECTS

Short program:
The internship can be hosted by a company or a research center. The subject must be coherent with the main topics covered in the Physics of Data programme. The duration of the internship should be at least 3-4 months and should not exceed 6-7 months. The research activity must be supervised by a staff member of the company or research center; such activity can be the subject of the student's thesis.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP8082711/NO

STATISTICAL MECHANICS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. ENZO ORLANDINI

Credits: 6 ECTS

Prerequisites:
Statistical Mechanics (course given at the third year of the laurea triennale) Thermodynamics

Short program:

Examination:
The verification of the acquired knowledge takes place through a common written test with 1-2 exercises to be solved analytically and 1-2 open questions on basic concepts. In this way we should be able to test the knowledge, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The second part of the exam will be oral and will be based on a discussion on the various topics discussed in class.
STATISTICAL MECHANICS OF COMPLEX SYSTEMS

Master's degree in PHYSICS OF DATA ORD. 2018, Second semester

Lecturer: Prof. AMOS MARITAN

Credits: 6 ECTS

Prerequisites:
Good knowledge of mathematical analysis, calculus and basic physics. For "Physics of Data" students the course has 6 CFU. However, if they are not adequately trained in statistical mechanics, they are encouraged to follow all 9 credits

Short program:
The program can be summarized as follows Statistical mechanics and Entropy Ising model Variational principles in statistical mechanics Complex networks Principle of maximum entropy and inference Diffusion Processes and stochastic dynamics Montecarlo simulations Dynamics of and on networks Population dynamics with applications to ecosystems Percolation on networks. Neural networks

Examination:
The first part of the verification of the acquired knowledge will evaluate the homework exercises and the participation of the students in the class discussions The second part will takes place through, a common written test with 1-2 exercises to be solved and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The third part is oral and it will be based on a discussion on the various topics of the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7081659/NO

THEORETICAL PHYSICS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. PIERPAOLO MASTROLIA

Credits: 6 ECTS

Short program:

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7081638/NO

THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS

Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. PARIDE PARADISI

Credits: 6 ECTS

Short program:

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCP7081657/NO

VISION AND COGNITIVE SYSTEMS
Master's degree in PHYSICS OF DATA ORD. 2018, First semester

Lecturer: Prof. LAMBERTO BALLAN

Credits: 6 ECTS

Prerequisites:
The student should have basic knowledge of computer programming and algorithms, as well as mathematics, probability theory and statistics, linear algebra. It is also advisable to be familiar with basic concepts in machine learning and pattern recognition.

Short program:
The course will cover the topics listed below: - Introduction: From human cognition to machine intelligence and cognitive systems; brief intro to artificial intelligence, cognitive computing and machine learning; the AI revolution: current trends and applications, major challenges. - Cognitive Services: Basic concepts; Language, Speech, and Vision services; major providers and APIs (IBM Watson, AWS, Google Cloud); enabling technologies. - Machine Learning and applications: Classification; intro to deep learning and representation learning; training and testing; evaluation measures; algorithm bias. - Early Vision and Image Processing: Machine perception; image formation, sampling, filtering and linear operators; image gradients, edges, corners; designing effective visual features (SIFT and gradient based features); image matching. - Visual Recognition and beyond: "Teaching computers to see": bag-of-features, spatial pyramids and pooling; representation learning in computer vision, convolutional neural networks; R-CNN and segmentation; image captioning, multi-modal scenarios and beyond the fully-supervised learning paradigm. - Hands-on Practicals: What's in the box? How to build a visual recognition pipeline; using cognitive services for image recognition/understanding; combining different services and modalities.

Examination:
The student is expected to develop, in agreement with the instructor, a small applicative project. In addition, the student must submit a written report on the project, addressing in a critical fashion all the issues dealt with during its development. During the exam students are asked to present and discuss their project, and answer a few questions about the topics addressed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2443/000ZZ/SCQ1097939/NO

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Master's degree in PHYSICS ORD. 2021

HADRONIC PHYSICS

Lecturer: to be defined

Credits: 6 ECTS

More information:

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Master's degree in PHYSICS ORD. 2021

ACCELERATOR PHYSICS

Lecturer: Dott. ANDREA PISENT

Credits: 6 ECTS

Short program:
1. Introduction, particle accelerators for research and applications, like medicine, cultural heritage and energy. Definition of acceleration and luminosity, various kind of accelerators, electrostatic and radiofrequency. 2. Focusing of a charge particle beam, paraxial optics, magnetic quadrupoles and multipoles. Periodic focusing systems and alternating gradient, stability of beam transport, role of resonances. Courant and Snyder invariant, emittance. Circular orbits, equations of motion in magnetic dipoles, dispersion and chromaticity. 3. Ion sources, electrostatic acceleration and injectors. The beam acceleration with an RF field. Phase stability principle. How to produce bunched beams. 4. Linear accelerators and RF cavities. The challenge of intense beams, the space charge, the instabilities, the beam halo and small losses. 5. How the same basic principles apply to different kind of accelerators, llinacs, cyclotrons, synchrotrons, colliders. Some example of relevant accelerators (realized and under construction).

Examination:
Oral exam on the topics developed in the course, with the possibility of starting from a topic chosen by the student. The aim is to ascertain the learning of the fundamental concepts underlying modern accelerators.
**ADVANCED PHYSICS LABORATORY**

Master's degree in **PHYSICS ORD. 2021**, Second semester

**Lecturer:** Prof. GIAMPAOLO MISTURA

**Credits:** 6 ECTS

**Prerequisites:**
Laboratory courses of previous years and basic skills in optics and electronics

**Short program:**
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum.

**Examination:**
Written report and oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093559/NO

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**APPLICATIONS FOR THERAPY**

Master's degree in **PHYSICS ORD. 2021**, First semester

**Lecturer:** to be defined

**Credits:** 12 ECTS

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081919/NO

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**ASTROPARTICLE PHYSICS**

Master's degree in **PHYSICS ORD. 2021**, Second semester

**Lecturer:** Prof. FRANCESCO D’ERAMO

**Credits:** 6 ECTS

**Prerequisites:**
Theoretical Physics of the Fundamental Interactions (MOD. A and MOD. B) in the first semester.

**Short program:**

**Examination:**
Oral exam.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081703/NO

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**ATOMIC AND PLASMA PHYSICS**

Master's degree in **PHYSICS ORD. 2021**, First semester

**Lecturer:** to be defined

**Credits:** 6 ECTS

**More information:**
BASIC EXPERIMENTAL NUCLEAR PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS


COMMON ADVANCED COURSE

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS


COMPUTING AND NUMERICAL METHODS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS


EXPERIMENTAL NUCLEAR PHYSICS AND ACCELERATORS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS


HEAVY ION REACTIONS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof.ssa GIOVANNA MONTAGNOLI

Credits: 6 ECTS

Prerequisites:
Knowledge of the basic concepts of quantum mechanics and of nuclear physics is required

Short program:
Introduction • Basic concepts on Nuclear Reactions • Nucleon-Nucleon Scattering • Heavy-ion interactions • Direct Reactions and Nuclear Structure • Transfer Reactions between Heavy-ions • Compound Nucleus Reactions • Sub-barrier Fusion and related experimental techniques • Barrier Distributions and Fusion Hindrance • Nuclear reactions of astrophysical interest . Relativistic Heavy-ions collisions . Evidence of the Quark-Gluon Plasma formation

Examination:
The exam will be oral including the whole program of the course The students have to be able to solve the exercises proposed during the course.
INTRODUCTION TO RADIATION DETECTORS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. ROBERTO STROILI

Credits: 6 ECTS

Prerequisites:
Knowledge of electromagnetic phenomena, electromagnetic waves included. Basic notions about special relativity and quantum mechanics.

Short program:

Examination:
Oral.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081437/NO

MANY BODY THEORIES IN NUCLEAR PHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093558/NO

METROLOGY AND DATA ANALYSIS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081917/NO

NUCLEAR ASTROPHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. ANTONIO CACIOLLI

Credits: 6 ECTS

Prerequisites:
Elements of quantum mechanics, nuclear physics, and general physics

Short program:
Thermonuclear reactions. Definition of nuclear cross section, astrophysical S-factor, reaction rate, and Gamow peak. Nuclear burnings during hydrostatic and explosive stellar evolutionary phases. Elements of stellar modelling. Hydrogen burning: p-p chains, CNO, NeNa, MgAl cycles. Helium burning: triple-alpha reaction and alpha + 12C. Advanced nuclear burnings (C, Ne, O, Si). Neutron-capture reactions (s and r; slow and rapid) For each topic we provide an overview of the most relevant results in the recent literature. How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances) How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results) The environmental background and how to shield it (passive and active shielding) Elements on detectors (gamma, neutrons, and charged particles) Experimental measurements of the cross section (from the experimental yield to the S-factor) Targets typology (gas, jet, and solid target). Target production techniques and how targets influence the experimental measurements. How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances) How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results) The environmental background and how to shield it (passive and active shielding) Underground experiment Brief discussion on indirect methods (Trojan Horse, ANC, …).

Examination:
A 10 minutes presentation on an aspect of the course (usually an astrophysical issue and a related reaction study) and some question related to the presentation and course program.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081704/NO

NUCLEAR REACTIONS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093547/NO

NUCLEAR STRUCTURE: PROPERTIES AND MODELS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093543/NO

QUANTUM MECHANICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: to be defined

Credits: 6 ECTS

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093543/NO

RADIOACTIVITY AND NUCLEAR MEASUREMENTS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. MARCO MAZZOCCO

Credits: 6 ECTS

Prerequisites:
The student must have attended the courses of "Introduction of Nuclear Physics" and "Nuclear Physics"

Short program:

Examination:
Oral examination. The student will be asked some questions concerning the different topics presented during the lectures. It is also foreseen a detailed analysis of one of the arguments by the student.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCP7081740/NO
## Advanced Optics and Metrology

**Master's degree in** PHYSICS ORD. 2021, First semester  
**Lecturer:** Prof. GIACOMO CIANI  
**Credits:** 6 ECTS  
**Prerequisites:**  
Basic knowledge of geometric optics, structure of matter and quantum mechanics.  
**Short program:**  
**Examination:**  
Oral exam  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/004PD/SCQ0093549/NO

## Advanced Physics Laboratory A

**Master's degree in** PHYSICS ORD. 2021, Second semester  
**Lecturer:** Prof. GIAMPAOLO MISTURA  
**Credits:** 6 ECTS  
**Prerequisites:**  
Laboratory courses of previous years and basic skills in optics and electronics  
**Short program:**  
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum.  
**Examination:**  
Written report and oral exam.  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCQ0093551/NO

## Advanced Physics Laboratory B

**Master's degree in** PHYSICS ORD. 2021, First semester  
**Lecturer:** Prof. MARCO BAZZAN  
**Credits:** 6 ECTS  
**Prerequisites:**  
Laboratory courses of preceding years and basic skills in optics and electronics  
**Short program:**  
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum techniques.  
**Examination:**  
Written report and oral examination.
ADVANCED TOPICS IN PHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites: CONTENT NOT PRESENT

Short program: CONTENT NOT PRESENT

Examination: CONTENT NOT PRESENT


BIOLOGICAL PHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. FULVIO BALDOVIN

Credits: 6 ECTS

Prerequisites: Basic understanding of thermodynamics and statistical mechanics. Basic elements of probability theory. Lectures and study material are in English.

Short program:

Examination:
The exam consists of two parts: a written test based on a list of exercises delivered during the lessons (use of textbook and lecture notes is allowed); an oral test on the topics of the course and, optionally, on a further topic chosen by the student.


BIOPHOTONICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. FABIO MAMMANO

Credits: 6 ECTS

Prerequisites: The course requires knowledge of Electromagnetism, Optics, and Biological Physics.

Short program:

Examination:
The verification of the expected knowledge and skills is carried out with an exam divided into two phases. In the first phase, a written exam is carried out which consists in reporting on three topics drawn by lot from among those studied in depth during the course. In the second phase an oral test is carried out which consists in the presentation by the student of a scientific article on optical super-resolution techniques. The final grade is expressed as the average in the judgments of the two tests.

