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SCUOLA DI SCIENZE

SCHOOL OF SCIENCE

UNIVERSITY OF PADOVA

CATALOGUE OF ENGLISH LANGUAGE COURSES FOR ERASMUS, FOREIGN AND ITALIAN STUDENTS

ACADEMIC YEAR 2020-2021:

First semester: September 28th, 2020 to January 16th, 2021
Winter exams session: January 18th, 2021 to February 27th, 2021
Second semester: March 1st, 2021 to June 14th, 2021
Summer exams session: June 14th, 2021 to July 17th, 2021
Extra exams session: August 23rd, 2021 to September 18th 2021

ERASMUS MASTER DEGREES AND MASTER DEGREES WITH A PROGRAM OF COOPERATION WITH OTHER EUROPEAN UNIVERSITIES

ALGANT (Algebra, Geometry And Number Theory)
see information on http://lauree.math.unipd.it/algant/

MAPPA (Mathematical Analysis and Probability)
see information on http://mappa.math.unipd.it/

MASTER DEGREES WITH A PROGRAM OF COOPERATION WITH OTHER EUROPEAN UNIVERSITIES FOR COMMON DEGREES

An agreement between the University of Padova and the French Universities Paris Diderot-Paris 7 and Paris Descartes. has been established since the academic year 2010-11 for the release of a common degree between the Master Degree in Molecular Biology and the Master de Sciences Santé et Application. This project requires the mobility of students (up to 6 per year) within the ERASMUS program. More information is available on http://biologia-molecolare.biologia.unipd.it/lauree-magistrali/lm-in-biologia-molecolare/
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SECOND CYCLE DEGREES WITH ALL THE COURSE UNITS HELD IN ENGLISH:

ASTROPHYSICS AND COSMOLOGY

ADVANCED ASTROPHYSICS
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Andrea Paola Marigo
Credits: 6 ECTS
Prerequisites:
General astrophysics, fundamentals of radiative processes and stellar evolution

Short program:

Examination:
Written and/or oral examination

More information:

ASTROPHYSICS LABORATORY 1: HIGH ENERGY INSTRUMENTATION
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Eugenio Alessio Bottacini
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 which includes supermassiva black holes, accretion disks, neutron stars, supernovae remnants
5) fitting of data, simulating 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/2020/LM/SC/SC2490/000ZZ/SCQ0093339/N0

**ASTROPHYSICS LABORATORY 1: INFRARED AND OPTICAL INSTRUMENTATION**
Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Roberto Ragazzoni
Credits: 6 ECTS

**Prerequisites:**
Fundamentals of Physics and Astronomy.

**Short program:** ...
1) Basic principles of optics and image formation: Nature of light and geometrical nature of thin lenses and of conical sections. Concept of stigmatic and non stigmatic imaging. Optical copies and Lagrange invariant. Relevance of the position and size of the stop in an optical system and its effects on the overall property.
2) Two mirrors telescope: Schwarzschild, Cassegrain, Gregorian and Ritchey-Chretienne solutions. The problem of the background in astronomical imaging and in particular in the infrared. Definition of the thermal and non-thermal infrared portion of the spectra. Vignetting and field of view in Cassegrain telescopes. Difference between images formed by parabolic and spherical mirrors and the case of Arecibo-like design. Examples of telescopes and instrumentation employing the various concepts devised.
4) Detectors: Charge Coupled Devices Detectors, principles of working and basic parameters. Quantum efficiency, charge transfer efficiency, read out noise. CCD principle of working and effects on the Poissonian apparent noise. Concept of the avalanche photo diodes and quenching.
5) Experiments in the optical laboratory: Poisson's spot, turbulence simulation and speckle formations.
6) Observations at the Asiago Astronomical Observatory: Speckle interferometry.

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

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCQ0093338/N0

**ASTRO-STATISTICS AND COSMOLOGY**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Michele Liguori
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.


Short program: ...
Applications: power spectrum estimation in cosmological datasets (Cosmic Microwave Background and Large Scale Structure), MCMC for cosmological parameter estimation, component separation, Gravitational Wave data analysis, Fisher matrix forecasting for future cosmological surveys.

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


ASTROPHYSICS LABORATORY 2

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Luca Malavolta
Credits: 6 ECTS

Prerequisites:
Basic knowledge of astronomy and astrophysics. Basic knowledge of stellar evolution. Basic knowledge of stellar photometry and spectroscopy.

Short program: ...
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.
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: ...
Valutazione delle relazioni sulle esperienze di laboratorio ed esame orale.

More information:

ASTROPHYSICS OF THE INTERSTELLAR MEDIUM
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: 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) Magneto-hydrodynamics, Alfvén waves, Galactic magnetic field; generalized virial theorem; ambipolar diffusion
5) Numerical techniques for the solution of the magneto-hydrodynamic 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/2019/LM/SC/SC2490/000ZZ/SCP9086353/N0

COMPACT OBJECT ASTROPHYSICS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Giovanni Carraro
Credits: 6 ECTS
Prerequisites:
Classical electrodynamics, special relativity, general astronomy and astrophysics

Short program: ...
Compact objects. Late stages of stellar evolution, core-collapse supernovae. White dwarfs, neutron stars and black holes.
layer.

Examination: ...
Oral examination

More information:

COSMOLOGY OF THE EARLY Universe

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: 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

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2490/000ZZ/SCP7081761/N0

EXOPLANETARY ASTROPHYSICS

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Giampaolo Piotto
Credits: 6 ECTS
Prerequisites:
Basic knowledge (at bachelor level) of Physics, Astronomy and Astrophysics.
Short program: ...
Overview of the Solar systems planets and satellites
Exoplanet search techniques.
Programs for the search for exoplanets, groundbased and from space, present and future.
General physical properties of exoplanets.
Exoplanets and extrasolar planetary systems of particular interest.
Search and characterization projects of exoplanets and exoplanetary systems using: radial
velocity, photometry, astrometry, transiting time variations and other methods.
Exoplanet formation.
Examination: ...
Oral exam on the course program
More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2490/000ZZ/SCP9086352/N0

FLUID AND PLASMA DYNAMICS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Tommaso Bolzonella
Credits: 6 ECTS
Prerequisites:
Nessuno
Short program: ...
The course presents, at an advanced level, some of the main subjects of the physics of fluids
and plasmas.
During the course examples and applications from both astrophysics and controlled fusion
will be presented.

Introduction
Fluids and plasmas in nature and laboratory. Characteristics and limitations of theories
describing neutral fluids and plasmas. Non-collisional Boltzmann equation.

Neutral fluids
Collisional Boltzmann equation.
Moment equations and fluid dynamics derivation.
Ideal fluids; macroscopic derivation of fluid dynamics.
Viscous flows.
Linear theory of waves and instabilities. Perturbative approach.
Turbulence in neutral fluids; Kolmogorov theory.

Plasmas
Basic properties of plasmas; plasmas in nature and laboratory.
Plasma orbit theory.
Dynamic of many charged particles.
Kinetic theory of plasmas, BBGKY hierarchy, Vlasov equation.
Two fluid model.
Collisionless processes in plasmas; Landau damping.
Collisional processes and the one-fluid model.
Diffusion and transport.
Basic magnetohydrodynamics; some simple examples of MHD instabilities.
Theory of magnetic topologies; magnetic reconnection; Sweet-Parker model. Magnetic
helicity.
Dynamo theory. Parker’s turbulent dynamo. Mean field magnetohydrodynamics.
Examination: ...
FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY (ALSO OFFERED IN THE MASTER DEGREE IN PHYSICS - EXAM OF THE FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY / IN THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF THE PHYSICAL UNIVERSE)

Master degree in Astrophysics and Cosmology, First semester
Lecturer: 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.
* Shortcomings of the standard cosmological model: horizon, flatness problems, etc.
• 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.
* 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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCP9086381/N0

**FUNDAMENTALS OF MODERN PHYSICS**
Master degree in **Astrophysics and Cosmology**, First semester
Lecturer: Chiara Maurizio
Credits: 6 ECTS

**Prerequisites:**
Fundamentals of quantum physics and structure of matter.

**Short program:**
1) Solution of the Schroedinger equation for a system of two particles in a central potential. Spherical harmonics and radial solution. Relevant expectation values. Virial theorem for a one-electron atom.
2) Time independent perturbation theory (non degenerate and degenerate case). Examples. Time-dependent perturbation theory: perturbation switched on at to and then constant, periodic perturbation. Rabi frequency.
5) Photoelectric effect: cross section for one-electron atom in 1s state. Comparison with experimental data.
6) Scattering: differential cross section for elastic and inelastic (Rayleigh and Thomson) scattering. Partial waves and corresponding cross section calculation.
8) Zeeman effect: normal (examples, observed transitions and polarization, Paschen-Bach case), anomalous, case of ultra strong magnetic fields.
9) Stark-Lo Surdo effect for one-electron atoms: linear (n=1, n=2) and quadratic (n=2). Atomic static polarizability. Quenching of the 2s state of hydrogen. Ionization induced by an electric field.
10) Many-electron atoms. Triplet and singlet states. Pauli exclusion principle (strong and


12) Correction to the central field: L-S coupling (examples of electronic configuration, degeneracy.). j-j coupling.


14) Quantum statistics, occupation index: Bose-Einstein and Fermi-Dirac cases with examples.

**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 exam is passed if both partial exams have a sufficient score.

The full exam is made of a written part (organized similarly to the partial exams) plus an oral exam (needed only if the score of the written exam is <=21).

**More information:**

https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCP9086380/N0

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**GENERAL RELATIVITY FOR ASTROPHYSICS AND COSMOLOGY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS – EXAM OF GENERAL RELATIVITY AND IN PHYSICS OF DATA – EXAM OF GENERAL RELATIVITY)**

Master degree in Astrophysics and Cosmology, First semester

Lecturer: Marco Peloso

Credits: 6 ECTS

**Prerequisites:**

Knowledge of Special Relativity

**Short program:**

1. Preliminaries


3. Gravity as Geometry


4. The Einstein equations

Parallel transport and curvature. Covariant derivative, Riemann, Ricci, and Einstein tensor. The source of curvature. Einstein equations and weak field approximation.

5. Geodesics

The geodesic equation. Symmetries and Killing vectors. Local inertial frames and freely falling frames.

6. Schwarzschild Geometry


7. Horizons and Coordinate Systems
8. Rotations and Kerr Geometry
Geodetic precession around a non-rotating, and a slowly rotating body. Kerr metric and the ergosphere.
9. Cosmology
10 Gravitational waves (if time permits)

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

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCQ0093378/N0

HIGH ENERGY ASTROPHYSICS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Astrophysics and Cosmology, First semester
Lecturer: Alberto Franceschini
Credits: 6 ECTS

Prerequisites:
The mandatory courses of 1st year of the Master Degree in Astronomy.

Short program: ...
6) Cosmic rays and acceleration mechanisms: Observational properties of cosmic rays. Fermi first-order and second order acceleration mechanisms.


11) Cosmic photon-photon and particle-photon opacities: Extragalactic background radiations, background energy density. Photon opacity, applications to observations.

**Examination:** ...

Oral discussion on the topics discussed during lectures.

**More information:**

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**MATHEMATICAL AND NUMERICAL METHODS**

Master degree in **Astrophysics and Cosmology**, First semester

Lecturer: Michela Mapelli

Credits: 6 ECTS

**Prerequisites:**


**Short program:**

Each lecture will consist in a part of theory and a part of exercises.

1. Brief summary of the linux operating system.
2. Brief summary of python programming.

6. Random numbers (random generators, uniform deviates, inversion method, rejection method); examples of random generation of astrophysical distributions.
7. Integration of functions (e.g. Monte Carlo method, trapezoidal rule).
8. Integration of ordinary differential equations (Euler scheme, Leapfrog scheme, Runge-Kutta scheme, Bulirsch-Stoer algorithm, Hermite scheme); examples: evolution of a binary system by gravitational wave emission; the astrophysical N-body problem.
10. Fourier transforms: the discrete Fourier transform, the fast Fourier transform.
11. Interpolation and extrapolation (linear, polynomial, cubic spline); application to an astrophysical sample.
13. Advanced python libraries for scientific data handling (e.g. astropy, pandas).
Examining:
Written exam (unless the covid-19 emergency requires to switch to an oral examination).

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCP9086342/N0

OBSERVATIONAL ASTROPHYSICS
Master degree in Astrophysics and Cosmology, First semester
Lecturer: 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.
9) General characteristics of the planet Mars. Comparison with the Earth.
10) Basic principles of the extrasolar planets detection techniques.
11) The gas in the Galaxy. HI 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:

ASTRONOMICAL INTERFEROMETRY
Master degree in Astrophysics and Cosmology, Second semester
Lecturer: 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/2020/LM/SC/SC2490/000ZZ/SCP9086348/N0

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**ASTRONOMICAL SPECTROSCOPY**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: 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/2020/LM/SC/SC2490/000ZZ/SCN1035986/N0

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**ASTROPARTICLE PHYSICS**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: 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
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) Cosmological Models: De Sitter model; Standard cosmological model; FLRW metrics and Friedmann equations; the cosmological constant
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) 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/2020/LM/SC/SC2490/000ZZ/SCP7081703/N0

**ASTROPHYSICS OF GALAXIES**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Alessandro Pizzella
Credits: 6 ECTS

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

**Short program:**
1) Luminosity function of galaxies. Spectroscopic and photometric classification of galaxies at high redshift. Effect of the environment. Main extragalactic surveys from space and ground-based telescopes. The local group and the nearby universe.
2) Galaxy kinematics with integral field spectroscopic, 5 hours
4) Scaling relations in spiral galaxies: Tully-Fisher relation and its evolution with redshift. Low and high surface brightness disks.
5) Galaxy clusters and dark matter distributions: Mass of galaxy clusters with X ray halos and gravitational lensing. Dark matter properties in galaxies and clusters.
6) Supermassive black holes in the center of galaxies.