More information:

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Master's degree in **PHYSICS ORD. 2021**, Second semester

**Lecturer:** Prof. FRANCESCO ANCILOTTO

**Credits:** 6 ECTS

**Prerequisites:**
Elementary notions of quantum physics and solid state physics. Fundamentals of thermodynamics: principles, thermodynamic potentials. No prior knowledge of computer programming is required.

**Short program:**
Basic concepts of thermodynamics and classical statistical mechanics. Classical Molecular Dynamics simulations; numerical integration of Newton equations. Monte Carlo method; Metropolis algorithm. Simulations in various statistical ensembles. Common features of simulations methods: initial and boundary conditions; calculation of inter-particle interactions. Calculation of thermodynamic and transport properties. Inter-molecular interactions: force-fields; atomic and coarse grained models. Variational methods for the solution of the Schrodinger equation. Hartree and Hartree-Fock theory. Elements of Density Functional Theory (DFT). 'First principles' simulations. The different computational methods will be discussed in relation their application to topics of interest for material science (crystals, surfaces, soft matter, nanostructured materials). In the computer exercises, students will carry out simple simulations, using open-source software packages of current use in materials science, and will learn how to interpret and present the results of simulations.

**Examination:**
Oral examination in which the students will discuss written reports, on the results of three numerical simulations (Monte Carlo, Molecular Dynamics and DFT calculations).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081717/NO

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Master's degree in **PHYSICS ORD. 2021**, First semester

**Lecturer:** Prof. SABINO MATARRESE

**Credits:** 6 ECTS

**Prerequisites:**
Fundamental concepts of quantum mechanics and special relativity

**Short program:**
Fundamental concepts of galactic and extra-galactic astrophysics • The classification of galaxies • Statistical properties of the galaxy population • Groups and clusters of galaxies Fundamental concepts of Cosmology • Main components of the Universe. ObservATIONAL evidence for the existence of dark matter and dark energy. • Expanding Universe and Cosmological Principle. • Robertson-Walker line-element. Geometrical properties. • Hubble constant and deceleration parameter. • Distances in Cosmology; redshift and Hubble law (low-redshift approximation). • Derivation of Friedmann equations (dust case); Newtonian and relativistic contributions • Friedmann models. • Cosmological constant: Einstein's static solution and de Sitter solution. Dynamical dark energy • Cosmological solutions for the spatially flat case. Universe models with non- zero spatial curvature. • Exact treatment of the Hubble law. Thermal history and early Universe • Number density, energy density and pressure of a system of particles in thermodynamic equilibrium. * Entropy conservation in a comoving volume. • Time-temperature relation in the Early Universe. • Shortcomings of the standard cosmological model: horizon, flatness problems, etc. • Inflation in the Early Universe: solution of the horizon and flatness problems. • Kinematics and dynamics of inflation: the "inflaton". • Old, new and chaotic inflation; slow-roll dynamics (basic account). • Baryon asymmetry in the Universe (basic account) • Primordial nucleosynthesis of light elements. • Hydrogen recombination: Saha equation. Matter-radiation decoupling. Cosmic Microwave background. • General definition of decoupling. Dark matter: general properties • Boltzmann equation in Cosmology and cosmic relics. • Hot/Cold/Warm Dark matter: definition, present abundance and general cosmological properties. Elements of stellar astrophysics • Gravitational contraction and conditions for hydrostatic equilibrium. • Adiabatic index and equilibrium. • Conditions for gravitational collapse. • Jeans theory of gravitational instability. • Contraction of a protostar. • Star formation and degenerate electron gas. • The Sun: general properties, radiative diffusion, thermonuclear fusion. • Stellar nucleosynthesis. • Stellar cycles. • Hertzsprung-Russell diagram. • Basics of stellar structure. Clayton model: Minimum mass of a star; maximum mass for a Main-Sequence star. • End-points of stellar evolution: white dwarfs, neutron stars, Chandrasekhar mass, black holes. The formation of cosmic structures • Linear evolution of perturbations in the expanding Universe (basic principles). • Spherical collapse of a cosmic proto-structure. • Mass-function of cosmic structures: Press-Schechter theory.

**Examination:**
Oral interview.
GENERAL RELATIVITY

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. MARCO PELOSO

Credits: 6 ECTS

Prerequisites:
Knowledge of Special Relativity

Short program:

Examination:
Questions on the topics presented during the course and solution of a simple / medium problem.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP9086381/NO

INTRODUCTION TO MANY BODY THEORY

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. PIER LUIGI SILVESTRELLI

Credits: 6 ECTS

Prerequisites:
Metodi Matematici

Short program:

Examination:
Oral exam and home-work exercises.

More information:

INTRODUCTION TO NANOPHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. GIOVANNI MATTEI

Credits: 6 ECTS

Prerequisites:

MODELS OF THEORETICAL PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. AMOS MARITAN

Credits: 6 ECTS

Prerequisites:
Good knowledge of mathematical analysis, calculus, elementary quantum mechanics and basic physics.

Short program:
Introduction; "The Unreasonable Effectiveness of Mathematics in the Natural Sciences (Wigner 1959)"; Gaussian integrals Wick theorem Perturbation theory connected contributions Steepest descent Legendre transformation Characteristic/Generating functions of general probability distributions/measures

Examination:
The first part of the verification of the acquired knowledge will evaluate the weekly exercises and the participation of the students in the class discussions. The second part is oral, and it will be based on a discussion on the various topics of the course.

More information:

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NANOFABRICATION

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. FILIPPO ROMANATO

Credits: 6 ECTS

Prerequisites:
third year courses in materials science, optics, matter structure

Short program:
Many of the impressive technical and scientific advances of the last two decades are based on the ability to control individual chemical-physical phenomena at the level of a few nanometers, that is, on the scale of size at which most natural phenomena occur. This control was obtained by developing micro and nano fabrication systems and processes for the realization of devices (also called lab-on-chip) capable of exchanging signals (detection and actuation) with systems of the size of a few nanometers, coining, in fact, the definition of nanotechnology. The course is aimed at students (materials sciences, physics) in view of the degree thesis for the broad correlation between physical, chemical, biochemical phenomena that nanofabrication processes require in view of the realization of nanostructures and nanodevices. Opening themes towards the research of nanosciences are discussed. The course will discuss the miniaturization process and the scale reduction process of many natural phenomena that distinguish the functioning of nanodevices. The main nanofabrication technologies will be presented and examples of applications for the realization of nanoscience devices and experiments will be presented. After a general distinction between top-down and bottom-up processes, lithography technologies (UV, electronics, X-ray, ionic, imprinting, interferential etc), deposition processes (plasma assisted, in vapor or chemical phase, will be illustrated); sol-gel etc.) and subtraction in the gas phase (reactive ion etching, milling) or liquid (chemical etching). The manufacturing technology of silicon-based electronic devices will be reviewed. Simulation exercises for the design of nanosystems are proposed. The course is completed by visits to the nanofab Padua at the LaNN laboratory and in Trieste at the CNR nanofabrication laboratories at the Elettra synchrotron. During these visits there will be practical demonstrations of the lithographic processes treated during the classroom course.

Examination:
Deepening of a topic, preparation of a presentation, written discussion. Oral exam, presentation of the paper and verification of the learning of the main concepts of nano lithography.

More information:

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NON-PERTURBATIVE QUANTUM FIELD THEORY

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. PIERALBERTO MARCHETTI

Credits: 6 ECTS

Prerequisites:
Theoretical physics of the fundamental interactions and Quantum field theory or Models of theoretical physics and Structure of matter

Short program:
Quantum field theory (QFT) is a common framework in many branches of physics, exhibiting an unexpected unity in the description of elementary quantum processes that deeply modified our view of physical reality. Many of the key results of QFT are obtained through a perturbative expansion, but there are crucial areas of applications that do not rely on it. The aim of the course is to provide a view of some results in these areas, with examples both in elementary particle and condensed matter physics, emphasizing the underlying common features. Examples are only outlined, but not discussed in detail and in the following program are between brackets. Some topics in the program might be alternative, depending on the interests and knowledge of the students. Proposed program 1) Reconstruction theorem: What precisely a QFT is, how one can reconstruct quantum fields out of correlation functions, how they are related to experiments. 2) Quantum solitons: kinks (phi4, polyacetylene), vortices (Higgs model, superconductors), monopoles (Dirac, t'Hooft-Polyakov, spin ice), and their role in the phase transitions. 3) Anomalies: chiral anomaly (the eta mass problem in QCD) and parity anomaly (topological insulators, graphene).

Examination:
Oral examinations

More information:
### NUCLEAR PHYSICS

**Master's degree in PHYSICS ORD. 2021, First semester**

**Lecturer:** Prof.ssa SILVIA MONICA LENZI  
**Credits:** 6 ECTS  
**Prerequisites:** Quantum mechanics

**Short program:**  
Program of Nuclear Physics 2021/2022  
First part: Nuclear Structure and Nuclear Models  
- Introduction: The nucleus as a laboratory of Quantum Mechanics  
- Symmetries and the Nuclear Force  
- Experimental tools in nuclear structure  
Second part: Nuclear reactions Introduction  
- Nucleon-Nucleon Scattering  
- Nuclear Reactions  
- Interactions between heavy ions  
- Direct nuclear reactions between heavy ions  
- Multi-nucleon transfer reactions between heavy ions  
- Compound nuclear reactions  
- Fusion reactions below the Coulomb barrier  
- Superheavy nuclei  
- Reactions of astrophysical interest

**Examination:**  
The exam consists on an oral examination that includes the discussion of the exercises proposed during the course, and eventual presentation of a research work on one of the several subjects proposed by the professors.

**More information:**  

### OPTICS AND LASER PHYSICS

**Master's degree in PHYSICS ORD. 2021, First semester**

**Lecturer:** Prof.ssa TIZIANA CESCA  
**Credits:** 6 ECTS  
**Prerequisites:** Topics learned in basic courses of Mathematics and Physics.

**Short program:**  
Classical optics:  
- propagation of electromagnetic waves;  
- polarization, birefringence, interference and diffraction;  
- geometrical optics and matrix method;  
- main optical instruments;  
- Lasers: - the laser idea and proprieties of laser beams;  
- absorption, spontaneous emission, stimulated emission;  
- gain and population inversion;  
- optical cavities and pumping;  
- cw lasers;  
- pulsed lasers: Q-switch and mode-locking;  
- examples of main different laser types: gas lasers, solid-state lasers  
Introduction to Quantum Optics:  
- Photon statistics - buching and antibuching;  
- weak and strong coupling: Purcell effect and Rabi splitting.

**Examination:**  
The exam is written and comprises two exercises and one open question.

**More information:**  

### PHYSICS LABORATORY

**Master's degree in PHYSICS ORD. 2021, First semester**

**Lecturer:** Dott. FRANCESCO RECCHIA  
**Credits:** 6 ECTS  
**Prerequisites:** Physics laboratory courses of the first three years.

**Short program:**  
This course propose to the students some modern physics experiments that allow the approach to measurement techniques in use for the study of Fundamental Interactions, Matter and Astrophysics. Each student will carry out three experiments. The experiments proposed are:  
1) Cosmic Rays  
2) Compton Scattering  
3) Positronium decay  
4) Gamma-ray imaging  
5) Fast timing  
6) Plasma Physics  
7) X-ray fluorescence  
8) Natural radioactivity and radon counting.  
In the first five experiments the students will be trained to the use of scintillator for the detection of particles and gamma-rays and to the use of the relative electronics.  
Multiparameter events will be constructed exploiting timing coincidences between multiple detectors.  
The data will be analysed using the ROOT data analysis framework.  
In the Plasma Physics experiment the students will study the conditions that allow the formation of plasma starting from a small quantity of neutral gas. They will study the physical characterisations of the plasma by means of electronics measurements.
The students will have to deal with vacuum and residual gas measurement techniques. The X-fluorescence and natural radioactivity experiments will be performed using high-resolution semiconductor detectors (Silicon and HPGe). They will train the students to spectroscopy techniques of the X and gamma radiation and to the relative analysis techniques.

Examination:
Written report by the group on the experiments performed. Individual interview with presentation of one of the experiment and possible short questions about the other two experiments. The presentation will concern the description of the physical phenomena, the experimental apparatus with the relative electronics and the data taking and analysis.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081617/NO

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### PHYSICS OF COMPLEX SYSTEMS

**Master's degree in PHYSICS ORD. 2021, First semester**

**Lecturer:** Prof. ANTONIO TROVATO

**Credits:** 6 ECTS

**Prerequisites:**
Students are expected to already know the main concepts of equilibrium statistical mechanics, including phase transition, critical exponents and the renormalization group.

**Short program:**

**Examination:**
Examination based on the choice and on the oral presentation of a specific topic related to the ones taught during the course. During the oral presentation, possible connections with other parts of the program will be the subject of further questions. The presentation will focus either on a book chapter or on a scientific research paper, generally but not necessarily a review. It is also possible to focus on a computational mini-project related to the topics taught in the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081763/NO

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### PHYSICS OF FLUIDS AND PLASMAS

**Master's degree in PHYSICS ORD. 2021, First semester**

**Lecturer:** Dott. TOMMASO BOLZONELLA

**Credits:** 6 ECTS

**Prerequisites:**
None

**Short program:**

**Examination:**
Oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081743/NO
PHYSICS OF NUCLEAR FUSION AND PLASMA APPLICATIONS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Dott.ssa LIDIA PIRON

Credits: 6 ECTS

Prerequisites:
Knowledge of electromagnetism principles. A knowledge of the different plasma descriptions (kinetic, two-fluids, magnetohydrodynamics) is useful but not required, since essential notions will be provided during the course.

Short program:

Examination:
Oral exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC2382/002PD/SCP7081798/NO

PHYSICS OF SEMICONDUCTORS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. DAVIDE DE SALVADOR

Credits: 6 ECTS

Prerequisites:

Short program:

Examination:
Oral exam. During the semester it will be possible to give a mid-term oral exam about the first part of the course concerning on physical principle; at the end a second oral exam on the devices and processes will complete the final grade.
QUANTUM INFORMATION AND COMPUTING

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. SIMONE MONTANGERO

Credits: 6 ECTS

Prerequisites:
Quantum mechanics and elements of programming.

Short program:

Examination:
The exam will be a final project composed of programming, data acquisition, and analysis, which will be discussed orally.

More information:

SOLID STATE PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. FRANCESCO ANCILOTTO

Credits: 6 ECTS

Prerequisites:
Knowledge of elements of elementary quantum mechanics. Knowledge of elements of elementary Statistical Mechanics (distribution functions, statistical ensembles, ensemble averages, etc.)

Short program:
Chemical bonds in solids; The structure of crystals; Bravais lattices and bases; Simple crystal structures; Reciprocal lattice; Diffraction by periodic structures and experimental techniques; The Bragg law; Adiabatic approximation; Lattice dynamics; Harmonic approximation, The dynamical Matrix; phonons; Monoatomic and diatomic linear chains; Spectroscopy of phonons; Thermal properties of crystals; Lattice specific heat; Anharmonic effects: thermal expansion, thermal conductivity of insulating materials; "free" electrons model; Electronic specific heat; electrostatic screening in a Fermi gas.; Bloch theorem; Band structure; "quasi-free" electron approximation; "tight binding" approximation; Examples of band structures; Transport phenomena; The Drude model; Hall effect in metals; Semiclassical model; The concept of "hole"; Electrical and thermal conductivity in metals; Law of Wiedemann and Franz; Semiconductors; Cyclotron Resonance; Carriers concentration in intrinsic and extrinsic semiconductors; "Doping" and dopant states; electron and hole mobility; Electrical conductivity in semiconductors; Hall effect in semiconductors; The Fermi surface in real metals. Superconductivity.

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081660/NO

STATISTICAL MECHANICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. ENZO ORLANDINI

Credits: 6 ECTS

Prerequisites:
Statistical Mechanics (course given at the third year of the laurea triennale) Thermodynamics

Short program:
In short, the contents of the program can be summarised as follows: Thermodynamics of phase transitions. Critical points, order parameters and critical exponents. Phase transitions and spontaneous symmetry breaking. Analytical tools to solve spins model in 1D, transfer matrix formalisms. Mean field theories. Ginzburg Landau theory, Ginzburg criterion and upper critical dimension. Scaling theory and Kadanoff block spin argument. Renormalisation group in real space. Universality. Please note that some topics may vary.

Examination:
The verification of the acquired knowledge takes place through a common written test with 1-2 exercises to be solved analytically and 1-2 open questions on basic concepts. In this way we should be able to test the knowledge, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The second part of the exam will be oral and will be based on a discussion on the various topics discussed in class.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081659/NO

STRUCTURE OF MATTER

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. LUCA SALASNICH

Credits: 6 ECTS

Prerequisites:
All the exams of the B.Sc. in Physics.

Short program:

Examination:
Colloquium of about 30 minutes.

More information:

TEACHING AND LEARNING PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof.ssa ORNELLA PANTANO

Credits: 6 ECTS

Prerequisites:
Core knowledge of classic and modern physics.

Short program:
Physics teaching and learning: main topics and approaches in physics education research. Core ideas in physics, scientific practices and crosscutting concepts in natural sciences. Historical development of physics ideas that carry special significance for physics teaching and learning. Different theoretical approaches to students' understanding of physics content and student difficulties, and their application in physics teaching. The role and importance of student interest, motivation and metacognition in learning physics. Student-centered approaches to physics teaching and learning. The role of laboratory work and technologies in physics learning and teaching. Educational potential of out-of-school settings: benefits and opportunities offered by experiences outside the classroom. Physics education research in different areas of physics, for example: mechanics, waves, optics, electromagnetism, relativity and quantum mechanics. Application of didactical methods and technologies for the design of teaching and learning sequences for specific physics topics.

Examination:
The examination will consist of two parts: (1) written assignments during the course (40%); (2) a final educational project on a selected topic in physics (60%).

More information:
# THEORY OF STRONGLY CORRELATED SYSTEMS

Master's degree in **PHYSICS ORD. 2021**, First semester

**Lecturer:** Prof. LUCA DELL'ANNA  
**Credits:** 6 ECTS  

**Short program:**  

**Examination:**  
Oral examination  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/002PD/SCP7081742/NO

## ADVANCED PHYSICS LABORATORY A

Master's degree in **PHYSICS ORD. 2021**, Second semester

**Lecturer:** Prof. GIAMPAOLO MISTURA  
**Credits:** 6 ECTS  

**Prerequisites:**  
Laboratory courses of previous years and basic skills in optics and electronics  

**Short program:**  
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum.  

**Examination:**  
Written report and oral exam.  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081700/NO

## ADVANCED PHYSICS LABORATORY B

Master's degree in **PHYSICS ORD. 2021**, First semester

**Lecturer:** Prof. MARCO BAZZAN  
**Credits:** 6 ECTS  

**Prerequisites:**  
Laboratory courses of preceding years and basic skills in optics and electronics  

**Short program:**  
General experimental techniques for the physics laboratory, in particular: electronics, optics, cryogenics and vacuum techniques.  

**Examination:**  
Written report and oral examination.  

**More information:**  
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081758/NO

## ADVANCED QUANTUM FIELD THEORY
Master’s degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. MARCO MATONE

Credits: 6 ECTS

Prerequisites:
Students are assumed to have adequate knowledge of both canonical quantization and the path integral formulation of quantum field theory. In particular, we assume the knowledge of the path integral quantization of the \(\phi^4\) theory and of Quantum Electrodynamics.

Short program:

Examination:
The exam consists of an oral test that can begin with a short seminar on a topic to be agreed with the teacher.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081759/NO

Advanced Topics in Physics

Master’s degree in PHYSICS ORD. 2021, Second semester

Lecturer: Dott. JEAN-SEBASTIEN CAUX

Credits: 6 ECTS

Prerequisites:
CONTENT NOT PRESENT

Short program:
CONTENT NOT PRESENT

Examination:
CONTENT NOT PRESENT

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCQ0093399/NO

Advanced Topics in the Theory of the Fundamental Interactions

Master’s degree in PHYSICS ORD. 2021, First semester

Lecturer: Dott. LUCA DI LUZIO

Credits: 6 ECTS

Prerequisites:
A basic knowledge of theoretical physics of the fundamental interactions, in particular of quantum field theory.

Short program:
- Relevant, Marginal, Irrelevant operators for a relativistic QFT in d space-time dimensions. - The Wilsonian action: definition; evaluation in perturbation theory: exact result at the tree-level. - Integrating out: exercises and examples. - The Fermi Lagrangian from the full electroweak theory. - Formulation of the Standard Model as an EFT. - Introduction to loops in EFT, \(\hbar\)bar counting. Euler-Heisenberg (EH) Lagrangian in the bottom-up approach, up to dimension-8 operators. Tree-level ultraviolet completion by an axion-like particle. - Matching of EH Lagrangian with QED: Feynman rules of EFT and calculation of loops in QED. - Birefringence of the vacuum. Equations of motion (EOM) of electromagnetic field from EH Lagrangian; linearization in classical background and solution; experimental status. - Landscape versus swampland of EH EFT; positivity of \(a_1^{}\) and \(a_2^{}\) coefficients from analyticity, crossing symmetry and unitarity applied to light-by-light forward scattering amplitude. - Applications. Positivity constraints on the EFT for a Goldstone mode. Born-Infeld electrodynamics and matching to EH Lagrangian. - S-matrix equivalence theorem; local field redefinitions and equivalent effective
**APPLIED ELECTRONICS**

Master's degree in PHYSICS ORD. 2021, Second semester

**Lecturer:** Prof. PIERO GIUBILATO

**Credits:** 6 ECTS

**Prerequisites:**
- Basic solid-state physics on semiconductors (crystal lattice, Fermi distribution, levels energy distribution, etc.)
- Analogue electronics (linear networks, active and passive devices, amplifiers, operational amplifiers, filters, etc.)
- Standard programming languages (syntax, structure, use of libraries, etc.)
- Basic knowledge of computational software (e.g. Mathematica, Matlab)

**Short program:**

- **PART 1** - Devices (1 week) - Basic knowledge of device physics, diode and transistor, either BJT or MOS. - Principle of working of the diode and the transistor (BJT and MOS). Simplified physical model of the MOS transistor (implants, gate, oxide) and how this influences its performances (parasitic capacitance, power consumption, etc.). - Quick overview of some basic circuits using diodes and transistor for specific purposes (rectifier, voltage pump, etc.).
- **PART 2** - Digital logic building blocks (2 weeks) - Basic microelectronics manufacturing concepts (lithography, feature size, etc.). - Basic logic gates (NOT, AND, NAND, ...) and their realization with CMOS transistors.
- **PART 3** - Digital systems (4 weeks) - Digital microelectronics basics: analog computers, noise margin, integration processes, microprocessors, Moore's law, the limit of scaling, analog/digital signal interface. - Different level of design (system, behavioural, RTL, gates, transistor, device, ...) and the associate languages/tools.
- HDL languages and simulation tools of the trade: SPICE, what it is and how it works, ideal elements vs. real elements, MOS transistor basic model, example of IV curves for a MOS, response of an inverter and an operational amplifier.
- Timing and power considerations in the realization of the basic gates.
- Memory elements basic blocks: mono-stable, bi-stable, S-R flip-flop, J-K flip-flop, D flip-flop and their properties.
- **PART 4** - Digital systems (3 weeks) - Digital microelectronics basics: analog computers, noise margin, integration processes, microprocessors, Moore's law, the limit of scaling, analog/digital signal interface. - Different level of design (system, behavioural, RTL, gates, transistor, device, ...) and the associate languages/tools.
- HDL languages and simulation tools of the trade: SPICE, what it is and how it works, ideal elements vs. real elements, MOS transistor basic model, example of IV curves for a MOS, response of an inverter and an operational amplifier.
- Timing and power considerations in the realization of the basic gates.
- Memory elements basic blocks: mono-stable, bi-stable, S-R flip-flop, J-K flip-flop, D flip-flop and their properties.
- **PART 5** - Digital systems (3 weeks) - Digital microelectronics basics: analog computers, noise margin, integration processes, microprocessors, Moore's law, the limit of scaling, analog/digital signal interface. - Different level of design (system, behavioural, RTL, gates, transistor, device, ...) and the associate languages/tools.
- HDL languages and simulation tools of the trade: SPICE, what it is and how it works, ideal elements vs. real elements, MOS transistor basic model, example of IV curves for a MOS, response of an inverter and an operational amplifier.
- Timing and power considerations in the realization of the basic gates.
- Memory elements basic blocks: mono-stable, bi-stable, S-R flip-flop, J-K flip-flop, D flip-flop and their properties.
- **PART 6** - Digital systems (3 weeks) - Digital microelectronics basics: analog computers, noise margin, integration processes, microprocessors, Moore's law, the limit of scaling, analog/digital signal interface. - Different level of design (system, behavioural, RTL, gates, transistor, device, ...) and the associate languages/tools.
- HDL languages and simulation tools of the trade: SPICE, what it is and how it works, ideal elements vs. real elements, MOS transistor basic model, example of IV curves for a MOS, response of an inverter and an operational amplifier.
- Timing and power considerations in the realization of the basic gates.
- Memory elements basic blocks: mono-stable, bi-stable, S-R flip-flop, J-K flip-flop, D flip-flop and their properties.