**Examination:**
Oral exam.
CELESTIAL MECHANICS (ALSO OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING – EXAM COMPUTATIONAL ASTODYNAMICS)
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: 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:**
1) The equations of motion of gravitating systems.
2) The Two-Body Problem and an initial value problem (IVP).
3) The Two-Body Problem and a boundary value problem (BVP).
4) Orbital maneuvers.
5) Space and time reference systems.
6) The computation of a Keplerian ephemeris.
7) Preliminary orbit determination.
8) Keplerian relative motion and its generalization.
9) Regularization and Universal Formulation of the Two-Body Problem.
10) The TBP as a boundary value problem (BVP) – Lambert targeting.
11) The Problem of Three Bodies and its homographic solutions.
13) The theory of Patched Conics and the design of gravity-assist interplanetary trajectories.
14) Elements of perturbations and a the motion of an artificial Earth satellite.

**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/2020/LM/SC/SC2490/000ZZ/SCN1035988/N0

GALACTIC DYNAMICS
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: Enrico Maria Corsini
Credits: 6 ECTS

**Prerequisites:**

**Short program:**
1) Overview of the properties of galaxies: Morphology. Photometry. Kinematics. Scaling relations.
Stable and unstable orbits. Orbits in a two-dimensional nonaxisymmetric rotating potential. Jacobi integral. Lagrangian points. Corotation. Families of orbits x1, x2, x3, x4. Introduction to the orbits in a three-dimensional triaxial potential. 


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

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCP9086385/N0

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**GRAVITATIONAL PHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS AND IN PHYSICS OF DATA – EXAM OF RELATIVISTIC ASTROPHYSICS)**

Master degree in **Astrophysics and Cosmology**, Second semester

Lecturer: Giacomo Ciani

Credits: 6 ECTS

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

**Short program:**
Elements of general relativity. Gravitational waves (GW) in linearized theory; TT-gauge and detector frame; interaction with free falling masses and rigid bodies.

Generation of GW. Quadrupole and post-newtonian approximations. Energy and momentum loss by gravitational wave emission. Examples of GW sources: stable and coalescing binary systems, rotating rigid bodies, extreme mass-ratio inspirals.

GW detection. Hulse-Taylor system. Fundamentals of stochastic signals and noise theory.

Resonant bars detectors. Modern GW interferometers: basic principle, noise sources, fundamental and technical limitations. Future GW experiments. Elements of data analysis.


**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/2020/LM/SC/SC2490/000ZZ/SCP708179/N0

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**MULTIMESSENGER ASTROPHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS – EXAM MULTIMESSENGER ASTROPHYSICS)**

Master degree in **Astrophysics and Cosmology**, Second semester

Lecturer: Elisa Bernardini

Credits: 6 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 types of particles and 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 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 witnessed the triumph of multi-messenger astrophysics with 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). This event happened just few days after another success of multi-messenger astrophysics: the detection of gravitational waves from two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A).

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/2020/LM/SC/SC2490/000ZZ/SCP7081762/N0

**NUCLEAR ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: Paola Marigo
Credits: 6 ECTS

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2490/000ZZ/SCP7081704/N0

**OBSERVATIONAL COSMOLOGY**
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: Alberto Franceschini
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:**

2) The large scale structure of the Universe: Local properties. Angular and spatial correlation functions. Higher order correlations. Limber relation. Power-spectrum of the cosmic structures. Relationship of the power-spectrum and $\xi(r)$. Observational data on the large scale structure. The initial power-spectrum of the perturbations. 3D mapping of galaxies, clusters, AGNs. Counts-in-cells. Outline of fractal and topological analyses of the large-scale structure of the universe.


**Examination:**
Oral discussion
PLANETARY ASTROPHYSICS
Master degree in Astrophysics and Cosmology, Second semester
Lecturer: 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.
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 fluid dynamics 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/2020/LM/SC/SC2490/000ZZ/SCP7081805/N0

RADIATIVE PROCESSES IN ASTROPHYSICS
Master degree in Astrophysics and Cosmology, Second semester
Lecturer: Roberto Turolla
Credits: 6 ECTS
Prerequisites:
Classical electrodynamics, special relativity, general astronomy and astrophysics
Short program:
The radiation field
Bremsstrahlung
Synchrotron radiation. Cyclotron and synchrotron power. Synchrotron emission spectrum for
a single charge and for a power-law energy distribution of electrons. Polarization of
Selection rules. Transition rates, bound-bound and bound-free transitions for Hydrogen. Line
broadening mechanisms.

**Examination:**
Oral examination

**More information:**

**SELECTED TOPICS IN MODERN ASTROPHYSICS** *(nuovo insegnamento)*
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: da definire
Credits: 6 ECTS

**Prerequisites:**
Da fare

**Short program:**
Da fare

**Examination:**
Da fare

**More information:**

**STELLAR ASTROPHYSICS**
Master degree in **Astrophysics and Cosmology**, Second semester
Lecturer: Antonino Milone
Credits: 6 ECTS

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

**Short program:**
1) Color-magnitude diagrams: transformation luminosity-magnitude and color-temperature, bolometric corrections, effect of reddening, metallicity and chemical composition.
2) Definition of stellar population. historical background, present-day view. Stellar clusters as prototype of simple populations. The initial mass function.
3) Determination of the physics and structure parameters of stellar population from photometry (age, reddening, metallicity).
4) Chemical composition of stellar populations.
5) Binaries, Blue Stragglers, X-ray Binaries, black holes and other exotic objects in star clusters.
6) Population III stars. Hunting the first stars of the Universe.
7) The Galactic halo
   - Ultra faint dwarfs
   - Dwarf galaxies
   - Globular clusters. Multiple stellar populations. Horizontal branch and second-parameter problem.
8) Galactic Bulge.
9) Thin and thick disk.
   Open clusters. Multiple stellar populations in Magellanic Clouds clusters and the eMSTO phenomenon. Solar neighbours.
10) Star formation history in dwarf galaxies and in the Milky Way.

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

More information:

**SUBNUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: 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:**
Introduction and recap
Tools for calculation
Detectors for particle physics experiments
Cross section e+e-→μ+μ- and e+e-→hh
Deep Inelastic Scattering
The Gluon
QCD, Partons and jets
Electroweak interaction: introduction
Experimental tests of Electroweak interaction
Cabibbo Theory and Cabibbo-Kobayashi-Maskawa Matrix
CP and T violation, the B meson system. Tests of CKM
Neutrino and Standard Model
Higgs Properties

**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/2020/LM/SC/SC2490/000ZZ/SCP7081697/N0

**THEORETICAL COSMOLOGY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS OF DATA – EXAM OF COSMOLOGY)**
Master degree in *Astrophysics and Cosmology*, Second semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS

**Prerequisites:**
Fundamentals of Cosmology and Astrophysics

**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 gravitazional 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/2020/LM/SC/SC2490/001PD/SCP9086384/N0

**THEORETICAL PHYSICS**
Master degree in Astrophysics and Cosmology, Second semester
Lecturer: Stefano Rigolin
Credits: 6 ECTS

**Prerequisites:**

**Short program:**
1. Classical and quantum mechanics of particles.
   Lagrangian, action, principle of least action, Hamiltonian, Poisson brackets, Quantization, Symmetries in Quantum Mechanics, Schroedinger, Heisenberg and interaction picture.
2. Classical field theory.
   Noether’s theorem, Spacetime symmetries and conserved quantities, internal symmetries and conserved charges.
4. Scalar field.

Classical and quantum complex scalar field. Internal symmetry and conserved charge. The scalar propagator.

5. Spinors.
Lorentz group and its representations. Spinor fields. Lagrangian for a Dirac spinor field.

Lorentz gauge. Gauge fixing. Lagrangian and Hamiltonian densities in the Feynman gauge.

7. Interactions.
Interactions in a classical field theory. The S-matrix expansion and transition probability. T-products.

8. QED.
S-matrix expansion in QED. Feynman diagrams in coordinate space and in momentum space.

**Examination:**
Written. Solution of one or more problems.

**More information:**

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**CYBERSECURITY**

**CYBERSECURITY AND CRYPTOGRAPHY: PRINCIPLES AND PRACTICES (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER ENGINEERING [; MATHEMATICS; ICT FOR INTERNET AND MULTIMEDIA; COMPUTER ENGINEERING; COMPUTER SCIENCE EXAM OF CRYPTOGRAPHY)**

Master degree in Cybersecurity, Annual

Lecturer: 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. Migliardi; 6 credits): OS, Programming.

**Short program:**
Key exchange, Key exchange in three steps, secret splitting, secret sharing, secret broadcasting, timestamping. Signatures with RSA and discrete log.

For the second part (Prof. Conti and Prof. Migliardi; 6 credits):

**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. Migliardi; 6 credits): Written Exam, Homeworks, oral test.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCQ0089579/N0

**COGNITION AND COMPUTATION (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COGNITIVE NEUROSCIENCE AND CLINICAL NEUROPSYCHOLOGY AND DATA SCIENCE)**

Master degree in **Cybersecurity**, First Semester

Lecturer: Marco Zorzi

Credits: 6 ECTS

**Prerequisites:**
The course requires preliminary knowledge of machine learning and probability theory. Familiarity with basic concepts of cognitive psychology 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 elaborating one topic assigned during the course, which must be hand over on the day of the written exam.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCQ0089498/N0
COMPUTER AND NETWORK SECURITY: ADVANCED TOPICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE EXAM OF COMPUTER AND NETWORK SECURITY)

Master degree in Cybersecurity, First Semester
Lecturer: 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/2020/LM/SC/SC2542/000ZZ/SCQ0089598/N0

HUMAN COMPUTER INTERACTION (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN APPLIED COGNITIVE PSYCHOLOGY EXAM OF HUMAN COMPUTER INTERACTION)

Master degree in Cybersecurity, First Semester
Lecturer: 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
Detailed examples and training on research methods and techniques for the design and the evaluation of interactive systems will be discussed during lessons.

**Examination:**

NOT ATTENDING: The exam will be oral with 3 questions on the book, one of which is proposed as an exercise (see the book for examples). In case of Corona Virus Emergency the oral exam will be given on-line.

ATTENDING: The exam will be based on a personal research work to be carried out during the course as homework and on a short oral presentation and discussion test. A report will summarize the work done in a similar way to a scientific paper or a professional report. The research to be developed will be summarized in a report that will include the following points:

1. Introduction, theoretical contextualization, benchmarking
2. Design / co-design process
3. Prototype development / modification (for those with less technical experience there are solutions)
4. Evaluation - data analysis (ex: UX, usability, presence, acceptance)
5. Results - final discussion.

Any technology may be developed / adopted for research as long as it is interactive (e.g. web, robot, virtual / augmented reality, smart home devices, work tools, Arduino tools, vehicles, musical instruments, mobile / tablet apps).

**More information:**

https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCP7079403/N0

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**INFORMATION SECURITY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA EXAM OF INFORMATION SECURITY)**

Master degree in Cybersecurity, First Semester

Lecturer: Nicola Laurenti

Credits: 6 ECTS

**Prerequisites:**

The class requires previous basic knowledge in:
1. Communication or computer networks.
2. Digital communications
3. Algorithms and computational complexity
4. Statistics, probability, and information theory

**Short program:**

The exam is split into two parts:
1. A written exam with analytical questions and quantitative problems
2. A traditional oral exam on the class topics

The student must first take the written exam. If he/she passes the written exam, the student is admitted to the oral exam, after which he will obtain his/her final grade.

**Examination:**

The exam is split into two parts:
1. A written exam with analytical questions and quantitative problems
2. A traditional oral exam on the class topics

The student must first take the written exam. If he/she passes the written exam, the student is admitted to the oral exam, after which he will obtain his/her final grade.

**More information:**

https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCQ0089463/N0
LAW AND DATA (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN DATA SCIENCE EXAM OF LAW ANDA DATA)
Master degree in Cybersecurity, First Semester
Lecturer: Elisa Spiller
Credits: 6 ECTS
Prerequisites:
No prerequisites
Short program:
- the concept of data; personal, sensitive and economic data; big data
- the concepts of identity and digital identity
- property of data, choices in the management of data
- supranational, international and national laws on data processing
- civil and criminal protection of privacy
- new contents and concepts of privacy: big data, cell phones; videos; wearable technologies, etc.
- the right to be forgotten
- social network, right to be forgotten, responsibility
- provider's criminal responsibility
- civil and criminal aspects of profiling activity
- automatic data processing, human responsibilities
- big data (collection, analysis, processing) and their influence on fundamental rights
- the issue of genetic data
- big data and economy
- phishing
- financial crimes and artificial intelligence
Examination:
Written Exam
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCP7079399/N0

MACHINE LEARNING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER ENGINEERING EXAM OF MACHINE LEARNING)
Master degree in Cybersecurity, First Semester
Lecturer: Fabio Vandin
Credits: 6 ECTS
Prerequisites:
Short program:
Motivation; components of the learning problem and applications of Machine Learning. Supervised and unsupervised learning.
PART I: Supervised Learning
1. Introduction: Data, Classes of models, Losses.
2. Probabilistic models and assumptions on the data. The regression function. Regression and Classification.
3. When is a model good? Model complexity, bias variance tradeoff/generalization (VC dimension, generalization error).
5. Classes of nonlinear models: Sigmoids, Neural Networks.
6. Kernel Methods: SVM.
8. Validation and Model Selection: Generalization Error, Bias-Variance Tradeoff, Cross Validation. Model complexity determination.

PART II: Unsupervised learning
2. Dimensionality reduction: Principal Component Analysis (PCA).

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/2020/LM/SC/SC2542/000ZZ/SCP8082660/N0

SERVICE MANAGEMENT (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ENTREPRENEURSHIP AND INNOVATION EXAM OF SERVICE MANAGEMENT)
Master degree in Cybersecurity, First Semester
Lecturer: Marco Ugo Paiola
Credits: 6 ECTS

Prerequisites:
None

Short program:
[3] Service innovation and technology: using data and I4.0 technologies to improve the firm’s service footprint and renovate the business models
[4] 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:
For attending students:
Final marks will be based on: a team work that will be evaluated and presented at the end of the course; a written individual exam, based on selected chapters of the textbook, topics presented and discussed in classroom, and additional readings and case studies.
For NON-attending students:
Non-attending students will take a written exam based on the readings (textbook and selected scientific papers, see below).

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCQ0089465/N0
BIG DATA COMPUTING (Numerosita' canale 1)
Master degree in Cybersecurity, Second Semester
Lecturer: 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
Programming frameworks: MapReduce/Hadoop, Spark
Clustering
Association Analysis
Graph Analytics (metriche di centralità, scale-free/Power-law graphs, fenomeno dello small world, uncertain graphs)
Similarity and diversity search
Examination:
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 3-4 students, and of an individual written test comprising both theory questions and exercises.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCP7079297/N2CN1

BIG DATA COMPUTING (Numerosita' canale 2)
Master degree in Cybersecurity, Second Semester
Lecturer: 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
Programming frameworks: MapReduce/Hadoop, Spark
Clustering
Association Analysis
Graph Analytics (metriche di centralità, scale-free/Power-law graphs, fenomeno dello small world, uncertain graphs)
Similarity and diversity search
Examination:
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 3-4 students, and of an individual written test comprising both theory questions and exercises.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCP7079297/N2CN2

BIOMETRICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA EXAM OF BIOMETRICS)
Master degree in Cybersecurity, Second Semester
Lecturer: Simone Milani
Credits: 6 ECTS

Prerequisites:
In order to attend the course, students must possess a basic knowledge in Calculus and Probability Theory.
Attendees will have the opportunity of testing their preliminary knowledge with an online test.
Basic knowledge of Matlab software is required.

Some preliminary knowledge on computer vision and machine learning can be useful (although not strictly necessary). Such topics are described in detail within the Computer Vision and Machine Learning courses.

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 Gait analysis

b.7 Other biometric measurements

**Examination:**
Final evaluation will be performed by means of a written exam and the development of a final report (concerning one of the lab sessions chosen by the student). 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/2020/LM/SC/SC2542/000ZZ/SCQ0089500/N0

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**DEEP LEARNING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE EXAM OF DEEP LEARNING))**

Master degree in *Cybersecurity*, Second Semester
Lecturer: 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 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/2020/LM/SC/SC2542/000ZZ/SCP9087561/N0

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**DIGITAL FORENSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA EXAM OF DIGITAL FORENSICS)**

Master degree in *Cybersecurity*, Second Semester
Lecturer: Simone Milani
Credits: 6 ECTS

**Prerequisites**
In order to attend the course, students must possess 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). Basic knowledge of Matlab software is required.

Some preliminary knowledge on image processing, local descriptors, and data classification are required. Such topics are described in detail within the Computer Vision and Machine Learning course. In case students did not attend the mentioned course, they can be provided with some online material to compensate the missing knowledge.

**Short program:**
Introduction to digital forensics. Data processing in legal issues.

a.1) Disk forensics.
   a.1.1. Introduction, identification of evidences, data seizure and acquisition, authentication, processing and analysis, documenting the results. Maintaining the "Chain of Evidence".
   a.1.2. Disk encryption, data encryption cracking, malicious use of encryption (ransomware).

a.2) Network forensics.
   a.2.1. Data transmission protocols and web servers.
   a.2.2. Data tapping strategies: eavesdropping by sniffing, router information processing, server logs analysis, wireless traffic collection and processing, eavesdropping by malware.
   a.2.3. Intrusion detection.
   a.2.4. Identity theft and phishing.
   a.2.5. Anti-forensics strategies: encryption and obfuscation. The TOR protocol.

a.3) Multimedia forensics.
   a.3.1. The acquisition of multimedia data. Digital camera and microphone models.
   a.3.2. Image/Video source authentication from noise (PRNU) or firmware identification (CFA interpolation, compression strategies).
   a.3.3. Multimedia data embedding: steganography and steganalysis, watermarking.
   a.3.5. Real cases examples.
   a.3.6. Audio source authentication. Audio tampering and its detection.

a.4) Social network forensics.
   a.4.1. Data sharing and diffusion on social networks.
   a.4.2. Social network data pool: social footprint, communication pattern, images and videos, activity, applications.
   a.4.3. Strategies for user identification, localization (space and time), and profiling.

b.1) Cybercrimes
   b.1.1. Fundamentals of criminal law: constitutional principles; definition of crime; essential elements of crime.
   b.1.2. Sources of international and supranational law on the prevention and repression of cybercrime. The transnational character of cybercrime.
   b.1.3. Definition of cybercrime; distinction between cybercrime in a narrow sense (computer crime) and cybercrime in a broader sense (computer-related crime).
   b.1.4. Analysis of some types of cybercrimes, in particular: unauthorized access to computer or telecommunications systems; illicit possession and diffusion of access codes; illegal
interception, interruption or hindrance of computer or telecommunications systems; damages to computer systems and data; 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. Pretrial, reactive and proactive investigations.

b.2.3. Means for obtaining evidence. Inspections, searches, seizures, interceptions of conversations or communications.

b.2.4. Clone copy. Beat stream image.

b.2.5. The role of the digital forensics expert and the right 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/2020/LM/SC/SC2542/000ZZ/SCQ0089501/N0

**MOBILE AND IOT SECURITY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE EXAM OF MOBILE AND IOT SECURITY)**
Master degree in **Cybersecurity**, Second Semester
Lecturer: Eleonora Losiouk
Credits: 6 ECTS

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

**Short program:**


**Examination:**
Written

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2542/000ZZ/SCQ0089502/N0

**QUANTUM INFORMATION AND COMPUTING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA EXAM OF QUANTUM INFORMATION AND COMPUTING)**
Master degree in Cybersecurity, Second Semester
Lecturer: 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:
- two homeworks (20%)
- two reports on lab activity (20%)
- oral (60%)
The final grade will be the weighted average with the above reported percentage

**More information:**

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**STOCHASTIC PROCESSES**
Master degree in Cybersecurity, Second Semester
Lecturer: 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:**

**VISION AND COGNITIVE SERVICES (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE EXAM OF VISION AND COGNITIVE SERVICES)***

Master degree in Cybersecurity, Second Semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS

**Prerequisites:**
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

**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.

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- 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 teacher, 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/2020/LM/SC/SC2542/000ZZ/SCP9087563/N0

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**DATA SCIENCE**

**BIOINFORMATICS (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in Data Science, First semester
Lecturer: 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.

**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP7079405/N0

**BIOLOGICAL DATA**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in **Data Science**, First semester

Lecturer: Silvio Tosatto

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/2019/LM/SC/SC2377/000ZZ/SCP7079337/N0
BUSINESS ECONOMIC AND FINANCIAL DATA
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Data Science, First semester
Lecturer: Mariangela Guidolin
Credits: 6 ECTS
Prerequisites:
Basic statistics: descriptive statistics and probability. Inferential statistics: estimation, confidence intervals and hypothesis testing.
Short program:
Decomposing and analysing economic time series: latent component approaches and ARMA modelling.
Enhancing the analysis of economic and financial time series data: some case studies.
Business and marketing data analyses: the joint use of cross-sectional and temporal dimension and the introduction of dynamic modelling.
Examination:
Homework and Final Presentation.
More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP7079231/N0

COGNITION AND COMPUTATION SERVICES (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN CYBERSECURITY)
Master degree in Data Science, First semester
Lecturer: Marco Zorzi
Credits: 6 ECTS
Prerequisites:
The course requires preliminary knowledge of machine learning and probability theory. Familiarity with basic concepts of cognitive psychology 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 elaborating one topic assigned during the course, which must be hand over on the day of the written exam.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCQ0089498/N0

FUNDAMENTALS OF INFORMATION SYSTEMS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MOLECULAR BIOLOGY ORD. 2020))
Master degree in Data Science, First semester
Lecturer: 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). Eventually, at the end of this submodule students will be able to implement all the stages of a typical machine learning pipeline: from collecting data to building predictive models for solving either a classification or a regression problem.
- Databases
  This submodule is dedicated to data storage, and it covers the following topics:
  - Architecture of Database management systems (DBMS). Relational modelling.
  - Logical and Physical Design of a Relational Database.
  - Basic Principles of Normalization.
  - 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:
  Analysis of algorithms: correctness and running time. Asymptotic analysis.

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:
The student is expected to pass a written and an oral exam.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCP7078720/N0

GAME THEORY (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Data Science, First semester
Lecturer: Elvina Gindullina
Credits: 6 ECTS

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

Short program:
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons
Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle
Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization
Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value
Resource allocation
Utilities, choices, and paradoxes
Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems

**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:**

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**HIGH DIMENSIONAL PROBABILITY FOR DATA SCIENCE**

Master degree in **Data Science**, First semester

Lecturer: 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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCQ0093688/N0

HUMAN COMPUTER INTERACTION (OFFERED IN THE MASTER DEGREE IN APPLIED COGNITIVE PSYCHOLOGY)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Data Science, First semester
Lecturer: 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
14 Introducing Evaluation 495
15 Evaluation Studies: From Controlled to Natural Settings
Detailed examples and training on research methods and techniques for the design and the evaluation of interactive systems will be discussed during lessons.

**Examination:**

NOT ATTENDING: The exam will be oral with 3 questions on the book, one of which is proposed as an exercise (see the book for examples). In case of Corona Virus Emergency the oral exam will be given on-line.

ATTENDING: The exam will be based on a personal research work to be carried out during the course as homework and on a short oral presentation and discussion test. A report will summarize the work done in a similar way to a scientific paper or a professional report. The research to be developed will be summarized in a report that will include the following points:

1. Introduction, theoretical contextualization, benchmarking
2. Design / co-design process
3. Prototype development / modification (for those with less technical experience there are solutions)
4. Evaluation - data analysis (ex: UX, usability, presence, acceptance)
5. Results - final discussion.

Any technology may be developed / adopted for research as long as it is interactive (e.g. web, robot, virtual / augmented reality, smart home devices, work tools, Arduino tools, vehicles, musical instruments, mobile / tablet apps).

**More information:**

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**LAW AND DATA (OFFERED IN THE MASTER DEGREE IN CYBERSECURITY)**

Master degree in **Data Science**, First semester
Lecturer: Elisa Spiller
Credits: 6 ECTS

**Prerequisites:**
No prerequisites

**Short program:**
- The concept of data; personal, sensitive and economic data; big data
- The concepts of identity and digital identity
- Property of data, choices in the management of data
- Supranational, international and national laws on data processing
- Civil and criminal protection of privacy
- New contents and concepts of privacy: big data, cell phones; videos; wearable technologies, etc.
- The right to be forgotten
- Social network, right to be forgotten, responsibility
- Provider's criminal responsibility
- Civil and criminal aspects of profiling activity
- Automatic data processing, human responsibilities
- Big data (collection, analysis, processing) and their influence on fundamental rights
- The issue of genetic data
- Big data and economy
- Phishing
- Financial crimes and artificial intelligence

**Examination:**
Written Exam

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP7079399/N0

NETWORK SCIENCE (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA EXAM OF NETWORK SCIENCE (MOD.B))

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Data Science, First semester
Lecturer: 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 (e.g., MatLab, Python, C, Java, Linux). Moreover: 1. for the INTERNET module: to be familiar with the most basic networking and communication concepts and terms (ISO/OSI model, packet-based networks, routing); 2. for the NETWORK SCIENCE module: 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; Evolving networks.
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 - Dendrograms; Girvan Newman method and betweenness; Louvain modularity optimisation; Spectral clustering; Consensus clustering; Measuring similarities in clustering outcomes; 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 course has the following methods of examination:
INTERNET module:
The final exam will be the same for both ATTENDING and NON-ATTENDING students since it does not rely on in-class activities. The exam consists of two parts, namely: 1. a WRITTEN EXAM at the computer, 2. a LAB TEST. Students will be offered four attempts to pass the written and the lab tests. During in-class lectures, the students may be offered to participate to some (in class or at home) activities, such as peer-reviewing of other students’ reports, participating in-class discussion and taking part to problem-solving competitions. The active participation to such initiatives may bring a few extra points (up to 3) to the students.
NETWORK SCIENCE module:
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 project is foreseen in two ways: 1. for ATTENDING students in which the students are guided towards intermediate project objectives (HOMEWORKS) coherently with the development of the
lessons, and complete the project at the end of the course; 2. for NON-ATTENDING students, in which the development of the project takes place in a single solution and is discussed in an oral exam in one of the four institutional dates. 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. The final grade is expressed as a combination of the judgments in the two modules (50%+50%).


MACHINE LEARNING (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE EXAM OF MACHINE AND DEEP LEARNING (MOD. A))
Master degree in Data Science, First semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS
Prerequisites:
The student should be familiar with basic concepts in Mathematics, Probability Theory and Statistics, Linear Algebra, and basic Programming skills.
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; optimization and gradient descent.
  Linear Classification Models; Logistic Regression; Regularization and model selection.
- Model complexity, its effectiveness and its evaluation
  Bias-Variance Tradeoff: how to deal with overfitting and underfitting problems; risk minimization 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
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/off/2020/LM/SC/SC2377/000ZZ/SCP8082660/N0

PROCESS MINING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE)
Master degree in Data Science, First semester
Lecturer: Massimiliano De Leoni
Prerequisites:
Basic notions of algorithms, data structures and programming, as acquired in course "Fundamental of Information Systems

Short program:
The course will cover the topics listed below:
1. MODELING AND ANALYSIS VIA THE BPMN LANGUAGE
   - Essential and Advanced Process Modeling in BPMN
   - Qualitative Analysis
   - Quantitative Analysis
   - Simulation-based analysis
2. MODELING AND ANALYSIS VIA PETRI NETS
   - Basic Concepts of Petri Nets
   - Usage of Petri Nets to model business processes
   - Structural Analysis of Petri Nets
   - Soundness of Business Processes: Basic Principles and Checking
3. PROCESS MINING
   - Introduction to Process Mining and Event Logs
   - Basic Techniques for Process Discovery and Limitations
   - Advanced Techniques for Process Discovery: Heuristic Miner and Inductive Miner
   - Conformance checking based on token replay
   - Conformance checking based on alignments
   - Mining the Additional Perspectives on Decision, Time and Resource
   - Social Network Analysis
4. PREDICTIVE PROCESS MONITORING
   - Basic Predictive Process Monitoring Techniques
   - Advanced Predictive Process Monitoring Techniques

Examination:
Written exam, and a mandatory project.