**Examination:**

Oral exam

**More information:**

https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081701/NO

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**ASTROPARTICLE PHYSICS**

Master's degree in PHYSICS ORD. 2021, Second semester

**Lecturer:** Prof. FRANCESCO D'ERAMO

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COSMOLOGY OF THE EARLY UNIVERSE

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. NICOLA BARTOLO

Credits: 6 ECTS

Prerequisites: Generally the bases useful to attend this course are provided by the various courses within a given chosen curriculum.

Short program: General introduction. The problem of the initial conditions: primordial density perturbations at the origin of the formation of the Large Scale Structure of the Universe. - Short recall of the main problems of the standard cosmological model - Inflationary cosmology in the Early Universe as a solution to the problems of the standard model Modeling: - Inflationary models: vacuum energy and the inflation field; dynamics of a scalar field in a Friedman-Robertson-Walker Universe; possible realizations of the inflationary scenario - Cosmological models of inflation and their main features (with examples also within high-energy particle physics) - Observational predictions of the inflationary models: from the quantum perturbations in an expanding universe to the primordial density perturbations; generation of primordial gravitational waves and their observability (cosmological and interferometric probes). Reheating phase and baryogenesis mechanisms Delta-N and in-in formalisms for the study of cosmological perturbations. Example: primordial non-Gaussianity Cosmological perturbations in General Relativity: - scalar, vector and tensor perturbations - gauge transformations - Einstein equations (linearly) perturbed around the Robertson-Walker metric Observational tests of the Early Universe

Examination: Oral exam


EXPERIMENTAL SUBNUCLEAR PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. RICCARDO BRUGNERA

Credits: 6 ECTS

Prerequisites: One assumes some prior knowledge: basic information regarding High Energy Physics and Quantum Electrodynamics coming from the courses of Subnuclear Physics, Theoretical Physics and Theoretical physics of the fundamental interactions


Examination: Oral

FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. SABINO MATARRESE

Credits: 6 ECTS

Prerequisites:
Fundamental concepts of quantum mechanics and special relativity

Short program:
Fundamental concepts of galactic and extra-galactic astrophysics • The classification of galaxies • Statistical properties of the galaxy population • Groups and clusters of galaxies Fundamental concepts of Cosmology • Main components of the Universe. Observational evidence for the existence of dark matter and dark energy. • Expanding Universe and Cosmological Principle. • Robertson-Walker line-element. Geometrical properties. • Hubble constant and deceleration parameter. • Distances in Cosmology; redshift and Hubble law (low-redshift approximation). • Derivation of Friedmann equations (dust case); Newtonian and relativistic contributions • Friedmann models. • Cosmological constant: Einstein's static solution and de Sitter solution. Dynamical dark energy • Cosmological solutions for the spatially flat case, Universe models with non-zero spatial curvature. • Exact treatment of the Hubble law. Thermal history and early Universe • Number density, energy density and pressure of a system of particles in thermodynamic equilibrium. • Entropy conservation in a comoving volume. • Time-temperature relation in the Early Universe. • Shortcomings of the standard cosmological model: horizon, flatness problems, etc. • Inflation in the Early Universe: solution of the horizon and flatness problems. • Kinematics and dynamics of inflation; the "inflaton". • Old, new and chaotic inflation; slow-roll dynamics (basic account). • Baryon asymmetry in the Universe (basic account) • Primordial nucleosynthesis of light elements. • Hydrogen recombination: Saha equation. Matter-radiation decoupling. Cosmic Microwave background. • General definition of decoupling. Dark matter: general properties • Boltzmann equation in Cosmology and cosmic relics. • Elements of stellar astrophysics • Gravitational contraction and conditions for hydrostatic equilibrium. • Adiabatic index and equilibrium. • Conditions for gravitational collapse. • Jeans theory of gravitational instability. • Contraction of a protostar. • Star formation and degenerate electron gas. • The Sun: general properties, radiative diffusion, thermonuclear fusion. • Stellar nucleosynthesis. • Stellar cycles. • Hertzsprung-Russell diagram. • Basics of stellar structure. Clayton model: Minimum mass of a star; maximum mass for a Main-Sequence star. • End-points of stellar evolution: white dwarfs, neutron stars, Chandrasekhar mass, black holes. The formation of cosmic structures • Linear evolution of perturbations in the expanding Universe (basic principles). • Spherical collapse of a cosmic proto-structure. • Mass-function of cosmic structures: Press-Schechter theory.

Examination:
Oral interview.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP9086381/NO

GENERAL RELATIVITY

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. LUCA MARTUCCI

Credits: 6 ECTS

Prerequisites:
Theoretical Physics is recommended.

Short program:
The Equivalence Principle; spacetime geometry; dynamics of point particles on curved spacetimes; Einstein's equations; Newtonian limit; gravitational waves; spacetime symmetries and maximally symmetric spaces; the Schwarzschild solution and its properties; Schwarzschild black holes; more on black holes (Penrose diagrams, charged and rotating black holes); black hole thermodynamics.

Examination:
Questions on the topics presented during the course and solution of a simple problem.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081661/NO

INTRODUCTION TO MANY BODY THEORY

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. PIER LUIGI SILVESTRELLI

Credits: 6 ECTS

Prerequisites:
Metodi Matematici

Short program:

Examination:
Oral exam and home-work exercises.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081699/NO

INTRODUCTION TO RADIATION DETECTORS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. ROBERTO STROILI

Credits: 6 ECTS

Prerequisites:
Knowledge of electromagnetic phenomena, electromagnetic waves included. Basic notions about special relativity and quantum mechanics.

Short program:

Examination:
Oral.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081437/NO

MEDICAL PHYSICS

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Dott.ssa LAURA DE NARDO

Credits: 6 ECTS

Prerequisites:
Knowledge of radiation-matter interaction phenomena, principles and methods for detecting particles and electromagnetic radiation, radioactive decays.

Short program:
• Biological and health effect of ionizing radiations. • Introduction to dosimetry of ionizing radiation. • Radiation detectors for dosimetry and related metrology aspects. • Basic concepts in image processing: image properties, noise and contrast, frequency domain; filtering, edge detection and image enhancement, transformations, segmentation; image quality. • Imaging in diagnostics: images production with X rays and radioactive tracers (scintigraphy and gamma camera, tomography with single-photon emission (SPECT), tomography with positron emission (PET and TOF-PET), hybrid scanners). • Principles of radiotherapy with photons, electron and hadrons. Internal radiotherapy and radionuclide therapy. • Medical radionuclides production. • Introduction to magnetic resonance imaging (MRI). • Introduction to echography imaging. • Principles of hyperthermia.

Examination:
Oral examination. The exam will focus on the topics covered during the lessons. Furthermore, the student will prepare a presentation (Power Point or similar) on a detailed analysis of one or more recent scientific works related to one of the topics of the course or the result of a simulation / data analysis. The topic of the presentation will be agreed with the teacher. This presentation will allow to evaluate the communication skills, the degree of judgment autonomy and the learning abilities of the student.
MULTIMESSENGER ASTROPHYSICS

Master's degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof.ssa ELISA BERNARDINI

Credits: 3 ECTS

Prerequisites:
This course is addressed to students with basic knowledge of elementary particles and their interactions and nuclear physics.

Short program:
The term “multi-messenger” is quite new and increasingly used in astronomy and astroparticle physics. It refers to combining information from different cosmic messengers (i.e. photons, cosmic rays, neutrinos and gravitational waves) to gain a deeper understanding of the astrophysical objects we observe in the sky. Visible light only reveals a very small portion of the mysteries of the Universe. Astronomical observations are nowadays routinely performed with different telescopes across the whole electromagnetic spectrum, from radio waves through visible light, all the way to gamma-rays. At the highest energies, the most violent processes in the Universe are at work. Whatever produces high energy gamma-rays, is expected to accelerate particles to energies that exceed the capabilities of man-made accelerators a billion times. Such particles can reach the Earth as cosmic rays, first discovered more than 100 years ago, still nowadays one of the most mysterious "messages" from our Universe. Cosmic rays may interact in the vicinity or their sources or even along their way to Earth, to produce elusive particles called neutrinos and gamma-rays. While cosmic rays are deflected during their journey by intergalactic magnetic fields, neutrinos and photons, being neutral particles, keep memory of their source's direction. Their trajectory becomes thus crucial to unravel the origin of cosmic rays. Neutrinos are extremely difficult to detect. Cubic-kilometer detectors are necessary to observe neutrinos at energies larger than few tens of GeV. The year 2013 witnessed the first clear observation of neutrinos from distant astrophysical objects by the IceCube detector at the South Pole, opening a new observational window to the Universe. The most extreme astrophysical objects, connected with the most violent phenomena in our Universe, are often associated with black holes or neutron stars. Whenever two such compact objects orbit around each other, they are expected to produce gravitational waves. The year 2015 witnessed the first direct observation of gravitational waves emitted by two merging black-holes (GW150914), measured by the LIGO detectors in the USA. The discovery was celebrated by the Nobel-prize for physics. The year 2017 witness the triumph of multi-messenger astrophysics with the detection of gravitational waves from two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A). Just few days after another event celebrated the success of multi-messenger astrophysics: the first identification of a source of cosmic neutrinos, the blazar TXS 0506+056, helped by the electromagnetic observations that followed the detection of a high energy neutrino (IceCube-170922A). Both results greatly demonstrate the potential of multi-messenger astrophysics in observing and understanding the most extreme and mysterious phenomena in our Universe. This course will illustrate its foundations.

Examination:
Oral examination.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP9088180/NO

NON-PERTURBATIVE QUANTUM FIELD THEORY

Master's degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof. PIERALBERTO MARCHETTI

Credits: 6 ECTS

Prerequisites:
Theoretical physics of the fundamental interactions and Quantum field theory or Models of theoretical physics and Structure of matter

Short program:
Quantum field theory (QFT) is a common framework in many branches of physics, exhibiting an unexpected unity in the description of elementary quantum processes that deeply modified our view of physical reality. Many of the key results of QFT are obtained through a perturbative expansion, but there are crucial areas of applications that do not rely on it. The aim of the course is to provide a view of some results in these areas, with examples both in elementary particle and condensed matter physics, emphasizing the underlying common features. Examples are only outlined, but not discussed in detail and in the following program are between brackets. Some topics in the program might be alternative, depending on the interests and knowledge of the students. Proposed program 1) Reconstruction theorem: What precisely a QFT is, how one can reconstruct quantum fields out of correlation functions, how they are related to experiments. 2) Quantum solitons: kinks (phi4, polyacetylene), vortices (Higgs model, superconductors), monopoles (Dirac, t'Hooft-Polyakov, spin ice), and their role in the phase transitions. 3) Anomalies: chiral anomaly (the eta mass problem in QCD) and parity anomaly (topological insulators, graphene).