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP7079235/N0

STATISTICAL LEARNING (C.I.)
Master degree in Data Science, Annual
Credits: 12 ECTS

Modules of the integrated course unit:
- STATISTICAL LEARNING 1 (MOD. A)
- STATISTICAL LEARNING 2 (MOD. B)

Common characteristics of the Integrated Course unit:
Prerequisites:
Basic probability theory; multivariable calculus; linear algebra; basic computing skills.
Examination: written test for mod-A e B

STATISTICAL LEARNING 1 (MOD. A)
Specific characteristics of the Module
Lecturer: Alberto Roverato

Short program:
Part 1: Modes of Inference
- Data: summary statistics, displaying distributions; exploring relationships
- Likelihood: the likelihood, likelihood for several parameters
- Estimation: maximum likelihood estimation; accuracy of estimation; the sampling distribution of an estimator; the bootstrap
- Hypothesis testing
- Other approaches to inference.

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

*Specific characteristics of the Module*

Lecturer: Alberto Roverato

**Short program:**

Part 2

- Models: normal linear models; inference for linear models; generalized linear models; inference for generalized linear models
- Model selection
- Multivariate Analysis: dimension reduction; classification; clustering

**More information:**

[https://didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCP7079226/N0](https://didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCP7079226/N0)

**STATISTICAL METHODS FOR HIGH DIMENSIONAL DATA**

*Information concerning the students who enrolled in A.Y. 2019/20*

Master degree in **Data Science**, First semester

Lecturer: 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. **STATISTICAL METHODS FOR TEXT MINING**
   3.1 Introduction
   3.2 Data preparation and preprocessing (text scanning, stemming, tagging)
   3.2 Dimensionality reduction and t-SNE
   3.3 Topic models and Latent Dirichlet Allocation
   3.4 Classification models
   3.5 Sentiment analysis and iSA (integrated Sentiment Analysis)
4. **CLUSTERING**
   4.1 Introduction to clustering and recall of basic algorithms (hierarchical and non-hierarchical)
   4.2 Model-based clustering
   4.3 Gaussian mixtures
5. **TOPICS IN STATISTICAL LEARNING AND DATA MINING METHODS**
   5.1 Generalization of boosting: Adaboost as additive logistic model, Gradient boosting and XGboosting
5.2 Association rules and Market basket analysis
6. COMPUTATIONAL ISSUES

Examination:
Practical and oral exams.

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP9087918/N0

STOCHASTIC METHODS
Master degree in Data Science, First semester
Lecturer: 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
   - Continuous time Markov Chain.

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/2020/LM/SC/SC2377/000ZZ/SCP7079197/N0

DEEP LEARNING (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)
Master degree in Data Science, Second semester
Lecturer: 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 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/2020/LM/SC/SC2377/000ZZ/SCP9087561/N0

FINANCIAL MATHEMATICS FOR DATA SCIENCE (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING EXAM FOR STOCHASTIC METHODS FOR FINANCE)
Master degree in Data Science, Second semester
Lecturer: Martino Grasselli
Credits: 6 ECTS
Prerequisites:
Stochastic analysis
Short program:
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.
Black&Scholes via PDE and via Girsanov.
Hedging and completeness in the Black&Scholes framework.
Feynman-Kac formula and risk neutral pricing in continuous time.
Put Call parity, dividends and static vs dynamic hedging.
The Greeks and the Delta-Gamma hedging. Delta-Gamma-Vega neutral portfolios.

Barrier options pricing in the Black&Scholes model.
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.
Change of numeraire and Forward Risk Neutral measure.

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

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCQ0093689/N0

INTRODUCTION TO MOLECULAR BIOLOGY
Master degree in Data Science, Second semester
Lecturer: Maria Pennuto
Credits: 6 ECTS
Prerequisites:
None.

**Short program:**
This course has the goal to provide students with the notions necessary to understand the following aspects:

**GENETICS:**
1. Mendel's laws (Mendelian genetics) and exceptions to Mendel's laws (non-Mendelian genetics): Hereditary characters.
2. The theory of evolution: From Lamarck to Darwin.
3. Historical perspective on the discovery of DNA: From transmission of characters to the concept of GENE.
4. The dogma of biology: DNA→RNA→PROTEIN.
5. The cell: Organelles, compartments, functions.

**DNA**
2. Structure: Double helix.
3. The genetic code: DNA is read in triplets.
4. DNA replication.
5. Techniques for DNA purification: Large scale and small scale DNA preparations.
6. Techniques to amplify DNA: PCR.

**RNA**
3. RNA transcription: Regulation of gene expression.
4. Techniques for RNA purification and conversion to cDNA.
5. Techniques for analysis of gene expression of a gene of interest and omics: RT-PCR, microarrays, NGS.

**PROTEIN**
2. Structure: Primary, secondary, tertiary, and quaternary structure.
3. The process of translation: From RNA to protein synthesis.

This course includes LABORATORY experience (at least 25h/48h) with the preparation of DNA, RNA, and proteins, expression of target genes in cells and analysis of protein function in cultured cells. A particular focus will be on protein sample preparation for the generation of omics data (proteomics) analyzed in Biological Data Analysis.

**Examination:**
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:**

**KNOWLEDGE AND DATA MINING**
Master degree in **Data Science**, Second semester
Lecturer: Luciano Serafini
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: written examination or project development.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCP7079318/N0

MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)
Master degree in Data Science, Second semester
Lecturer: TO BE DEFINED
Credits: 6 ECTS
Prerequisites:
Background on Matrix Theory: Type of matrices: Diagonal, Symmetric, Normal, Positive Definite; Matrix canonical forms: Diagonal, Schur; Matrix spectrum: Kernel, Range, Eigenvalues, Eigenvectors and Eigenspaces Matrix Factorizations: LU, Cholesky, QR, SVD

Short program:
1. Numerical methods for large eigenvalue problems
   • The power method
   • Subspace Iterations
   • Krylov-type methods: Arnoldi (and sketches of Lanczos + Non-Hermitian Lanczos)
   • (Optional) Sketches of their block implementation
   • Singular values VS Eigenvalues
   • Best rank-k approximation
2. Network centrality
   • Perron-Frobenius Theorem
   • Centrality based on eigenvectors ((HITS and Pagerank)
   • Centrality based on matrix functions
3. Data and network clustering
   • (Sketches) K-Means algorithm
   • Principal component analysis and dimensionality reduction
   • Laplacian matrices, Cheeger constant, nodal domains
   • (Optional) Lovasz extension, exact relaxations
4. Multiway Data Analysis
   • Tensors Decompositions: Tucker Decomposition, Multilinear Singular Value Decomposition, Canonical Poliadic Decomposition.
   • Numerical Methods for tensor decomposition
   • Applications: Face Recognition Using Tensor SVD and Tensor Data Fusion
   • Tensor eigenproblems: hypergraph Eigenvector Centralities
   • (Sketches) Higher order power method

Examination:
Written exam

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2377/000ZZ/SCP7079406/N0

OPTIMIZATION FOR DATA SCIENCE
Master degree in Data Science, Second semester
Lecturer: Francesco Rinaldi
Credits: 6 ECTS

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

**Short program:**
1. Linear optimization: Theory and algorithms
   (a) LP models for Data science;
   (b) Duality;
   (c) Simplex method;
   (d) Interior point methods;
2. Convex sets and convex functions
   (a) Convexity: basic notions;
   (c) Convex functions: Basic notions and properties (gradients, Hessians..);
3. 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;
4. Constrained convex optimization
   (a) Models in data science;
   (b) Characterizations of optimal sets;
   (c) Polyhedral approximation methods;
   (d) Gradient projection methods;
5. 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 5 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:

**STRUCTURAL BIOINFORMATICS (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)**
Master degree in Data Science,—Second semester
Lecturer: Damiano Piovesan
Credits: 6 ECTS

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

**Short program:**
The course consists of two parts:
1) Introduction to living matter (2 credits):
   1.1) Introduction to organic chemistry, weak interactions and energy
   1.2) Structure and function of DNA and proteins
   1.3) Lipids, membranes and cellular transport
   1.4) Experimental methods for structure determination
2) Computational Biochemistry (4 credits):
   2.1) Biological Databases
   2.2) Software libraries and concepts for sequence alignments and database searches
   2.3) Sequence - structure relationship in proteins and structural classification
   2.4) Methods for the prediction of protein structure from sequence, the CASP experiment
   2.5) Methods for the prediction of protein function and interactions, the CAFA experiment
   2.6) Non-globular proteins, disorder and structural repeats

**Examination:**
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis)
1) Written test of the biochemistry concepts (ca. 30%)
2) Software project (ca. 40%)
3) Project presentation and critical evaluation (ca. 30%)

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2377/000ZZ/SCP7079278/N0

VISION AND COGNITIVE SERVICES (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)
Master degree in Data Science, Second semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS

**Prerequisites:**
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

**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 teacher, 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/2020/LM/SC/SC2377/000ZZ/SCP9087563/N0

GEOPHYSICS FOR NATURAL RISKS AND RESOURCES

APPLIED GEOPHYSIC
Master degree in Geophysisc for N atural Risks and Resources, First Semester
Lecturer: 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, electromagnetic, 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 seismics, 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/2020/LM/SC/SC2543/000ZZ/SCQ0089219/N0
**ELECTROMAGNETISM**
Master degree in *Geophysics for Natural Risks and Resources*, First Semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
**Prerequisites:**
Not defined
**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089220/N0

**GEOLOGY FOR GEOPHYSICS**
Master degree in *Geophysics for Natural Risks and Resources*, First Semester
Lecturer: Valerio Olivetti
Credits: 6 ECTS
**Prerequisites:**
Basic knowledge in geology and geophysics.
**Short program:**
The content of the course will be structured around the Apennine case history. Rocks, observations, and data collected during the field trip will be used to reconstruct the time-space evolution of an orogeny and to show the signature of geodynamic processes in the geological record.
The following fillings will be, therefore, treated:

- Plate tectonics and the Wilson cycles
- Continental extension, rifting and drifting
- The subduction factory and the orogenic processes. Apennines subduction: slab retreat, Tyrrhenian back-arc basin and intra-orogenic sedimentary basin.
- The metamorphic processes
- The volcanic processes. Origin of the Apennines volcanism and geodynamics significance.
- Mountain uplift, exhumation, erosion: definition, quantification and mechanism.
**Examination:**
The examination consists in a written test focused on the different arguments of the course and on the observation made during the field trip
**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089221/N0

**SOLID EARTH GEOPHYSICS**
Master degree in *Geophysics for Natural Risks and Resources*, First Semester
Lecturer: Lapo Boschi
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 exams 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/2020/LM/SC/SC2543/000ZZ/SCQ0089218/N0
ADVANCED STATISTICS FOR PHYSICS ANALYSIS (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)

Master degree in Geophysics for Natural Risks and Resources, Second Semester
Lecturer: Alberto Garfagnini
Credits: 6 ECTS
Prerequisites: None

Short program:
- 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:
The exam consists of a written test where students (individually) are requested to solve analytically statistical exercises and the presentation of a research project carried out in group; such research project focuses on modern physics topics where statistical tools and concepts described in course play a major role

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCP8082557/N0

APPLIED GEODESY

Master degree in Geophysics for Natural Risks and Resources, Second Semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
Prerequisites: None

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089239/N0

DIGITAL DATA PROCESSING

Master degree in Geophysics for Natural Risks and Resources, Second Semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
Prerequisites: None

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089229/N0

GEOPHYSICS FOR CULTURAL HERITAGE

Master degree in Geophysics for Natural Risks and Resources, Second Semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
Prerequisites: None

More information:
GEORESOURCES
Master degree in **Geophysisc for N atural Risks and Resources**, Second Semester
Lecturer: Massimiliano Zattin
Credits: 6 ECTS
Prerequisites: Basic geological background

Short program:
2. Metallic and industrial mineral resources; hydrocarbon resources:
   a. Notes on the classification, geological setting and distribution of ore (magmatic, hydrothermal, sedimentary, supergene) and hydrocarbon (conventional and unconventional) deposits.
   b. Physical properties of ore and reservoir bodies (density, electric and magnetic properties, morphology, continuity, volume). Relationships between ore bodies, host rocks and host-rock alterations.
   c. Mineral exploration stages (regional, area selection, pre-feasibility, feasibility, mining) and role of geophysics in each of them.
   d. Case studies with examples of application of geophysics in mineral and hydrocarbon exploration.

Examination:
Interview

More information:

MANAGEMENT AND ANALYSIS OF PHYSICS DATASETS  **(OFFERED IN THE MASTER DEGREE IN PHISICS OF DATA EXAM OF MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B) )**
Common characteristics of the Integrated Course unit MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)
Master degree in **Geophysisc for N atural Risks and Resources**, Second Semester
Lecturer: Jacopo Pazzini
Credits: 6 ECTS
Prerequisites: Elements of analysis and algebra.
General physics.
Statistics.
Basic programming elements.

Short program:
Part 1) Distributed computing
Distributed Computing systems and the Grid paradigm
Computing Models
Dask principles
Setup of a cluster with Dask
Data movement and analysis on dask cluster
Machine learning on a dask cluster
Part 2) Data Management
Data Workflows in scientific computing
Storage Models
Data management components:
- Name Servers and databases
- Data Access protocols
- Reliability
- Availability
- Access Control and Security
- Cryptography
- Authentication, Authorization, Accounting
- Scalability
- Cloud storage
- Block storage
- Analytics
- Data Replication
- Data Caching
- Monitoring, Alarms
- Quota

**Examination:**
Development of a project assigned at the end of the course. Presentation and discussion of the project, questions on the material presented in class.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089438/N0

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**MATHEMATICAL PHYSICS FOR THE EARTH SYSTEM**
Master degree in **Geophysics for Natural Risks and Resources**, Second Semester
Lecturer: Lapo Boschi
Credits: 6 ECTS

**Prerequisites:**
High-school level maths and physics (trigonometry, derivatives, integrals, Newton's laws)

**Short program:**
- Elements of linear algebra and calculus
- Theory of gravitation
- Elements of fluid dynamics
- Elements of acoustics
- Elasticity theory
- Linear inverse problems
- Elements of informatics (Matlab/Octave)

**Examination:**
Written exams 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/2020/LM/SC/SC2543/000ZZ/SCQ0089222/N0

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**NUMERICAL METHODS FOR CONTINUOUS SYSTEMS**
Master degree in **Geophysics for Natural Risks and Resources**, Second Semester
Lecturer: 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:**
1. Review of PDEs for classical problems in science and engineering (convection diffusion, linear elastic problem, Stokes problem, de Saint Venant and Navier Stokes equations)
2. FEM methods for elliptic equations and stabilization (SD, SUPG);
3. Mixed formulations and saddle point problems;
4. Extensions to systems of PDEs - stability and (INF-SUP/LBB condition;
5. Stokes equation
6. Method of Lines for parabolic equations
7. Discretization of Navier Stokes equations
8. Practical implementations.

**Examination:**
Oral examination with discussion on the student projects and assignments

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089198/N0

**NUMERICAL METHODS FOR GEOSCIENCES**
Master degree in Geophysical for Natural Risks and Resources, Second Semester
Lecturer: 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) ir direct (Gauss elimination) methods.

**Examination:**
Oral and practical test

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2543/000ZZ/SCQ0089223/N0

**NUMERICAL METHODS FOR HIGH PERFORMANCE COMPUTING (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING - INGEGNERIA MATEMATICA)**
Master degree in Geophysical for Natural Risks and Resources, Second Semester
Lecturer: Carlo Janna
Credits: 6 ECTS

**Prerequisites:**
None

**Short program:**
1. Navier-Stokes and de Saint-Venant equations and their simplifications: Stokes problem; convection-diffusion equation; linear elasticity;
2. FEM methods and stabilization (INF-SUP/LBB condition);
3. Mixed formulations and saddle point problems;
4. Finite volumes and finite differences;
PETROPHYSICS
Master degree in Geophysisc for N atural Risks and Resources, Second Semester
Lecturer: Eloisa Di Sipio
Credits: 6 ECTS
Prerequisites:
Basic knowledge of mathematics, physics and geophysics acquired during the Bachelor degree.

Short program:
The course contents consist of:
1. Rocks- Classification and general properties: overview of rocks’ and incoherent deposits’ physical properties, introduction to laboratory measurement methods on rock samples and cores;
2. Pore space properties: porosity, specific internal surface, fluids in the pore space, permeability, capillary pressure;
3. Nuclear Magnetic Resonance (NMR): principles, measurements and applications
4. Density: definition, density of rock constituents, density of rocks;
5. Nuclear/Radioactive Properties: natural radioactivity, interactions of gamma radiations and neutron radiations;
6. Elastic properties: elastic properties of rocks;
7. Geomechanical properties: fundamental geomechanical properties and processes in lithic materials, deformation, stress and strain;
8. Electrical properties: electrical properties of lithic and unconsolidated materials, role of interstitial fluids;
9. Thermal Properties: thermal properties of minerals and rocks;
10. Magnetic Properties: magnetic properties of minerals and rocks;
11. Well-logging: basic concepts, techniques, data and interpretation examples;
12. Classroom and laboratory exercises on some of rocks’ petrophysical properties.

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/2020/LM/SC/SC2543/000ZZ/SCQ0089199/N0

PHYSICS DATA ANALYSIS (OFFERED IN THE MASTER DEGREE IN LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B))
Master degree in Geophysisc for N atural Risks and Resources, Second Semester
Common characteristics of the Integrated Course unit
Lecturer: Marco Baiesi
Credits: 6 ECTS
Prerequisites:
Even though not strictly required, the development of the class assumes the attendance of at least two physics laboratory classes during the bachelor degree.

**Short program:**
- Gradient descent methods
- Ridge and LASSO regularization
- Deep neural networks and convolutional version
- Clustering
- Data visualization
- Energy-based models
- Restricted Boltzmann machines
- Combination of models

**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:**

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**SEISMIC RESPONSE OF BUILT STRUCTURES**

Master degree in *Geophysics for Natural Risks and Resources*, Second Semester

Lecturer: Francesca Da Porto

Credits: 6 ECTS

**Prerequisites:**
None

**More information:**

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**STATISTICAL MECHANICS OF COMPLEX SYSTEMS (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING)**

Master degree in *Geophysics for Natural Risks and Resources*, Second Semester

Lecturer: 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.

**Examination:**
STRUCTURAL GEOLOGY AND EARTHQUAKES
Master degree in Geophysics for Natural Risks and Resources, Second Semester
Lecturer: Giulio Di Toro
Credits: 6 ECTS
Prerequisites:
Basic 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 Folds and Structure of Fault Zones, Earthquake mechanics and the seismic cycle, Earthquakes and Tectonics, Earthquake forecasting and hazard (including earthquake-triggered landslides and tsunamis), 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/2020/LM/SC/SC2543/000ZZ/SCP8082536/N0

MOLECULAR BIOLOGY

APPLIED STATISTICS (OFFERED IN THE MASTER DEGREE IN BIOLOGIA SANITARIA)
Master degree in Molecular Biology, First semester
Lecturer: 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:
- Elementary methods. Inference on a proportion and comparison of two proportions. Student's t: one sample, two samples, paired data. Large sample inference. Nonparametric methods: Wilcoxon (one and two samples) and Kruskal-Wallis tests. Correlation coefficient.
Examination:
Written exam. Students are required to answer a number of questions concerning the statistical analysis of a real data set.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2445/005PD/SCP8085059/N0

BIOCHEMISTRY
Master degree in Molecular Biology, First semester
Lecturer: 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 treated. 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/2020/LM/SC/SC2445/005PD/SCP8085067/N0

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**CELL BIOLOGY**
Master degree in Molecular Biology, First semester
Lecturer: 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 the topics covered in class. The discussion of the articles is an integral part of the program. Lectures will cover 5 main topics:
1) In vitro cultures, methods for cellular molecular biology. Physical principles behind the most common microscopy techniques.
2) Chromatin Biology and nuclear organization to address fundamental questions in Epigenetics and Gene Regulation as well as in cellular differentiation and nuclear reprogramming. Mechanisms of epigenetic regulation, including DNA methylation and post-translational modification of histones, and the roles of chromatin-assembly modifying complexes, non-coding RNAs and nuclear organization. X chromosome inactivation. Cell Memory and Genomic Imprinting. Centromeres and telomeres chromatins.
3) Main principles of autophagy and related diseases

**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 (7 CFU) described in the course content at section 2 to 5 will be assessed with six 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/2020/LM/SC/SC2445/007PD/SCP8085218/N0

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**EPIGENETICS AND EPIGENOMICS**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Molecular Biology, First semester
Lecturer: Carlo Fiore Viscomi
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 epigenetics and epigenomics, with a particular focus on their role in human diseases.

Short program:
Introduction: What is epigenetics?
The composition of chromatin: the epigenome and molecules involved in chromatin regulation
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)
Proximal and distant DNA regions involved in genome regulation: DNA and chromatin modifications and regulation of genome expression (internal and external factors)
Examples of dynamic changes in the three-dimensional architecture of chromatin and gene regulation.
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)
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 GAS5 as decoy, 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
Heritability of DNA modifications: global role during early development and gametogenesis, X-chromosome inactivation.
Reversibility of epigenetic patterns: approaches for epigenome reprogramming (nuclear transfer, cell fusion, cell extracts, cloned genes or proteins, mRNAs)
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. 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).
Epigenetic modifications and multifactorial syndromes.
Regulating the epigenome in the therapy of human diseases
Epigenetic control of the mitotic cell cycle
Epigenetics of cancer: uncontrolled replication, epigenetic changes leading to transformation, abnormal patterns of methylation, histone modifications and cancer, epigenetics of tumour metastasis.

Examination:
written final exam (open questions) in presence or online.

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2445/005PD/SCP9087941/N0
FUNDAMENTALS OF INFORMATION SYSTEMS (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE))
Master degree in Molecular Biology, First semester
Lecturer: Giogia Maria Di Nunzio
Credits: 6 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:

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 and (group) project. The project is due by the end of the first session of exams.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2445/007PD/SCP7078720/N0

MODELS IN GENETIC DISEASE RESEARCH
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Molecular Biology, First semester
Lecturer: 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:**

**MOLECULAR AND CELL BIOLOGY OF PLANTS**
Master degree in **Molecular Biology**, First semester
Lecturer: 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+, an intracellular second messenger; methods of measuring intracellular Ca2+ concentration; calcium transients and calcium signatures (4h).
Plant hormones (auxins, gibberellins, cytokinins, ethylene, abscissic acid): biosynthesis, actions, transport and developmental effects; signal transduction pathways (16h).
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 (6h).
Blue light and red light responses: light perception, signal transduction and plant responses to light environmental conditions (6h).
Plant reproductive development: floral meristem development, floral organ identity genes, ABCDE model to explain the flower development; the control of flowering (8h).
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 (14h).
Plant–microorganism interactions: cellular and molecular surveys about mycorrhiza, Rhizobium-Leguminosae symbiosis and plant-Agrobacterium interaction (10h).
16h (1 CFU) of practical work are planned on the following topics:
1) Somatic embryogenesis in the model system Daucus carota, tobacco micropropagation
2) Isolation of protoplasts from plant cell suspension cultures; fluorescence imaging of intracellular compartments
3) Protein extraction and quantification from Arabidopsis thaliana cell cultures stably expressing the calcium-sensitive photoprotein aequorin
4) Analysis of protein expression by SDS-PAGE and immunoblotting.

**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:**
MOLECULAR GENETICS
Master degree in Molecular Biology, First semester
Lecturer: 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.
Basics of Derivatives, Integrals and Differential Equations
Mathematical Modeling.
Static Network Models.
Markov Models.
Mutual Information, Relevance Networks and Bayesian Networks.
The Mathematics of Biological Systems.
Parameter Estimation from Noisy Data: Grid Searches, Hill Climbing, Genetic Algorithms.
Signaling Systems.
Population Systems.
SIR Model Simulation.
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.

COMPUTATIONAL ANTHROPOLOGY
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Molecular Biology, Second semester
Lecturer: 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:**

**COMPUTATIONAL ANTHROPOLOGY**
Information concerning the students who enrolled in A.Y. 2020/21

**More information:**

**GENOMICS AND NGS DATA ANALYSIS**
Master degree in Molecular Biology, Second semester
Lecturer: Giorgio Valle
Credits: 9 ECTS

**Prerequisites:**
The content of the course has been defined keeping in mind the program of the first level degree in Molecular Biology of the University of Padua. In particular it is expected that the students have a good knowledge of Genetics, Molecular Biology and Bioinformatics. It would be useful to have a basic knowledge in informatics and programming. The course is in English, therefore the students should have a reasonable command of spoken and written English.

**Short program:**
It is a 9 credits course that includes 56 hours of classroom teaching (7 credits) and 32 hours of practicals (2 credits). The activity is articulated into 6 sections as follows:
Section 1) DNA sequencing technology and its application to genome sequencing, RNAseq, ChIPseq, BisulfiteSeq;
Section 2) Analysis and management of "Next Generation Sequencing" (NGS): data: mapping sequences on the reference genome, de novo assembly of genomes, analysis of mate pairs, analysis of transcriptomic and splicing data, analysis of methylome, analysis of single cell sequencing;
Section 3) Epigenomics: structure and function of non-coding RNA, nuclear architecture of the genome;
Section 4) Functional genomics, proteomics, interactomics, gene inactivation, integration of complex data, gene prediction and genomic annotation;
Section 5) Genomics and personalized medicine: analysis of polymorphisms, linkage disequilibrium and GWAS, resequencing of genomes and exomes, data integration and systems biology;
Section 6) Practicals in the laboratory where the students will be able to challenge themselves in the production of NGS libraries and in the application of bioinformatics to analyse genomic and transcriptomic data.

**Examination:**
The final exam is oral, however the evaluation is articulated into three parts: 1) a written session in which the student must describe the results of the laboratory practicals, that must be submitted at least one week before the official date of the exam, 2) a quiz session on Moodle, that will take place at the beginning of the day of the exam, 3) an oral discussion on the topics of the course and on the results achieved on the practicals. 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/2020/LM/SC/SC2445/007PD/SCQ0094199/N0

**MICROBIAL METAGENOMICS**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in **Molecular Biology**, Second semester

Lecturer: 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.

Basic concepts regarding microbial community analysis. Structure of the microbial communities, ecological indices, similarity measures.

Marker genes based analysis. Amplicon sequencing analysis using different marker genes (16S rRNA, 18S rRNA, ITS, viral markers, other examples).

Video lessons Rob Knight - 16S amplicon sequencing. General resume regarding marker gene analysis and the use of specific software (QIIME, Mothur).

Metagenomic inference. How to infer the genetic composition of a microbiome starting from amplicon sequencing data using PICRUST.

Analysis of shotgun metagenomic reads. Approaches and software used for analyzing shotgun sequence data without performing the assembly process.

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.

Metatranscriptomics. Analysis of RNA-seq data to analyze the gene expression at community-level.

Video lessons Rob Knight - Statistical analyses. Statistical approaches to the study of metagenomics.

Metabolic flux balance analysis. Methods to the investigation of metabolic fluxes in complex microbial populations.

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.

Marine metagenomics. The structure of the marine microbiome, how approaches changed during the years for the investigation of this complex microbial community.

Soil metagenomics. The composition of the soil microbiome described from a number of examples.

Human gut metagenomics. The human gut microbiome, its role in determining specific diseases.

Viruses metagenomics. The metagenomics of viruses performed from shotgun sequencing data.

Conclusions and final remarks.

**Journal club.** Students will select a paper and will present in critical way methods and findings.
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.