Examination:
Oral examinations

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081762/NO
NUCLEAR ASTROPHYSICS

Master’s degree in PHYSICS ORD. 2021, Second semester

Lecturer: Prof. ANTONIO CACIOLLI

Credits: 6 ECTS

Prerequisites:
Elements of quantum mechanics, nuclear physics, and general physics

Short program:
Thermonuclear reactions. Definition of nuclear cross section, astrophysical S-factor, reaction rate, and Gamow peak. Nuclear burnings during hydrostatic and explosive stellar evolutionary phases. Elements of stellar modelling. Hydrogen burning: p-p chains, CNO, NeNa, MgAl cycles. Helium burning: triple- alpha reaction and alpha + 12C. Advanced nuclear burnings (C, Ne, O, Si). Neutron-capture reactions (s and r: slow and rapid) For each topic we provide an overview of the most relevant results in the recent literature. How to determine the reaction rate for several cases (direct capture, narrow resonances, broad resonances) How to perform a nuclear astrophysics experiment (every topic will be discussed with of existing experimental facilities and their most recent results) The environmental background and how to shield it (passive and active shielding) Underground experiment Brief discussion on indirect methods (Trojan Horse, ANC, …).

Examination:
A 10 minutes presentation on an aspect of the course (usually an astrophysical issue and a related reaction study) and some question related to the presentation and course program.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081704/NO

NUCLEAR PHYSICS

Master’s degree in PHYSICS ORD. 2021, First semester

Lecturer: Prof.ssa SILVIA MONICA LENZI

Credits: 6 ECTS

Prerequisites:
Quantum mechanics

Short program:
Program of Nuclear Physics 2021/2022 First part: Nuclear Structure and Nuclear Models • Introduction: The nucleus as a laboratory of Quantum Mechanics • Symmetries and the Nuclear Force • Theoretical Models: The nuclear deformation, Surface vibrations, Rotating nuclei 2) Microscopic Models: Mean-field Models, Interacting Shell Model The Nilsson Model • Experimental tools in nuclear structure Second part: Nuclear reactions Introduction • Nucleon-Nucleon Scattering • Nuclear Reactions • Interactions between heavy ions • Direct nuclear reactions between heavy ions • Multi-nucleon transfer reactions between heavy ions • Compound nuclear reactions • Fusion reactions below the Coulomb barrier • Superheavy nuclei • Reactions of astrophysical interest

Examination:
The exam consists on an oral examination that includes the discussion of the exercises proposed during the course, and eventual presentation of a research work on one of the several subjects proposed by the professors.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081658/NO

PHYSICS LABORATORY

Master’s degree in PHYSICS ORD. 2021, First semester

Lecturer: Dott. FRANCESCO RECCHIA

Credits: 6 ECTS

Prerequisites:
Physics laboratory courses of the first three years.

Short program:
This course propose to the students some modern physics experiments that allow the approach to measurement techniques in use for the study of Fundamental Interactions, Matter and Astrophysics. Each student will carry out three experiments. The experiments proposed are: 1) Cosmic Rays 2) Compton Scattering 3) Positronium decay 4) Gamma-ray imaging 5) Fast timing 6) Plasma Physics 7) X-ray fluorescence 8) Natural radioactivity and
radon counting. In the first five experiments the students will be trained to the use of scintillator for the detection of particles and gamma-rays and to the use of the relative electronics. Multiparameter events will be constructed exploiting timing coincidences between multiple detectors. The data will be analysed using the ROOT data analysis framework. In the Plasma Physics experiment the students will study the conditions that allow the formation of plasma starting from a small quantity of neutral gas. They will study the physical characterisations of the plasma by means of electronics measurements. The students will have to deal with vacuum and residual gas measurement techniques. The X-fluorescence and natural radioactivity experiments will be performed using high-resolution semiconductor detectors (Silicon and HPGe). They will train the students to spectroscopy techniques of the X and gamma radiation and to the relative analysis techniques.

Examination:
Written report by the group on the experiments performed. Individual interview with presentation of one of the experiment and possible short questions about the other two experiments. The presentation will concern the description of the physical phenomena, the experimental apparatus with the relative electronics and the data taking and analysis.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081617/NO

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**QUANTUM FIELD THEORY**

Master's degree in PHYSICS ORD. 2021, Second semester

**Lecturer:** Prof. GIANGUIDO DALL'AGATA

**Credits:** 6 ECTS

**Prerequisites:**
Relativistic quantum mechanics. Classical field equations and canonical quantization of fields.

**Short program:**
1. The LSZ Reduction Formula. 1.1 A new approach to Quantum Field Theory. 1.2 Correlators and the LSZ reduction formula. 2. The Path integral in Quantum Mechanics. 2.1 Intuitive introduction to path integrals. 2.2 From Schröedinger equation to the path integral. 2.3 The partition function. 2.4 Operators and time ordering. 2.5 The continuum limit and non-commutativity. 3. Perturbation Theory. 3.1 Correlators and scattering amplitudes. 3.2 Free field theory. 3.3 Perturbation theory. 3.4 Feynman Diagrams. 3.5 Borel resummation*. 3.6 Exact results - localization*. 4. Effective and quantum action. 4.1 Wilsonian effective action. Integrating out fields. 4.2 The 1pi effective action. 5. Path integral quantization of ? ?4. 5.1 Dimensional analysis. 5.2 The free theory. 5.3 The interacting theory. 5.4 The Coleman-Weinberg potential. 6. Quantising spin 1/2 and spin 1 fields. 6.1 Path integral for Dirac fermions. 6.2 Path integral for photons. 7. Perturbative renormalization. 7.1 Divergences. 7.2 Superficial degree of divergence and BPHZ theorem. 7.3 1-loop propagator in ? ?4. 7.4 On-shell renormalisation. 7.5 Dimensional regularization. 7.6 QED Renormalization. 8. Renormalization Group. 8.1 Renormalization and integrating out degrees of freedom. 8.2 The Callan-Symanzik equations. 8.3 Anomalous dimensions. 8.4 Renormalization group flow. 8.5 Counterterms and the continuum limit. 8.6 Polchinski equations. 8.7 The local potential approximation. 8.8 The Gaussian Critical point and Landau poles. 8.9 The Wilson-Fisher critical point. 8.10 Zamolodchikov's C-theorem. 9. Symmetries. 9.1 Symmetries in quantum field theories. 9.2 Ward-Takahashi identities. 9.3 Current conservation in QFT. 10. Quantization of non-abelian gauge theories. 10.1 Classical Yang-Mills theories. 10.2 Gauge fixing and the path integral. 10.3 Fadeev Popov determinants and ghosts. 10.4 BRST symmetry and the physical Hilbert space

**Examination:**
The examination is oral. It will be performed with general questions on the topics of the course, including the derivation of the main results and possibly the resolution of simple problems.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081702/NO

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**RADIOACTIVITY AND NUCLEAR MEASUREMENTS**

Master's degree in PHYSICS ORD. 2021, Second semester

**Lecturer:** Prof. MARCO MAZZOCCO

**Credits:** 6 ECTS

**Prerequisites:**
The student must have attended the courses of "Introduction of Nuclear Physics" and "Nuclear Physics"

**Short program:**

Examination:
Oral examination. The student will be asked some questions concerning the different topics presented during the lectures. It is also foreseen a detailed analysis of one of the arguments by the student.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081740/NO

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<td>Lecturer: Prof. FRANCESCO ANCILOTTO</td>
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<td>Credits: 6 ECTS</td>
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<tr>
<td>Prerequisites: Knowledge of elements of elementary quantum mechanics. Knowledge of elements of elementary Statistical Mechanics (distribution functions, statistical ensembles, ensemble averages, etc.)</td>
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<tr>
<td>Short program: Chemical bonds in solids; The structure of crystals; Bravais lattices and bases; Simple crystal structures; Reciprocal lattice; Diffraction by periodic structures and experimental techniques; The Bragg law; Adiabatic approximation; Lattice dynamics; Harmonic approximation, The dynamical Matrix; phonons; Monoatomic and diatomic linear chains; Spectroscopy of phonons; Thermal properties of crystals; Lattice specific heat; Anharmonic effects: thermal expansion, thermal conductivity of insulating materials; &quot;free&quot; electrons model; Electronic specific heat; electrostatic screening in a Fermi gas.; Bloch theorem; Band structure; &quot;quasi-free&quot; electron approximation; &quot;tight binding&quot; approximation; Examples of band structures; Transport phenomena; The Drude model; Hall effect in metals; Semiclassical model; The concept of &quot;hole&quot;; Electrical and thermal conductivity in metals; Law of Wiedemann and Franz; Semiconductors; Cyclotron Resonance; Carriers concentration in intrinsic and extrinsic semiconductors; &quot;Doping&quot; and dopant states; electron and hole mobility; Electrical conductivity in semiconductors; Hall effect in semiconductors; The Fermi surface in real metals. Superconductivity.</td>
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<tr>
<td>Examination: Oral exam</td>
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<td>More information: <a href="https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081660/NO">https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081660/NO</a></td>
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<td>Master's degree in PHYSICS ORD. 2021, Second semester</td>
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<tr>
<td>Lecturer: Prof. PARIDE PARADISI</td>
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<td>Credits: 6 ECTS</td>
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<tr>
<td>Prerequisites: Students should be familiar with the fundamental aspects of field theory, quantum electrodynamics and the calculation of amplitudes for physical processes through Feynman diagrams.</td>
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<tr>
<td>Examination: Oral examination</td>
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</tbody>
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**STATISTICAL MECHANICS**

Master's degree in PHYSICS ORD. 2021, First semester

**Lecturer:** Prof. ENZO ORLANDINI

**Credits:** 6 ECTS

**Prerequisites:**
Statistical Mechanics (course given at the third year of the laurea triennale) Thermodynamics

**Short program:**

**Examination:**
The verification of the acquired knowledge takes place through a common written test with 1-2 exercises to be solved analytically and 1-2 open questions on basic concepts. In this way we should be able to test the knowledge, the scientific vocabulary, the ability to synthesis and critical discussion acquired during the course. The second part of the exam will be oral and will be based on a discussion on the various topics discussed in class.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081659/NO

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**SUBNUCLEAR PHYSICS**

Master's degree in PHYSICS ORD. 2021, Second semester

**Lecturer:** Prof.ssa DONATELLA LUCCHESI

**Credits:** 6 ECTS

**Prerequisites:**
Principles of nuclear and sub-nuclear physics, principles of quantum mechanics, relativistic dynamics, quantum field theory, Feynman graphs, interaction radiation with matter.

**Short program:**

**Examination:**
The exam will be based on an assignment given in advance to the students. It will be constituted by exercises or open questions and a discussion on open topics among those discussed during the lectures. During the discussion questions on the arguments of the class can be asked.

**More information:**
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081697/NO

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**TEACHING AND LEARNING PHYSICS**

Master's degree in PHYSICS ORD. 2021, First semester

**Lecturer:** Prof.ssa ORNELLA PANTANO

**Credits:** 6 ECTS

**Prerequisites:**
Core knowledge of classic and modern physics.

**Short program:**
Physics teaching and learning: main topics and approaches in physics education research. Core ideas in physics, scientific practices and crosscutting concepts in natural sciences. Historical development of physics ideas that carry special significance for physics teaching and learning. Different theoretical approaches to students' understanding of physics content and student difficulties, and their application in physics teaching. The role and importance of student interest, motivation and metacognition in learning physics. Student-centered approaches to physics teaching and learning. The role of laboratory work and technologies in physics learning and teaching. Educational potential of out-of-school settings: benefits and opportunities offered by experiences outside the classroom. Physics education research in different areas of physics, for example: mechanics, waves, optics, electromagnetism, relativity and quantum mechanics. Application of didactical methods and technologies for the design of teaching and learning sequences for specific physics topics.

**Examination:**

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The examination will consist of two parts: (1) written assignments during the course (40%); (2) a final educational project on a selected topic in physics (60%).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCQ1097889/NO

THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS

Lecturer: Prof. PIERPAOLO MASTROLIA
Prerequisites:
Principle of Theoretical Physics
Examination:
Written and oral exam

THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. A)

Lecturer: Prof. PIERPAOLO MASTROLIA
Master's degree in PHYSICS ORD. 2021, First semester
Credits: 12 ECTS

Short program:

THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. B)

Lecturer: Prof. PARIDE PARADISI
Master's degree in PHYSICS ORD. 2021, First semester
Credits: 12 ECTS

Short program:

THEORY OF STRONGLY CORRELATED SYSTEMS

Master's degree in PHYSICS ORD. 2021, First semester
Lecturer: Prof. LUCA DELL'ANNA
Credits: 6 ECTS

Short program:
SANITARY BIOLOGY

APPLIED STATISTICS

Master's degree in SANITARY BIOLOGY, First semester

Lecturer: Prof.ssa ALESSANDRA ROSALBA BRAZZALE

Credits: 6 ECTS

Prerequisites: The style is informal and only minimal mathematical notation will be used. There is no real prerequisite except elementary algebra. However, a previous introductory course in statistics is recommended.

Short program:

Examination:
Written exam on moodle platform

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2382/001PD/SCP7081742/NO

BIOCHEMISTRY OF DISEASES

Master's degree in SANITARY BIOLOGY, First semester

Lecturer: Prof. LUCA SCORRANO

Credits: 8 ECTS

Prerequisites: Biochemistry, Physiology and Pathology

Short program:
Introduction to class. Course organization. Distribution of material. designing and interpreting an experiment in biology how to critically read a research paper (w/example) Metabolic flexibility Interorganelar contact sites angiogenesis adipocyte biology neurodegeneration Design and analysis of a conditional knockout mouse Introduction to the lab rotation experiments Presentation of the lab rotation experiments by students Critical presentation of a paper by students course wrap up: questions, doubts, answers

Examination:
Evaluation of the overall active participation to classes and tutorials (30%) Evaluation of the lab report (30%) Evaluation of the final public presentation (40%)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1177/000ZZ/SCP5073118/NO

HUMAN PHYSIOLOGY

Master's degree in SANITARY BIOLOGY, First semester

Lecturer: Prof. LUIGI BUBACCO

Credits: 9 ECTS

Prerequisites:
The class requires previous knowledge of basic Biochemistry, cell Biology and General Physiology

Short program:
The Central Nervous System (8 hours) Neurons: Cellular and Network organization and Properties, Efferent Division: (10 hours) Autonomic and Somatic Motor Control. Sensory Physiology. Muscles physiology (8 hours) Control of Body Movement Cardiovascular Physiology (10 hours) Blood Flow and the Control of Blood Pressure and functional properties of Blood Respiratory Physiology (8 hours) Mechanics of Breathing, Gas Exchange and Transport The Kidneys (8 hours) Fluid and Electrolyte Balance Digestion (8 hours) Energy Balance and Metabolism. Endocrine Control of Growth and Metabolism (8 hours) Reproduction and Development (8 hours)

Examination:
Written exam, four open questions to be answered in two hours

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1177/000ZZ/SCN1032657/NO

MOLECULAR BIOLOGY AND GENETICS OF CANCER

Master's degree in SANITARY BIOLOGY, First semester

Lecturer: Prof. GIANLUCA OCCHI

Credits: 8 ECTS

Prerequisites:
The course has no specific prerequisites. Basic knowledge in cell biology, molecular biology is, however, desirable.

Short program:
1. Introduction on the molecular basis of cancer (0.25 CFUf) 2. Carcinogenesis and Cancer Genetics (2.5 CFUf) - Oncogenes and Signal Transduction - Tumor Suppressor Genes - DNA Repair Pathways and Human Cancer - Epigenetics and Cancer - Infectious Agents and Cancer - Notes on environmental Carcinogenesis 3. Cancer Biology (2.25 CFUf + 0.25 CFUp) - Cancer Stem Cells and the Microenvironment - Regulation of the Cell Cycle - Cell Growth - The Metabolism of Cell Growth and Proliferation - Apoptosis, Necrosis, and Autophagy - Cellular Senescence - Tumor Angiogenesis - Invasion and Metastasis - Inflammation and Cancer 4. Tumor Genomics (1 CFUf + 1 CFUp) - Use of next-gen sequencing in cancer - Cancer System Biology - Computational pan-Cancer Analysis 5. Molecular Pathology and Diagnostic (0.25 CFUp) - Biomarkers for diagnosis, risk, and therapy assessment 6. Notes on the molecular basis of cancer therapy These topics will be addressed in frontal lessons, specific seminars, and journal clubs. Internationally acknowledged experts in the field of tumor molecular oncology will be invited to hold seminars on specific topics. Practicals During the bioinformatic practicals, cutting-edge databases of omic tumor data will be presented in the context of research in molecular oncology. Tools for the consultation and analysis of these data will be also illustrated. During practicals, students will be invited to complete a small group research project. In addition, journal club will be held by the students on specific course topics. Practicals During the bioinformatic practicals, cutting-edge databases of omic tumor data will be presented in the context of research in molecular oncology. Tools for the consultation and analysis of these data will be also illustrated. During practicals, students will be invited to complete a small group research project. In addition, journal club will be held by the students on specific course topics. Practicals During the bioinformatic practicals, cutting-edge databases of omic tumor data will be presented in the context of research in molecular oncology. Tools for the consultation and analysis of these data will be also illustrated. During practicals, students will be invited to complete a small group research project. In addition, journal club will be held by the students on specific course topics. Practicals During the bioinformatic practicals, cutting-edge databases of omic tumor data will be presented in the context of research in molecular oncology. Tools for the consultation and analysis of these data will be also illustrated. During practicals, students will be invited to complete a small group research project. In addition, journal club will be held by the students on specific course topics. Practicals During the bioinformatic practicals, cutting-edge databases of omic tumor data will be presented in the context of research in molecular oncology. Tools for the consultation and analysis of these data will be also illustrated. During practicals, students will be invited to complete a small group research project. In addition, journal club will be held by the students on specific course topics.

Examination:
An oral exam will be held. The journal club and activities in the bioinformatic laboratories will be also scored.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC1177/000ZZ/SCQ0094178/NO

STATISTICAL SCIENCES ORD. 2014

INTRODUCTION TO STOCHASTIC PROCESSES

Master's degree in STATISTICAL SCIENCES ORD. 2014, First semester

Lecturer: Prof. BERNARDO D'AURIA

Credits: 9 ECTS

Prerequisites:
A basic course in Probability.

Short program:
MACHINE LEARNING

Master's degree in STATISTICAL SCIENCES ORD. 2014, First semester

Lecturer: Prof. FABIO AIOLLI

Credits: 6 ECTS

Prerequisites:
The student should be familiar with basic concepts in Probability and Analysis of multivariate functions. It is also advisable to have basic knowledge of Programming and Artificial Intelligence. The course does not have prerequisites.

Short program:
The course will cover the topics listed below - Introduction: When to apply Machine Learning techniques; Machine Learning Paradigms; Basic ingredients of Machine Learning. - Learning Concepts: The complexity of the Hypothesis Space, Complexity Measures; Examples of Supervised Learning Algorithms; - Decision Trees: Learning Decision Trees; Treatment of Numerical Data, Missing Data, Costs; Pruning Techniques and Derivation of Decision Rules. - Probabilistic Learning: Bayesian Learning; Examples of Application to Supervised and Unsupervised Learning (clustering); Optimal Bayes classifier; EM. - Neural Networks and Support Vector Machines: Introduction to Neural Networks; Classification Margin, Support Vector Machines for Classification and Regression, Kernel Functions. - Application Issues: Classification Pipeline, Data Representation, and Selection of Variables; Model Selection; Clustering; Ensemble Learning; Recommender Systems.

Examination:
The student has to pass a written examination and if deemed necessary by the teacher, an oral examination. There is also a project that can be replaced by activities during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SS1736/000ZZ/SCQ0093538/NO

THEORY AND METHODS FOR INFERENCE

Master's degree in STATISTICAL SCIENCES ORD. 2014, Second semester

Lecturer: Prof.ssa ALESSANDRA SALVAN

Credits: 9 ECTS

Prerequisites:
First year Master courses at the level of the courses Probability Theory and Statistics (Advanced) at the Department of Statistical Sciences.

Short program:

Examination:
1/3 homework, 1/3 final written exam, 1/3 written and oral presentation reviewing one or two recent research papers.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SS1736/000ZZ/SCP8082660/NO
CIRCULAR AND SUSTAINABLE WASTE MANAGEMENT

Master’s degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Lecturer: Prof.ssa MARIA CRISTINA LAVAGNOLO

Credits: 9 ECTS

Prerequisites:
Basic knowledge of chemistry and biochemistry, knowledge of pollution phenomena

Short program:
ICAR/03 (6 ECTS) • Waste management systems and strategies: circularity, sustainability and closing the loop of the materials • Worldwide waste production and quality • Glance at the current international legislations about waste management: definitions, European Waste Catalogue, Hazardous waste classification • Scheme of resource recovery and disposal of residues • Waste collection and transport, separate collection and material recovery • Mechanical selection schemes and processes, efficiencies and possibilities, separation of single fractions • Recycling and recovery processes of materials • Technologies of composting and anaerobic digestion • Thermal energy recovery from waste: thermal processes (gasification, pyrolysis, incinerator); RDF (refuse derived fuel) production and possibilities • Management and disposal of residues; strategies, landfill technologies and design (materials, barriers; leachate and biogas collection, treatment, land reutilisation); the sustainable landfill and the geological repository • Hazardous waste management • Innovative visions: Integrated waste and water management and recovery • Health and Waste CHIM/11 (2 ECTS) • Bio-stabilization processes for the biodegradable fraction: biochemical aerobic and anaerobic processes • Biorefinery of waste: biochemistry and processes, future possibilities D (1 ECTS) • The experiences of Private and Public Companies in the management of waste

Examination:
STUDENTS ATTENDING CLASS LECTURES: The exam consists into two parts: 1. Group work during the course The type of group work and the deadline of the assignment will be defined during the first day of lectures in class. This part of exam will be presented and discussed in class by each group. 2. Final written exam (1.5 h) Final mark will be the sum of the two evaluations. STUDENTS NOT ATTENDING: Final written exam (3.5 h)

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095491/NO

ECONOMICS FOR THE CIRCULAR ECONOMY

Master’s degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
Tutoring in economics ( 8 hours )

Short program:
• An overview on sustainability and circular economy • The relation between the economy and the environment • The economic functions of the environment • The material balance, IPAT identity, EKC curve • Natural resources and the circular economy: optimal management of renewable and non-renewable natural resources • The roots of environmental problems and the role of environmental politics • Efficiency, optimality, public goods and externalities. • Integrated assessment models (IAMs): climate and economy models. • Microeconomic modelling for the energy and the environment

Examination:
Teamwork written project ( to be delivered before the exam date ) + oral evaluation

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095593/NO

EUROPEAN UNION ENVIRONMENTAL AND ENERGY LAW

Master’s degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: Prof. BERNARDO CORTESE

Credits: 6 ECTS

Prerequisites:
No particular prerequisite

Short program:
### Green Chemistry and Innovative Chemical Process

**Master's degree in Sustainable Chemistry and Technologies for Circular Economy ORD. 2021, First semester**

**Lecturer:** Prof. MAURO CARRARO

**Credits:** 9 ECTS

**Prerequisites:**
Basic knowledge of general and of organic chemistry.

**Short program:**
- Principles of Green Chemistry, environmental metrics? Risk / wastes / pollution reduction in chemical processes?
- Selection of solvents and reactants, design of reactions with high atom economy?
- Alternative and not hazardous solvents: water, supercritical fluids, dimethyl carbonate, ionic liquids, deep eutectic solvents, from renewable sources, etc.
- Use of renewable platform chemicals as starting reagents to obtain both traditional and new chemical compounds?
- Green catalysis with homogeneous, supported, heterogeneous catalysts, solid acids and bases, organocatalysts, biocatalysis?
- Use of CO2 as carbon source/building block for carbon based compounds?
- Green reagents: oxidations with H2O2, O2, reductions with H2?
- Alternative activation methods: photochemistry, microwave or ultrasonic processing, electrochemistry?
- Bibliographic research in the main literature sources and selection of greener laboratory procedures?
- Team work on a green chemistry project?
- Analysis of industrial processes and possible innovative interventions with economic and environmental considerations?
- Examples of green industrial processes?
- Intrinsically safer design and process intensification?
- Practical examples of a green organic synthesis in the laboratory involving combined strategies (use of one alternative solvent, bio-based starting materials and catalysis)

**Examination:**
Oral exam; the student will report on a case study by a presentation. The team work, developed during the course, will also be evaluated.