**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:**

**MICROBIAL METAGENOMICS**
Information concerning the students who enrolled in A.Y. 2020/21
More information:

**MODELS IN GENETIC DISEASE RESEARCH**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Molecular Biology, First semester
Lecturer: 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/2019/LM/SC/SC2445/000ZZ/SCP8085071/N0

**MOLECULAR BIOLOGY OF DEVELOPMENT**
Master degree in Molecular Biology, Second semester
Lecturer: 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 developmenta 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): Diffusion reaction, French flag theory.
4) Genetic pathways controlling development, their function and visualization (1.5 CFU): Wnt, TGFβ, BMP, HH, Notch, Hypoxia, Hippo, STAT
5) germ layers induction and regionalization of the main axes (DV, AP, LR) in vertebrates and Drosophila, Examples of organ formation. (1 CFU)
Angiogenesis in model animals (1 CFU): Use of genetic animal models to study angiogenesis.
Molecular biology of endothelial cells. Developmental and pathological angiogenesis.
Laboratory (1 CFU): manipulation of the zebrafish embryo: whole mount staining and imaging of fluorescent embryo; Pharmacological treatment of zebrafish embryos with non-specific teratogens (alcohol) and specific agonists or antagonists.

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/2020/LM/SC/SC2445/005PD/SCP8085061/N0

NEUROBIOLOGY
Master degree in Molecular Biology, Second semester
Lecturer: Daniela Pietrobon
Credits: 10 ECTS

Prerequisites:
Physiology, Genetics, Cellular Biology, Molecular biology

Short program:
Module A (Prof Pietrobon): 7 CFU (56 hours) of lectures
1. Introduction. 2. anatomical and functional organization of the human nervous system. 3. Electrophysiological and optical techniques for measurement of neuronal electrical activity. Optogenetic techniques for selective stimulation of specific neurons. Examples of applications. 4. Specific firing patterns in different neurons, physiological role and experimental methods to investigate their molecular mechanisms. 5. Techniques for measurement of synaptic transmission. Biophysical and molecular mechanisms of neurotransmitter release; experimental methods for their study. 6. Mechanisms of short-term synaptic plasticity (facilitation, post-tetanic potentiation, depression) and of long-term synaptic plasticity (LTP, LTD, STPD). Learning and memory. 7. General functional organization of sensory systems; in depth discussion of one sensory system.
Module B (Prof Costa): 2 CFU (16 hours) of lectures + 1 CFU (16 hours) of laboratory.
The physiological basis of biological rhythms and the ramifications for the sleep-wake cycle. the normal modulation of circadian cycles and the effects when these are disrupted. The circadian rhythm and its relationship to the sleep/wake cycle examined along with the concepts of photic and nonphotic zeitgebers. Drosophila melanogaster as a Model System for molecular chronobiology. The genetic basis of circadian rhythm generation. The fly's circadian clock. The mammalian circadian clock. The neurophysiology of the pacemaker in the suprachiasmatic nuclei. The genetic basis of circadian rhythm generation. The internal sleep structure is governed by circadian rhythms and these rhythms also impact upon levels of alertness and cognitive performance. General day-time performance and quality of life if these rhythms are disrupted such as with sleep fragmentation or jet lag. The effects of sleep deprivation and shift work. Changes in sleep wake patterns with ageing. Clock related sleep syndroms. Laboratory training: practical exercises are organised to define the chronotype of
participants and to explore the hypothesis of a relationship between genetic variability in clock genes and sleep/wake preferences.

**Examination:**
Module A (Prof Pietrobon)
Written examination with three open questions, which aim to verify, besides the acquired knowledge on relevant topics, the ability of critical discussion and reasoning.
Module B (Prof Costa)
The examination is conducted in written form (open questions). The individual report on the practical experience maturated during the laboratory training is also evaluated.
The final mark is obtained as the weighted mean of the marks of the two modules.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2445/005PD/SCP8085065/N0

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### PHYSICS

**ADVANCED TOPICS IN PHYSICS**
Master degree in Physics, Annual
Lecturer da definire
More Information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2445/005PD/SCP8085065/N0

**ADVANCED PHYSICS LABORATORY B**
Master degree in Physics First semester
Lecturer 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:**

**ADVANCED QUANTUM FIELD THEORY**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: Marco Matone
Credits: 6 ECTS

**Prerequisites:**
Students should know the canonical quantization approach of a field theory, in particular of Quantum Electrodynamics, and should be acquainted with the path-integral formalism and the technique of Feynman diagrams.

**Short program:**
The course program largely follows that of last year available at https://www2.pd.infn.it/~matone/AdvQFT_Program_2019-2020.pdf
The parts concerning phi_6^3 and topological structures will be reduced, while more time will be devoted both to the quantization of Yang-Mills theories and to supersymmetric theories.
ADVANCED TOPICS IN THE THEORY OF THE FUNDAMENTAL INTERACTIONS

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: Ferruccio Feruglio
Credits: 6 ECTS

Prerequisites: A basic knowledge of theoretical physics of the fundamental interactions, in particular of quantum field theory.

Short program:
Part 1: INTRODUCTION AND EXAMPLES
- INTRODUCTION:
  Characterization of a physical system:
  degrees of freedom, relevant scale(s), symmetries.
- EXAMPLES OF EFT:
  the Fermi theory of weak interactions;
  derivation from the full electroweak theory.
  beyond the tree-level: Euler-Heisenberg Lagrangian;
  symmetry considerations and derivation from QED.
- THE SM AS AN EFT:
  recap of SM non-anomalous global symmetries;
  dimension 5 operators, violation of (B-L) and neutrino masses;
  possible microscopic origin (seesaw mechanism).
  dimension 6 operators, violation of B and proton decay;
  possible microscopic origin (GUTs);
  dimension 6 operators and flavour physics.
- EFT IN NON-PERTURBATIVE REGIME:
  the chiral Lagrangian; chiral symmetry breaking in QCD;
  EFT for light pseudoscalar mesons; breaking effects;
  anomaly of iso-axial current and neutral pion decay.
- OTHER EXAMPLES
Part 2: FORMAL ASPECTS
- EFT AND POWER COUNTING.
- INTEGRATING OUT HEAVY MODES:
  RGE flow and matching conditions;
  revisitation of the Euler-Heisenberg Lagrangian;
  other examples.
- APPELQUIST-CARAZZONE DECOUPLING THEOREM.
- EQUIVALENT EFFECTIVE LAGRANGIANS;
  independence of $S$-matrix elements on local field redefinitions.
- OPERATOR MIXING;
  anomalous dimensions; examples;
- EFT DESCRIBING A BROKEN PHASE:
  CCWZ construction; revisitation of the chiral Lagrangian;
  other examples.

Examination: Discussion of selected topics from the program of the course, including resolution of problems.

More information:
**BIOPHOTONICS**

Information concerning the students who enrolled in A.Y. 2019/20

Master degree in Physics, First semester

Lecturer: Fabio Mammano

Credits: 6 ECTS

**Prerequisites:**

Biological Physics

**Short program:**

Electromagnetic wave propagation: plane waves, spherical waves, phase velocity, irradiance, wave packets, group velocity, coherence length, interference.

Scalar diffraction theories: the Kirchhoff formulation, the Rayleigh-Sommerfeld formulation, the Huygens-Fresnel principle.

Geometrical optics: Optical path length, the principle of Fermat, ideal imaging systems, matrix methods in paraxial imaging, cardinal points and planes.

Apertures and stops, image-forming instruments, brightness and illumination of images, intensity fluctuations, detection noise.

The Debye integral representation of focused fields, irradiance distribution near focus (three-dimensional point spread function). Resolving power: the Rayleigh criterion. Minimum angular separation, visual acuity, phototransduction.

Transmitted light microscopy: angular spectrum of plane waves, diffraction gratings, abbe theory and resolution. Phase contrast, dark field, and differential interference contrast microscopy.

Fluorescence microscopy: molecular spectra, Jablonski diagram, Stokes' shift, life time and quantum efficiency, saturation of the excited state. Structure of the conventional fluorescence microscope.

Confocal microscopy: lateral resolution and axial resolution in the classical limit; optical sectioning and volume reconstruction; physical principles and applications of 2-photon excitation; advantages and disadvantages of different confocal systems.

Stimulated emission depletion (STED) nanoscopy and super-resolution.

Selected biophotonics applications: optical recording of changes in ion concentration. Optical sensors of Ca2+ ions, protons and other physiologically relevant ionic species. Imaging of Ca2+ at one and two wavelengths; local control of the concentration of Ca2+ and other active molecular species by UV photolysis of caged compounds; FRET, FRAP.

Intravital microscopy: biosensors, optochemogenetics, photodynamic therapy of cancer.

**Examination:**

Written and an oral exam. The written part concerns topics developed during the course. The oral exam consists in the presentation by the student of one or more original articles related to optical super-resolution techniques.

**More information:**


**COSMOLOGY OF THE EARLY UNIVERSE (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**

Information concerning the students who enrolled in A.Y. 2019/20

Master degree in Physics, First semester

Lecturer: 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 main features of the models 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

**Examination:**
Oral exam

**More information:**

**EXPERIMENTAL SUBNUCLEAR PHYSICS**
Master degree in Physics, First semester
Lecturer: 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

**Short program:**
Quantum Chromodynamics

QCD lagrangian, renormalization group equations, alpha_s as running coupling constant.
Hadronization processes.
Electroweak Theory

SU(2)xU(1) model, radiative corrections, physics at the Z0, interference and asymmetries at LEP, LEPII.
Goldstone model, Higgs mechanism, Higgs phenomenology, search for the Higgs boson.
Physics at the hadronic colliders: search and properties of the top quark and of the vector bosons
CKM Matrix

Hierarchy of the parameters, different parametrization. Unitarity triangle. Example of measurement of some elements of the CKM matrix
CP violation and oscillations

Oscillation and CP violation in the neutral B system
CP violation in the mesons decays

**Examination:**
Oral

**More information:**
https://en.didattica.unipd.it/02/2019/LM/SC/SC2382/001PD/SCP7081760/N0

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**FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY** *(OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)*

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics, First semester
Lecturer: 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.
* Shortcomings of the standard cosmological model: horizon, flatness problems, etc.
  - 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.
* 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

**More information:**

**GENERAL RELATIVITY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY  EXAM OF GENERAL RELATIVITY FOR ASTROPHYSICS AND COSMOLOGY)**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics, First semester
Lecturer: Marco Peloso
Credits: 6 ECTS

**Prerequisites:**
Knowledge of Special Relativity

**Short program:**
1. Preliminaries
3. Gravity as Geometry

4. The Einstein equations
Parallel transport and curvature. Covariant derivative, Riemann, Ricci, and Einstein tensor. The source of curvature. Einstein equations and weak field approximation.

5. Geodesics
The geodesic equation. Symmetries and Killing vectors. Local inertial frames and freely falling frames.

6. Schwarzschild Geometry

7. Horizons and Coordinate Systems

8. Rotations and Kerr Geometry
Geodetic precession around a non-rotating, and a slowly rotating body. Kerr metric and the ergosphere.

9. Cosmology

10 Gravitational waves (if time permits)

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

More information:

MEDICAL PHYSICS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: 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:
Introduction to dosimetry of ionizing radiation. Radiation dose and health risk.
- 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).
- Introduction to magnetic resonance imaging (MRI).
- NIR and introduction to echography imaging.
- Principles of radiotherapy with photons, electron and hadrons.
- Principles of hyperthermia.

Examination:
Oral examination. The student will present a detailed analysis of one of the arguments of the course. Questions concerning this presentation and other topics presented during the lectures are foreseen.

**More information:**

**MODELS OF THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)**

Master degree in **Physics**, First semester

Lecturer: Amos Maritan

Credits: 6 ECTS

**Prerequisities:**

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/measure

Brownian paths and polymer physics biopolymer elasticity. The random walk generating function, the Gaussian field theory and coupled quantum harmonic oscillators

Levy walks

Field theories as models of interacting systems

\( O(n) \) symmetric Phi^4– theory. The large \( n \) limit: Spherical (Berlin-Kac) model

Perturbative expansion. Introduction to renormalization group techniques and universality.

Generalized diffusion and stochastic differential equations. The Feynman-Kac formula:

Feynman path integrals and the quantum version of the Feynman-Kac formula.

Quantum mechanics (solvable model: free particle, harmonic oscillator)

Stochastic amplification and stochastic resonance

Non-perturbative methods: instantons

Statistical physics of random spin systems and the machine-learning problem

Random energy model, replica trick

**Examination:**

Final examination based on: Written and oral examination and weekly exercises proposed during the course

**More information:**

**NON-PERTURBATIVE QUANTUM FIELD THEORY**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in **Physics**, First semester

Lecturer: Pieralberto Marchetti

Credits: 6 ECTS

**Prerequisities:**

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), vortices (Higgs model, Kosterlitz-Thouless, superconductors), monopoles (Dirac, t’Hooft-Polyakov, spin ice), instantons (Yang-Mills theory) and their role in the phase transitions.
3) Low-dimensional systems: bosonization and duality (Thirring model, Luttinger liquids), fractional charges and fractional statistics (Jackiw-Rebbi model, polyacetilene, anyons in the fractional quantum Hall effect).
4) 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/...
• 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 with eventual presentation of a research work on one of the several subjects proposed by the professors.

More information:

OPTICS AND LASER PHYSICS (OFFERED IN THE MASTER DEGREE IN MATERIALS SCIENCE)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: 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 compriess two exercizes and one open question.

More information:

PHYSICS EDUCATION

Master degree in Physics, First semester
Lecturer: 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 practical 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. Astronomy as a context in which proposing topics of classical and modern physics.

**Examination:**
The examination will consist of two parts:
(1) written assignments during the course (40%);
(2) a final written project at the end of the course on the development and implementation of an empirical study on a selected topic in physics (60%).

**More information:**

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**PHYSICS OF COMPLEX SYSTEMS**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in Physics, First semester
Lecturer: 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:**
Introduction to the physics of complexity and of emergent phenomena (general points of view of P.W. Anderson, N. Goldenfeld, L.P. Kadanoff, ...)


Detailed balance in equilibrium. Linear response theory and transport phenomena. Onsager reciprocity relations with examples (Seebeck and Peltier effects, etc.)


Computational complexity and information theory. The random energy model and the random code ensemble. Complex energy landscapes and reweighting methods.