**More information:**
https://en.didattica.unipd.it/it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095594/NO

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### Health and Environment in Circular Economy

**Master's degree in Sustainable Chemistry and Technologies for Circular Economy ORD. 2021, Second semester**

**Lecturer:** to be defined

**Credits:** 6 ECTS

**Prerequisites:**
Basic knowledge in inorganic/organic/analytical chemistry and in instrumental analysis

**Short program:**
- Introductory topics. -The main environmental contaminants: chemical-physical properties, sources and environmental fate.
- Toxic properties, exposure routes and methodologies for estimating the effects on human health of the environmental pollutants: toxicological and epidemiological approaches.
- Specific topics. - Water pollution and water quality assessment. - Air pollution and air quality assessment, with a focus on the urban environment.
- The global effects of environmental pollution: ubiquitous pollutants, emerging pollutants, climate change.
- The EU Regulations (REACH and CLP) for the management of chemicals. Use of LCA models for the evaluation and replacement of “very high concern chemicals” in goods/articles aimed at a better sustainability of the production processes.
- Introduction to environmental certifications, in particular the environmental management systems of companies/organizations (UNI EN ISO14001), the environmental certification of product (UNI EN ISO 14021) and the use of LCA models for the assessment of the sustainability of production processes and goods/articles.

**Examination:**
Oral examination on the topics of the course.
OPERATIONS AND SUPPLY CHAIN MANAGEMENT

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: to be defined

Credits: 6 ECTS

Prerequisites:
None

Short program:
-->Lean management and process optimisation: presentation of principles and techniques that made significant changes to traditional production processes with a new view of continuous improvement. -->Quality system. Starting from traditional quality management models, the principles and tools that allow the application of advanced systems in the Quality area are presented: the Total Quality Management (TQM) approach, the organization for the TQM, the techniques and tools to apply and sustain the TQM over time (for example Six Sigma, SS, Value stream mapping, PDCA, statistical techniques for quality control). -->Supply Chain Management: the physical structure of the supply networks and the relationships between actors of the same network will be discussed. Furthermore, inter-organizational processes will be analysed. -->Closed loop supply chain and reverse logistics

Examination:
Written test Analysis of case studies: teamwork during the course

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095738/NO

PSYCHOLOGY, POLICY MAKING, AND EDUCATION TO A CIRCULAR ECONOMY

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: Prof. ENRICO RUBALTELLI

Credits: 6 ECTS

Prerequisites:
None

Short program:
- The role of heuristics, emotions, and different thinking systems on how to overcome resistance to fully embrace circular economy. - Basic notions of risk perception and why people may underestimate the impact of our actions on the environment. - Benefits of learning how to develop easy and flexible techniques to modify and improve human behavior. - Benefits of involving future generations in the circular economy paradigm. - The role of family and school context in passing down values of sustainability practices to children.

Examination:
Written exam.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095595/NO

RENEWABLE ENERGY TECHNOLOGIES

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Lecturer: Prof. MICHELE DE CARLI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of applied thermodynamics (laws of thermodynamics, thermodynamic processes, cycles, fluids), heat transfer and energy.

Short program:

Examination:
The exam consists of a written test (comprehensive of numerical exercises and theory questions) (max 28/30) + a group project to discuss in the final lecture (max 2/30).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095318/NO

SYNTHETIC BIOTECHNOLOGY

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Lecturer: Prof.ssa ELISABETTA BERGANTINO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of biochemistry.

Short program:
Introduction to the biological bases of cell and metabolism. Principles and techniques of genetic engineering referred, in particular, to the production of useful molecules and recombinant proteins (enzymes), in procaryotic and eukaryotic expression systems. Well-established host systems (E.coli and yeast) will be described, as used in the lab-scale but also in their extension to the industrial application (3 ECTS). Utilization of whole-cell organisms and enzymatic activities for the production or the degradation of molecules and materials. (2 ECTS) Innovative developments and examples of recent applications using enzymes for the chemical industry (biocatalysis) and for bioremediation (1 ECTS).

Examination:
Written exams with open questions, that will determine half the final grade (15/30). Oral presentations, in classroom, of a scientific article selected by the students among those proposed by the teacher, will contribute for the remaining half (further 15/30).

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095718/NO

THERMODYNAMICS AND CATALYSIS FOR CIRCULAR ECONOMY (C.I.)

Lecturer: Prof. ANTONINO POLIMENO

Prerequisites:
Basic knowledge of mathematics, physics, general & inorganic chemistry, organic chemistry and physical chemistry.

Examination:
Teamwork/oral exam; the student, either alone or in a team, will have the opportunity of reporting on a specific topic, or reading and commenting a reviewed paper

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095590/NO

Moduli del C.I.:
Chemical kinetics: catalytic cycle; catalytic site, single- and multi-site catalysis; TON and TOF; reaction rates and catalytic activity. Homogeneous catalysis in the liquid phase; specific and general acid (or base) catalysis; the Hammet acidity function; metal ions as Lewis acids; hydrolysis and condensation as case histories in acid-base catalysis. Fundamentals of transition metal coordination and organometallic chemistry; hydrogenation and hydroformylation of alkenes as case histories in organometallic catalysis. Gas-solid heterogeneous systems: non-supported and supported catalysts, ingredients and methods of preparation; Heterogeneous catalysts in action: the active surface, adsorption and surface reactions; adsorption isotherms and quasi-equilibrium approximation; Langmuir-Hinshelwood and Elay-Rideal mechanisms; kinetic laws of surface reactions; apparent activation energy and reaction orders in gas-solid catalytic reactions; deactivation of solid heterogeneous catalyst, catalyst lifetime and management. Porous and non-porous catalysts: measuring the pore volume and the specific surface area of a solid; the dispersion and distribution of the active component in a supported catalyst; mass-transport restrictions of the reaction rate; case histories in gas-solid heterogeneous catalysis for environmental control and industrial chemical manufacturing. Catalyst recycling for circular economy. Catalysis in circular economy: chemical recycling of polyethylene terephthalate.

CATALYSIS FOR CIRCULAR ECONOMY (MOD. B)

Lecturer: Prof. MARCO ZECCA

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First and Second semester

Credits: 12 ECTS

Short program:
Chemical kinetics in catalysis: catalytic cycle, catalytic site, single- and multi-site catalysis; TON and TOF; reaction rates and catalytic activity. Homogeneous catalysis in the liquid phase; specific and general acid (or base) catalysis; the Hammet acidity function; metal ions as Lewis acids; hydrolysis and condensation as case histories in acid-base catalysis. Fundamentals of transition metal coordination and organometallic chemistry; hydrogenation and hydroformylation of alkenes as case histories in organometallic catalysis. Gas-solid heterogeneous systems: non-supported and supported catalysts, ingredients and methods of preparation; Heterogeneous catalysts in action: the active surface, adsorption and surface reactions; adsorption isotherms and quasi-equilibrium approximation; Langmuir-Hinshelwood and Elay-Rideal mechanisms; kinetic laws of surface reactions; apparent activation energy and reaction orders in gas-solid catalytic reactions; deactivation of solid heterogeneous catalyst, catalyst lifetime and management. Porous and non-porous catalysts: measuring the pore volume and the specific surface area of a solid; the dispersion and distribution of the active component in a supported catalyst; mass-transport restrictions of the reaction rate; case histories in gas-solid heterogeneous catalysis for environmental control and industrial chemical manufacturing. Catalyst recycling for circular economy. Catalysis in circular economy: chemical recycling of polyethylene terephthalate.

THERMODYNAMICS OF PROCESSES AND MATERIALS (MOD. A)
Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First and Second semester

Credits: 12 ECTS

Short program:
MOD A - I semester - Basic concepts of thermodynamics - systems, - laws of thermodynamics - cycles and processes - Mass and energy conservation principles - Thermodynamics insights on the assessment of circular economy processes through case studies (e.g. food waste, steel production, other materials production, product refurbishment, vehicle provision, construction and equipment manufacture) - Chemical kinetics in solutions: - reaction rate and its dependence on experimental conditions - energy of activation - kinetic laws from reaction mechanisms (elementary reactions, order and molecularity, steady-state approximation, rate determining step, complex mechanisms).

UNDERSTANDING STATISTICS OF CIRCULAR ECONOMY

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: Prof.ssa FRANCESCA BASSI

Credits: 6 ECTS

Prerequisites:
Basic knowledge of math, algebra and calculus.

Short program:

Examination:
Written report on a specific case study and oral examination

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095722/NO

WATER RESOURCES MANAGEMENT IN THE CIRCULAR ECONOMY

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Lecturer: Dott.ssa GIULIA ZUECCO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of mathematics, physics, chemistry.

Short program:
Lectures, practical exercises, and discussion of case studies. • Introduction o Humans, water, and Earth: the actual global challenges • Climate o Climate change and natural disasters (floods and drought) o Hydrological extremes and frequency analysis • Exercises on case studies • Society o Socio-economic impact on Earth: The Great Acceleration o Population dynamics and land use changes o Water scarcity and hydro-political risk o Water pollution - Group work and discussion of case studies • Water resources management o Water for agriculture o Water for urban areas o Water footprint of crops and products - Examples and exercises on the estimation of the water footprint • Sustainable water cycle o Water and ecosystem services o Indicators of hydrological alteration o Integrated watershed management approach o Water for a sustainable socio-economic development: the circular water economy - Group work and discussion of case studies GIS Lab • Lab.1 - Introduction to GIS and remote sensing o Land use changes scenarios o NDVI and water stress • Lab.2 - Digital terrain analysis o Digital Elevation Models o Drainage network analysis

Examination:
Written examination, presentation of a technical report, group work on case studies.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/000ZZ/SCQ1095580/NO

BIOREFINERIES AND SUSTAINABLE ENERGY PRODUCTION AND STORAGE FOR CIRCULAR ECONOMY

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Lecturer: Prof. ANTONINO POLIMENO

Credits: 12 ECTS

Short program:
MOD A - I semester - Basic concepts of thermodynamics - systems, - laws of thermodynamics - cycles and processes - Mass and energy conservation principles - Thermodynamics insights on the assessment of circular economy processes through case studies (e.g. food waste, steel production, other materials production, product refurbishment, vehicle provision, construction and equipment manufacture) - Chemical kinetics in solutions: - reaction rate and its dependence on experimental conditions - energy of activation - kinetic laws from reaction mechanisms (elementary reactions, order and molecularity, steady-state approximation, rate determining step, complex mechanisms).
Lecturer: Prof. TOMAS MOROSINOTTO

Credits: 15 ECTS

Prerequisites:
Basic knowledge of physics and chemistry (as provided by previous courses: General and inorganic chemistry, thermodynamics and chemical kinetics)

Short program:

Examination:
Written test complemented by a teamwork/oral evaluation. The written test will consist of 6-8 open-ended questions and it aims at assessing the student's knowledge of the course contents and ability to synthetically present them. In the teamwork/oral evaluation the student, either alone or in a team, will be asked to develop an innovation project to develop new / improved industrial applications of biomass. The project will be planned to be presented to potential investors / to specific calls of Horizon Europe

More information:

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Lecturer: Prof.ssa ANNA STOPPATO

Credits: 6 ECTS

Prerequisites:
Basic knowledge of chemistry and thermodynamics

Short program:
• Introduction to LCA: from its origins to today, international reference standards, phases of the study. Deepening of ISO 14040-44 requirements: Goal and scope definition, Life cycle inventory, Life cycle impact assessment, Interpretation, conclusions and recommendations. Examples and case studies: application of ISO 14040-44 requirements in different industrial sectors, and focus on circular economy solutions. LCA in the market: Environmental Product Declaration, Carbon Footprint, and other LCA tools. Critical issues and recommendations of LCA methodology and LCA tools in the circular economy. Case studies, practical exercises and computer labs using the Simapro software

Examination:
Written test completed by an oral evaluation. The written test consists of 4 open-ended questions and aims to assess the student’s knowledge of the course contents, the clarity and the ability to synthesize them. The oral evaluation consists in the discussion of the report related to the exercise and has the objective to verify the ability of personal re-elaboration of the acquired knowledge and the ability to apply them to a specific case study.