**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.


PHYSICS OF FLUIDS AND PLASMAS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY EXAM OF FLUID AND PLASMA DYNAMICS)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: Tommaso Bolzonella
Credits: 6 ECTS
Prerequisites: Nessuno

Short program:
The course presents, at an advanced level, some of the main subjects of the physics of fluids and plasmas.
During the course examples and applications from both astrophysics and controlled fusion will be presented.

Introduction
Fluids and plasmas in nature and laboratory. Characteristics and limitations of theories describing neutral fluids and plasmas. Non-collisional Boltzmann equation.

Neutral fluids
Collisional Boltzmann equation.
Moment equations and fluid dynamics derivation.
Ideal fluids; macroscopic derivation of fluid dynamics.
Viscous flows.
Linear theory of waves and instabilities. Perturbative approach.
Turbulence in neutral fluids; Kolmogorov theory.

Plasmas
Basic properties of plasmas; plasmas in nature and laboratory.
Plasma orbit theory.
Dynamic of many charged particles.
Kinetic theory of plasmas, BBGKY hierarchy, Vlasov equation.
Two fluid model.
Collisionless processes in plasmas; Landau damping.
Collisional processes and the one-fluid model.
Diffusion and transport.
Basic magnetohydrodynamics; some simple examples of MHD instabilities.
Theory of magnetic topologies; magnetic reconnection; Sweet-Parker model. Magnetic helicity.
Dynamo theory. Parker's turbulent dynamo. Mean field magnetohydrodynamics.

Examination:
Oral exam


PHYSICS LABORATORY
Master degree in Physics, First semester
Lecturer: Gabriele Simi
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. 
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 experiments 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/2020/LM/SC/SC2382/001PD/SCP7081617/N0

PHYSICS OF NUCLEAR FUSION AND PLASMA APPLICATIONS

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: Emilio Martines
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:**

**PHYSICS OF SEMICONDUCTORS (OFFERED IN THE MASTER DEGREE IN MATERIALS SCIENCE EXAM OF PHYSICS AND TECHNOLOGY OF SEMICONDUCTORS)**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics, First semester
Lecturer: Davide De Salvador
Credits: 6 ECTS

**Prerequisites:**
Mathematical prerequisites:

Basic Physics Prerequisites

Quantum Physics Prerequisites:
Solid state physics Prerequisites

**Short program:**
Review of the crystal structure of the main semiconductors. Elementary semiconductors, compounds and alloys.
Review of solid state basic concepts ( Bloch theorem, effective mass, concept of hole ).
Origin and specificity of semiconductors band structure. The real bands (examples: GaAs, Si, Ge, AlGaAs ).
The envelope function method for the calculation of quantum states generated by aperiodic potential.
The mechanism of doping. The carriers in a homogeneous semiconductor as a function of doping and temperature ( semic. non-degenerate, intrinsic, ionized, partially ionized, in saturation ). The compensation by deep level.
The semiconductor non-homogeneous equilibrium. The case of the p-n junction.
Charge transport in semiconductors. Drift-diffusion equation. Intraband scattering phenomena and mobility in a semiconductor.

The mechanisms of generation and recombination in a semiconductor.
The equation of continuity. The case of the p-n junction under polarization.
The heterojunction joints metal / semiconductor, metal / oxide / semiconductor.
The quantum confinement in semiconductor quantum well, quantum wire, quantum dot.
LEDs, GaN based LED, photodetectors. Solid state laser architectures, quantum confinement effect on lasering. Photovoltaic cells. Different architectures and materials for photovoltaics.
Productive. Transistor bipolar and FET technologies. MOS structure.
Doping techniques. Ion implantation. Diffusion and defect.
Insulation, thermal oxidation.

**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.

**More information:**

**SOLID STATE PHYSICS**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics, First semester
Lecturer: 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:

SOLID STATE PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)
Information concerning the students who enrolled in A.Y. 2020/21
Master degree in Physics, First semester
Lecturer: 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:  

STATISTICAL MECHANICS  
Information concerning the students who enrolled in A.Y. 2019/20  
Master degree in Physics, First semester  
Lecturer: 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 criterium and upper critical dimension. Scaling theory and Kadanoff block spin argument.  
Renormalisation group in real space. Universality.  

Please note that some topics may vary  
Spontaneous symmetry breaking for continuous symmetry. Goldstone's theorem.  
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 (OFFERED IN THE MASTER DEGREE IN PHYSICS OF DATA)

Information concerning the students who enrolled in A.Y. 2020/21
Master degree in Physics, First semester
Lecturer: 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
Spontaneous symmetry breaking for continuous symmetry. Goldstone's theorem.

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.


THEORY OF STRONGLY CORRELATED SYSTEMS

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, First semester
Lecturer: Luca Dell’Anna
Credits: 6 ECTS
Prerequisites:
Nessuno

Short program:
Part 1: Introduction to the path integral
- Brief review of quantum mechanics for single particle and identical particles
- Second quantization: annihilation and creation operators
- Single-particle and double-particle operators
- Bosonic coherent states
- Grassmann algebra
- Fermionic coherent states
- Gaussian integrals with complex and grassmannian variables
- Feynmann integrals
- Partition function and imaginary time
- Equation of motion and stationary phase approximation
- Application of Feynman integrals for a double-well: instanton gas
- Functional integrals with coherent states
- Interacting particles: perturbation theory
- Functional integral for the electromagnetic field

Part 2: Applications
- Coulomb gas
* Perturbative approach
* Random Phase Approximation
* Functional integral method
- Non-interacting bosons: Bose-Einstein condensation
- Goldstone theorem
- Interacting bosons: Superfluidity
* Bogoliubov spectrum
* Landau criterion
* Action for the Goldstone mode
* Phenomenology
- Superconductivity
* Phenomenology and London equations
* Electron-phonon interaction
* Cooper problem
* BCS theory by functional approach: gap equation and critical temperature
* Ginzburg-Landau theory
* Action for the Goldstone mode
* Meissner effect and Higgs mechanism

Examination:
Oral examination

More information:

THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. A)
Master degree in Physics, First semester
Lecturer: Pierpaolo Mastrolia
Credits: 6 ECTS

Prerequisites:
Principle of Theoretical Physics

Short program:
Outline:
Lorentz-Poincare' Group and Representations.
Relativistic Wave Equations. Introduction to Classical Field Theory: Lagrangian and Stationary Principle, Noether Theorem.
Canonical Quantization for: Schrödinger field, Klein-Gordon field, Electromagnetic field.
Interacting Quantum Fields: S-matrix and Feynman rules.
Basic applications to QED.

Examination:
Written and oral exam

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2382/001PD/SCP9087857/N0
THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. B)
Master degree in Physics, First semester
Lecturer: Stefano Rigolin
Credits: 6 ECTS
Prerequisites: Principle of Theoretical Physics
Short program:
Programme:
1. Quantum Electrodynamics: Feynman rules, tree level processes (Rutherford, Compton and Bhabha scattering, Bremsstrahlung).
3. Quantum Chromodynamics: The "colour" algebra, Feynman rules and scattering amplitudes for gluons and quarks at tree level.
4. Electroweak gauge theory. The Fermi effective Lagrangian: Feynman rules and muon decay. SU(2)xU(1) gauge theory and Electroweak unification.
7. The electroweak Lagrangian for one and three families.
Examination:
Written and oral exam
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2382/001PD/SCP9087898/N0

ADVANCED PHYSICS LABORATORY A
Master degree in Physics, Second semester
Lecturer: 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:

ADVANCED PHYSICS LABORATORY (OFFERED IN THE MASTER DEGREE IN PHYSICS EXAM OF ADVANCED PHYSICS LABORATORY A)
Master degree in Physics, Second semester
Lecturer: 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:
APPLIED ELECTRONICS

Master degree in Physics, Second semester
Lecturer: Piero Giubilato
Credits: 6 ECTS

Short program:

PART 1 - Devices (1 weeks)
- 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...).
- MOS transistor dynamic behavior, linear region, inversion region, saturation region, power consumption, speed, parasitics, 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.
- Boolean algebra basics REVIEW (DeMorgan’s theorems) and its applications to basic gates combinations.
- More complex basic logic blocks: adder, multiplexer, parity checker, LUT.
- 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 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.
- Verilog language scope and basics, concept of synthesis and simulation code, modules encapsulation, timebase definitions, some elementary syntax and constructs (especially the synchronous blocks like always, etc..).
- Synchronous systems: how to deal with large system by using a common time-base. The clock properties (frequency, jitter) and implications. Description of the clock network, examples on how to cross different clock domains.
- Usage of memory elements to build a complete synchronous system. The reset procedure
- Finite State Machines types, principle of operation, and building elements. FSM analytical description and basic coding in Verilog.
- Actual memories type and use in computer and other logic: ROM, RAM, FLASH, EPROM, basic characteristics, behavior and device realization.
- Clock synthesis elements: VCO, DCO, PLLs, architecture and usage.

PART 4 - FPGA devices (3 weeks)
- FPGA basic architecture: configuration RAM, switching matrix, CLB blocks, LUT and registers. How to synthesize arbitrary functions by using LTUs.
- FPGA resources, usage of registers and counters. Implementation of simple state machines, connection of modules in a hierarchical structure. IO interfaces, serializers, deserializers, transceivers.
- Implementation of simple synchronous circuits in FPGA through Verilog description. Definition of inputs, outputs, clock, and reset.
- Usage of device primitive (MMCM) to synthesize high-frequency clocks within the device. Phase alignments of the clocks. Cross-domain clocks.
- FIFO memories and their usage.
- Slicing an operation in time to allow higher clock frequencies, latency and speed.
- Timing verification, corner cases, setup and hold times.
- Complex systems behavior and modelling, with special focus on radiation tolerance/resistance and mitigation techniques and topologies.
- Failure rate estimation through Markov Chains, protection schemes and their effectiveness, practical implemen.

**Examination:**
Oral exam

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2382/001PD/SCP7081701/N0

ASTROPARTICLE PHYSICS
Master degree in Physics, Second semester
Lecturer: Francesco D’Eramo
Credits: 6 ECTS

**Prerequisites:**
It is suggested to take the courses Theoretical Physics and Theoretical Physics of Fundamental Interactions in the first semester.

**Short program:**
1) Particle Physics
2) Neutrino Physics
3) Particle Physics in the Early Universe
4) Matter/Antimatter Asymmetry, Microscopic Models for Baryogenesis and Leptogenesis
5) Evidence for Dark Matter
6) WIMP Dark Matter
7) Axion Dark Matter
8) Inflationary Universe
9) Dark Energy and Quintessence Models

**Examination:**
Oral exam

**More information:**

BIOLOGICAL PHYSICS
Master degree in Physics, Second semester
Lecturer: Mario Bortolozzi
Credits: 6 ECTS

**Prerequisites:**
The course will be held in English.

**Short program:**
Introduction: what is biophysics, top-down and bottom-up approaches. 
The living cell: eukariotyc and prokaryotic cells, cell structure and function of its constituents, cell division. 
The water: structure and chemical-physical properties, water-protein interaction, optical properties of water, pH and buffering systems, cell incubators. 
Membranes and channels: conductance, cell equivalent circuit, Nernst potential, voltage-clamp technique, Hodgkin-Huxley model, neuronal action potential and its simulation, saltatory conduction and Schwann cell, patch-clamp, electrophysiology setup, derivation of cell electrical parameters, single channel current measurement, voltage-activated channel types and blockers, muscle and hair cell synapse, two-state channel model, three- and multi-state models, receptors, activation energies of a channel. 
Diffusion: Fick's laws, diffusion from a point source, random walk and Monte Carlo approach, particle interaction with boundaries, random walk on a grid, numerical simulations of the diffusion process, discretization of the diffusive Laplacian, hydration shells, Kramer equation, electrical mobility, Nernst-Planck equation. 
Permeability: partition coefficient, Goldman-Hodgkin-Kats equations, deviation from Ohm's law, ionic selectivity, single channel permeability, saturation, Eyring's theory, sodium and potassium channel models. 
Chemical reactions: enzymatic reactions, Michaelis-Menten equation, SERCA and PMCA pumps, fluorescent dyes, calcium (Ca2+) dyes, configuration of a fluorescence microscope, relationship between dye fluorescence and Ca2+ concentration, photobleaching, ratiometric dyes, non-equilibrium conditions between Ca2+ and the dye, numerical simulations of Ca2+ dynamics, generation of a reaction-diffusion model and comparison with experiments, Ca2+ dynamics in the inner ear and in cardiac cells, modeling a complex geometry using meshes. 
Molecular dynamics: DNA, RNA and proteins, the central dogma of biology, amino acids, folding and protein structures, simulation of protein dynamics, potential energy formula, computational algorithms, boundary conditions and examples of models. 
Neural networks: machine learning, learning approaches, artificial neuron and schemes of neural networks, error backpropagation, artificial vision and speech recognition, cerebral organoids, Boltzmann machines. 
Mathematical appendix: introduction to Matlab, variables and functions, how to write a simulation code, code optimization and debugging, numerical methods for the solution of a differential equation system, examples and exercises, development of a graphical interface in Matlab. 

Examination: 
The final check is composed of a written and an oral part. The written exam consists of writing a report on a biological model solved by the student using a numerical simulation in Matlab. The oral exam consists of presenting by Power Point slides a recent scientific paper related to the course arguments. 

More information: 

COMPUTATIONAL METHODS IN MATERIAL SCIENCE (OFFERED IN THE MASTER DEGREE IN MATERIALS SCIENCE EXAM OF COMPUTATIONAL METHODS FOR MATERIALS SCIENCE) 
Master degree in Physics, Second semester 
Lecturer: 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.
Intermolecular interactions: force-fields; atomistic and coarse grained models.
Variational methods for the solution of the Schrodinger equation.
Hartree and Hartree-Fock theory.
Elements of Density Functional Theory (DFT).