More information:

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Lecturer: Prof. ARTURO LORENZONI

Prerequisites:
No one specific basic knowledge is required; in general, the skills gained in the previous courses allow to follow the lessons properly

Examination:
The evaluation will be based on written, oral exams and team works. In Module A the student, either alone or in a team, will have the opportunity of reporting on a specific topic, or reading and commenting a reviewed paper. During Module B two written tests during the teaching time. If the vote is > or = 22/30 the vote can be registered, otherwise an oral examination is required.

More information:
Moduli del C.I.:
Energy Economics (Mod. B)
Sustainability strategies and Innovation management for Circular economy (Mod. A)

ENERGY ECONOMICS (MOD. B)

Lecturer: Prof. ARTURO LORENZONI

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Credits: 12 ECTS

Short program:
• Energy sector basic knowledge. • Exhaustible resources economic analysis: the Hotelling rule, the role of financial markets • Prices and market of fossil fuels • Market equilibria under competition, oligopoly and monopoly • Economic evaluation of energy investments; the role of uncertainty. • The electricity sector: organisation and operation • New business models for energy supply

SUSTAINABILITY STRATEGIES AND INNOVATION MANAGEMENT FOR CIRCULAR ECONOMY (MOD. A)

Lecturer: Prof.ssa VALENTINA DE MARCHI

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Credits: 12 ECTS

Short program:
• Introduction to sustainability strategies: analysis of strategic options (matrix Porter’ strategies applied to sustainable product/process). • Sustainability strategies and Corporate Social Responsibility • Managing product and process innovation: introduction to sources of innovation inside/outside the firm, open innovation paradigm. • Innovation in a circular economy framework: Drivers of eco-innovation (regulation, market, technology); circularity (Reduce, reuse, recycle) and product innovation (design, inputs) • Business models for circular economy: definition of business models and analyses of BM in the circular economy framework (circular suppliers, resource recovery, product life extension, sharing platform, product as a service) • Circular economy and value chain: role of buyers, suppliers, customers. Analysis of power and forms of governance in the (global) value chains and environmental sustainability.

CIRCULARITY IN BIOMASS PRODUCTIONS

Lecturer: Prof.ssa MICHELA ZANETTI

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, Second semester

Credits: 6 ECTS

Prerequisites:
Basic knowledge of the LCA method is required (introduced in 1 year, first semester in the course Circular and sustainable waste management; suggested the attendance to the Life Cycle Assessment course)

Short program:
• Introduction to wood (characteristic and properties; differences between softwood and hardwood) • Chemistry of biomass: photosynthesis and respiration • Cellulose, hemicelluloses, lignin and extractives: properties, isolation and applications • Timber supply chains (primary and secondary wood processing industries) • Wood products and related manufacturing and energetic impact of processes (sawn wood, wood panels,…) • Cascade usage of wood: methods to extend the time in which carbon is fixed • Energetic valorisation of wood • Solid biofuels (pellets, briquettes, wood chips and firewood) • Quality certifications of solid biofuel (ISO standard series 17225; ENplus, Biomassplus) • Measure to address air pollution form small combustions sources • Chemical valorisation of biomass: pulp & paper industry and concept of biorefinery • Agricultural systems and by-products/waste • Introduction of different material coming from Agriculture (by-products/waste) • Composition of most important agricultural by-products • Some “successful story” of by-product/waste reuse • The role of wood and agricultural products in the circular economy (team working)

Examination:
Report on a specific case study and written/oral evaluation.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/001PD/SCQ1095715/NO

MATERIALS DESIGN AND SELECTION FOR CIRCULAR ECONOMY

Lecturer: Prof.ssa SILVIA GROSS

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First semester

Credits: 9 ECTS
Prerequisites:
The course includes basic knowledge of organic and inorganic chemistry, physics and materials science. Basic knowledge of mathematics, physics and chemistry (as provided by previous courses)

Short program:
Module 1: Materials in circular economy and eco-informed material choice Introduction to materials: main features (composition, structure, morphology, structure-properties relationships), main classes (metals/alloys, polymers, ceramics/glasses) their relevance in main specific sectors (plastics, building & construction, metals, apparel & textiles, energy conversion and storage) in a circular economy perspective. Eco-informed material choice. Specific topics: -Basics on circular chemistry. -Embedding sustainability in the design/manufacturing of materials. Sankey diagrams of materials flow. -How to address criticality: material design to reduce CRM content and substitution approaches. -Introduction to material properties charts: development and use. Definition of materials indices: performance of a component according to a combination of properties; selection through charts and indices. Presentation of "pure" selection case studies, with discussion of the characteristic equations and derivation of selection indices. Materials selection with conflicting objectives: trade-off analysis. -Environmental impact monitoring methods. Case studies of graphical materials selection oriented to environmental sustainability (control of energy and carbon footprint) in primary production. -Materials life cycle: definition of boundaries, introductory remarks to LCA, principles of eco-auditing. Updates on environmental sustainability from inclusion of manufacturing step. Presentation and analysis of end-of-life options. Case studies of application of eco-audits: introduction to the CES (Cambridge Engineering Selector) software, comparison between disposable and reusable constructions, material substitution -Case studies on cost/environmental sustainability trade-off -Sustainability by means of material minimization: introduction of shape factors, with case studies. Module 2: Design and selection of functional molecules and materials for sustainable synthesis and circularity The module offers an overview of the modern computational tools available to design functional molecules and materials. Those theoretical aspects, which are mandatory to understand the described multi-scale computational strategies encountered in literature, will be concisely presented. During the practical sessions, students will learn how to solve basic computational problems, i.e. electronic structure calculations, computation of structural, thermochemical and spectroscopic, structural properties, description of elementary chemical reactions through hybrid methods in homogeneous and heterogeneous catalysis, and to easily read current literature focused on optimizing in silico circular processes. Fundamentals of quantum chemistry (Density Functional Theory) will be revisited in concise fashion aiming at the comprehension of the main methodological aspects. Molecular mechanics and force fields will be described, to introduce the hybrid DFT/MM approach and discrete solvation models. During the course, application of computational protocols to study chemical bond reactivity and chemical reactions will be discussed. To this purpose, practical examples will be presented to the students in the computing room of the Department of Chemical Sciences. In addition, seminars upon invitation of Italian and foreign experts, working in the field of computational chemistry for circular production, might be included. Module 3 Molecules and materials characterisation -Basics of radiation-matter interaction -Basics of analytical data treatment chemico-physical basics of selected analytical methods for molecules (e.g. UV-Vis, FT-IR, NMR) and materials (e.g. SEM and TEM microscopy, XRD, tomography, XRF)

Examination:
The verification of the expected knowledge is carried out through a written test. The written exam consists of 12 questions, on the whole program of the course. The student will also have the opportunity of preparing and presenting a specific topic of interest, to integrate the written exam.

More information:

**SUSTAINABLE MATERIALS AND RECYCLING FOR CIRCULAR ECONOMY (C.I.)**

Lecturer: Prof. MANUELE DABALA'

Prerequisites:
Basic knowledge of chemistry

Examination:
The verification of the acquired knowledge will take place through an exam for each course module and the method of examination will be detailed at the beginning of the lessons. The exam will assess the knowledge, the scientific lexicon, the ability of synthesis and critical discussion acquired during the course.

More information:
https://en.didattica.unipd.it/off/2022/LM/SC/SC2590/001PD/SCQ1095711/NO

Moduli del C.I.:
New plastics economy: polymers, biopolymers and their recycling (Mod. C)
Recycling and transformation of inorganic materials (Mod. B)
Sustainable mineral (geo)-resources and critical raw materials (CRM) (Mod. A)

**NEW PLASTICS ECONOMY: POLYMERS, BIOPOLYMERS AND THEIR RECYCLING (MOD. C)**

Lecturer: Prof. STEFANO MAMMI

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First and Second semester

Credits: 18 ECTS
Short program:
- Introduction to polymer science: general information on polymers and biopolymers.
- Terminology and elucidation of the concepts of biobased, biopolymers, bioplastics, biodegradability, compostability, biocompatibility, bioinspired, etc. with reference to EU regulation context.
- Examples of biobased/biodegradable polymers.
- Examples of functionalised and chemically modified biobased/biodegradable polymers.
- General overview on methods for the characterisation of polymers and biopolymers (e.g. microscopy-based methods, X-ray based methods, Gel permeation chromatography (GPC), methods for the determination of the molecular weight).
- Methods for the functionalisation and the chemical modification of polymers and biopolymers.
- Identification and sorting of polymers. Italian and European regulation on recovery, recycling and waste management. Reference to SUP European regulation.
- Recycling technologies: mechanical recycling, chemical recycling (solvolysis and thermolysis), waste heat recovery. Examples of recycling of polymers (PET, polyolefins, PS, PVC, thermosets).

RECYCLING AND TRANSFORMATION OF INORGANIC MATERIALS (MOD. B)

Lecturer: Prof. MANUELE DABALA'

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First and Second semester

Credits: 18 ECTS

Short program:
General introduction to recycling and to its relevance in addressing criticality and resource depletion. Metal and alloys: main features. Physics of extractive metallurgy: the stability of oxides and other metal-containing minerals, thermodynamics of reduction processes, thermodynamic costs and benefits of recycling, recycling effectiveness and efficiency (exergy). Metallurgical processing: principles of metal production, selected processing flow sheets (steel, copper-based metal, aluminium, zinc). Metal recycling from residues and end-of-life products: separation methods, steel and stainless-steel recycling, copper-scrap recycling, aluminium recycling, zinc-containing scrap recycling, metals recycling from WEEE (printed wire boards, photovoltaic cells, lamps...)
- Glass main features in terms of composition and structure. Glass technology: raw materials and calculation of batch composition; fusion processes and furnaces. Recycling of glass: collection of glass wastes; separation methods; energy and environmental considerations of glass recycling.

SUSTAINABLE MINERAL (GEO)-RESOURCES AND CRITICAL RAW MATERIALS (CRM) (MOD. A)

Lecturer: to be defined

Master's degree in SUSTAINABLE CHEMISTRY AND TECHNOLOGIES FOR CIRCULAR ECONOMY ORD. 2021, First and Second semester

Credits: 18 ECTS

Short program:
- Elements of economic geology: Reservoir and resources. Geological-economic parameters. The geographic and geological distribution of mineral resources. Classification of mineral resources: ferrous and non-ferrous metals; industrial minerals.
- Mineral resources and sustainability: a new perspective.
- The environmental impacts of mining: extractive wastes generated by prospecting, extraction, treatment and storage of mineral resources and the working of quarries.
- The social impacts and the abuse of human rights associated with the production of "Conflict minerals".
- The raw material-energy nexus: trends in mineral resource consumption; the energy required to produce a mineral resource and associated environmental impacts; the potential of recycling; long-term future trends and perspectives.
- Critical raw materials and the circular economy and in the EU context.
- Circular use of critical raw materials as in the EU list: selected metal recycling process (i.e. Platinum group minerals, Indium, Tantalum, Heavy and Light rare earth elements).