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:

GENERAL RELATIVITY
Master degree in Physics - Second semester
Lecturer: 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/2020/LM/SC/SC2382/001PD/SCP7081661/N0

INTRODUCTION TO MANY BODY THEORY
Master degree in Physics, Second semester
Lecturer: Pierluigi Silvestrelli
Credits: 6 ECTS

Prerequisites:
Metodi Matematici

Short program:
Second-quantization formalism.
Single-particle and two-particle operators in second quantization.
Hamiltonian of Coulomb systems.
Two-point Green functions; expectation value of a single-particle
operator, ground-state energy, Lehmann representation.
Adiabatic theorem and perturbative evaluation of the ground state.
Wick's theorem and Feynman diagrams for fermionic systems at $T=0$.
Self-energy, polarization diagrams (effective interaction), Dyson's
equations.
Ground-state energy of the degenerate electron gas ("jellium" model)
in the ring approximation (RPA).
Linear-response theory; applications:
screening of the electric charge (Friedel oscillations),
plasma oscillations, electronic scattering cross section for the
inelastic electron scattering.
Interacting Bose systems at $T=0$.
Temperature Green's functions: Wick-Matsubara' theorem and
Feynman diagrams.

**Examination:**
Oral exam and home-work exercises.

**More information:**

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**INTRODUCTION TO NANOPHYSICS (OFFERED IN THE MASTER DEGREE IN MATERIAL SCIENCE EXAM OF FUNDAMENTALS OF NANOSCIENCE)**

Master degree in **Physics**, Second semester
Lecturer: Giovanni Mattei
Credits: 6 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:**
1) Fundamentals of NanoScience (MSc in Materials Science, 4 + 4 = 8 CFU)
   MODULE A (4 CFU)
   - Classification, characteristics and general properties of nanostructured materials: quantum
     confinement and electronic properties. Size Equations.
   - Thermodynamic properties of nanostructured materials: thermodynamic size effect, nucleation
     (Gibbs-Thomson equation) and growth of nanostructures (Diffusion-Limited Aggregation and Ostwald Ripening regimes).
   - Nanostructures embedded in solid matrices: ion implantation for the synthesis and
     processing of metallic nanostructures. Verification of the nucleation and growth models.
   - Optical properties of nanostructured materials: (i) plasmonic properties of non-interacting
     metallic nanostructures (Mie theory and its extensions); (ii) interacting nanostructures
   - Characterization techniques of nanostructures: transmission and scanning electron
     microscopy in transmission (TEM) and in scanning (SEM) mode.
   MODULE B (4 CFU)
   Overview of the preparation methods of nanostructures (both top-down and bottom-up, with
   particular emphasis on the latter). Structural aspects and energy of nanostructures and
   methods for their stabilization. Defects in nano dimensional materials. Solid with controlled
   porosity. Forms of nanoparticles: thermodynamics vs. kinetics. Core-shell nanoparticles. Self-
   assembly and self-organization. Colloidal method. Templating effect. Preparation of
   nanoparticles, nanowires, nanotubes, thin films. Self-assembled monolayers. Langmuir and
   Growth methods for ultrathin films: CVD, MBE, PVD, ALE and PLD methods.
   Recall of the fundamental equations for electron and photon dynamics. Material properties for
electron and photon confinement. Density of states for confined systems in one, two or three
Properties of low dimensional carbon nanostructures: graphene and nanotubes. Tight binding approach for the description of their conduction, optical properties (absorption and emission) and Raman scattering (Kataura plots).
Models for the electron confinement in quantum dots in the weak and strong regime.
Confinement of electrons in metallic nanoparticles and plasmonic properties. Froehlich conditions and far and near field optical properties. SERS effect with plasmonic nanostructures.
Hints on the confinement of photons in photonic crystals.

2) Introduction to NanoPhysics (MSc in PHYSICS, 4 + 2 = 6 CFU)
The first 4 CFUs are the same as for MODULE A, previously described, which will be borrowed by the students of the 'Introduction to NanoPhysics' of the MSc Degree in Physics.
The remaining 2 CFUs address the following topics:
- Fundamental description of the dynamics of electrons and photons
- Confinement of electrons and photons in nanostructured or periodic materials:
  - 2D and 3D photonic crystals;
  - Meta-materials: (i) with hyperbolic dispersion and (ii) with negative refractive index;
  - Practical laboratory activities: (i) synthesis of Au spherical nanoparticles in solution; (ii) measurement of their UV-VIS transmittance spectrum; (iii) simulation of the experimental spectra with the Mie theory; (iv) electron microscopy characterization.

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.

More information:

INTRODUCTION TO RADIATION DETECTORS
Master degree in Physics, Second semester
Lecturer: Roberto Stroili
Credits: 6 ECTS

Prerequisites:
Knowledge of electromagnetic phenomena, electromagnetic waves included.
Basic notions about special relativity and quantum mechanics.

Short program:
A. Description of the considered physical phenomena: introduction on the quantities measured in nuclear, high energy physics and astroparticle physics experiments. Charged particles energy loss. Bethe-Block formula, discussion and application to the particle detectors. Particle identification.
Multiple Coulomb scattering. Bremsstrahlung, radiation length, radiation spectrum.
Photon-matter interaction, absorption coefficient, photoelectric effect, Compton effect, pair production.
Scintillation in inorganic and organica materials. Energy loss in gases, diffusion, electric field effect, drift velocity, magnetic field effect. Energy loss in semiconductors.

**Examination:**
Oral.

**More information:**

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**MATHEMATICAL PHYSICS (ALSO OFFERED FOR STUDENTS OF MASTER DEGREE IN MATHEMATICS – EXAM OF HAMILTONIAN MECHANICS)**
Master degree in Physics, Second semester
Lecturer: Paolo Rossi
Credits: 6 ECTS

**Prerequisites:**
Basics of algebra and differential geometry (the very basics of differential geometry will be recalled at the beginning of the course, if needed).
Basic knowledge of Hamiltonian mechanics and/or quantum mechanics would help putting the course content into context, but is not strictly needed.

**Short program:**
Hamiltonian systems in Poisson manifolds
(Poisson algebras, deformation theory, Poisson manifolds and their geometry,...).
Integrability
(reminder of Arnold-Liouville integrability, Lax representations, bihamiltonian structures,...).
Elements of quantization
(basic ideas of quantum mechanics, elements of deformation quantization, quantum mechanics in phase space,...).
Evolutionary Hamiltonian PDEs
(as infinite dimensional Hamiltonian systems, modern theory of integrable PDEs,...).

**Examination:**
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.

**More information:**

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**MULTIMESSENGER ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics, Second semester
Lecturer: Elisa Bernardini
Credits: 6 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 types of particles and 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
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. 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 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). This event happened just few days after another success of multi-messenger astrophysics: the detection of gravitational waves emitted by two merging neutron stars (GW170817), followed by a burst of gamma-rays (GRB 170817A).

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:**

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**NUCLEAR ASTROPHYSICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**

Master degree in **Physics**, Second semester
Lecturer: Teacher in charge not defined yet.
Credits: 6 ECTS
Syllabus non inserito

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2382/001PD/SCP7081704/N0

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**QUANTUM FIELD THEORY**

Master degree in **Physics**, Second semester
Lecturer: Gianguido Dall'Agata
Credits: 6 ECTS

**Prerequisites:**
Relativistic quantum mechanics. Classical filed equations and canonical quantization of the scalar and fermionic fields. Basic QED.

**Short program:**
Examination:
The examination is split in two parts. First there is a written admission test where the student is required to solve one of the problems assigned during the course. The oral examination will be performed with general questions on the topics of the course, including the derivation of the main results.

More information:

RADIOACTIVITY AND NUCLEAR MEASUREMENTS
Master degree in Physics, Second semester
Lecturer: Marco Mazzocco
Credits: 6 ECTS
Prerequisites:
The student must have attended the courses of "Introduction of Nuclear Physics" and "Nuclear Physics"

Short program:
Radioactive decays. Summaries of the interaction of charged and neutral particles with matter in the energy range of nuclear physics and detection techniques.
Low energy nuclear energy: Ion accelerators: ion source, beam transport, magnetic analysis. Magnetic spectrometers, neutron detectors, charged particles and gamma radiation.
Dynamics of heavy ion reactions: the different types of nuclear reactions from elastic diffusion
to complete fusion. Identification Techniques of Reaction Products, Detector Telescopes. Measurements of cross-section at energies around the Coulomb barrier. Angular distributions and excitation functions.


Low radioactivity techniques: The problem of environmental radioactivity, a good shielding material, a screening of shielding materials (lead, iron, OFHC copper, mercury). The Rn as contaminant in low radioactivity measures. Intrinsic Detector Radioactivity. Effects of cosmic radiation.


**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:**

**STANDARD MODEL**
Master degree in Physics, Second semester
Lecturer: Paride Paradisi
Credits: 6 ECTS

**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.

**Short program:**
1) Introduction of the course and review of the Standard Model
2) Discrete symmetries: C, P, T symmetries and the CPT theorem. Sakharov conditions.
3) Chiral symmetries of the QCD and determination of the CKM matrix
4) Neutrinos: neutrino masses and mixings, neutrino oscillation in vacuum and matter. Lepton flavor violation (mu -> e gamma) and lepton number violation (neutrinoless double beta-decay).
5) Effective Field Theories
6) Discovery of the weak neutral-current at low-energy
7) Electro-weak precision observables (EWPO) at LEP-I and LEP-II. Goldstone boson equivalence theorem
8) Renormalization: regularization and renormalization schemes, self energies and vertex correction of QED and the electron g-2. Ward identity and beta-function of QED.
10) Anomalies: axial and vector currents in QED. Ward identities. ABJ anomalies in the abelian and non-abelian cases. Anomalies in the SM. Global symmetries and anomalies.
12) Higgs physics: theoretical bounds for the Higgs boson mass (unitarity, triviality and vacuum stability bounds). Direct experimental bounds from LEP and Tevatron and indirect bounds from EWPTs. Higgs production mechanisms and decay modes. Calculation of the decay rate of Higgs → gluon gluon.

Examination:
Oral examination.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2382/001PD/SCP7081698/N0

STRUCTURE OF MATTER (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MATHEMATICAL ENGINEERING EXAM OF ADVANCED QUANTUM PHYSICS AND MASTER DEGREE IN PHYSICS OF DATA EXAM OF STRUCTURE OF MATTER)

Master degree in Physics, Second semester
Lecturer: Luca Salasnich
Credits: 6 ECTS

Prerequisites:
All the exams of the B.Sc. in Physics.

Short program:
5. Second quantization of the Schrodinger field. Field operators for bosons and fermions. Fock and coherent states of the bosonic field operator. Schrodinger field at finite temperature. Matter field for interacting bosons and fermions. Bosons in a double-well potential and the two-site Bose-Hubbard model.

Examination:
Colloquium of about 30 minutes.

More information:
**SUBNUCLEAR PHYSICS**
Master degree in *Physics*, Second semester
Lecturer: 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:**
Introduction and recap
Tools for calculation
Detectors for particle physics experiments
Cross section e+e-→mu+mu- and e+e-→hh
Deep Inelastic Scattering
The Gluon
QCD, Partons and jets
Electroweak interaction:introduction
Experimental tests of Electroweak interaction
Cabibbo Theory and Cabibbo-Kobayashi-Maskawa Matrix
CP and T violation, the B meson system. Tests of CKM
Neutrino and Standard Model
Higgs Properties

**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:**

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**PHYSICS OF DATA**

**ASTRO-STATISTICS AND COSMOLOGY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY )**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in *Physics Of Data*, First semester
Lecturer: Michele Liguori
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.
Cosmological perturbations: Jeans instability, power spectrum, growth factor.

**Short program:**
Applications: power spectrum estimation in cosmological datasets (Cosmic Microwave Background and Large Scale Structure), MCMC for cosmological parameter estimation,
component separation, Gravitational Wave data analysis, Fisher matrix forecasting for 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.
3) Oral examination with discussion of the course topics.

**More information:**

**COMPUTATIONAL ASTROPHYSICS**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in *Physics Of Data*, First semester
Lecturer: 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:**
- General introduction to the astrophysical N-body problem.
- N-body simulations: definition of an N-body simulation; concept of computational complexity; N-body units; exercises on N-body units.
- Examples of numerical algorithms to solve the astrophysical N-body problem: Euler, Leapfrog integrators; exercises with Euler and Leapfrog (motion of a binary system).

- Generation of the initial conditions for an N-body simulation (position, velocities, masses) via Monte Carlo methods: the initial mass function, the Plummer sphere, the Navarro Frank & White potential, Maxwellian distribution of velocities
- Direct N-body codes for collisional systems: Hermite scheme, block time-step algorithm, regularization algorithms.
- Project 1: integrate star cluster dynamics.
- General introduction to close encounters between single and binary stars.
- Project 2: integrate binary black hole formation/disruption through close dynamical encounters.
- Special purpose hardware, graphics processing units and high-performance computing in astrophysics.
- Tree codes, softening.
- Project 3: galaxy-galaxy interactions.
- Gas dynamics and algorithms for gas dynamics: smoothed particle hydrodynamics, mesh codes, adaptive mesh refinement codes, hybrid moving mesh codes.
- Sub-grid physics: star formation, sink particles, supernovae, radiative transfer.
- Project 4: molecular cloud collapse and star formation.
- Population-synthesis codes: simulating single and binary stellar populations. The formation of binary black holes and binary neutron stars. Combination of population synthesis and N-body simulations.
- Project 5: the formation of binary black holes from different stellar populations.

**Examination:**
Oral exam to discuss the scientific projects and the topics of the course.

**More information:**
DIGITAL SIGNAL PROCESSING (OFFERED IN THE MASTER DEGREE IN ICT FOR
INTERNET AND MULTIMEDIA)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics Of Data, First semester
Lecturer: Federica Battisti
Credits: 6 ECTS

Prerequisites:
This course has the following prerequisites: Basic knowledge of Mathematics, Probability
Theory, Statistics, Linear Algebra, fundamentals of signals and systems, knowledge on Fourier
analysis, and basics of Computer Programming (in Matlab or Python).

Short program:
The module will cover the following topics:
1. Shift-invariant discrete time linear systems; Systems defined by linear constant coefficient
difference equations; Z-transform and its properties.
2. Discrete Fourier Transform (DFT): definition, properties and usage in practical contexts;
FFT algorithms; fast convolution algorithms.
3. Design of linear phase FIR filters: windowed Fourier series technique; frequency sampling
method; minimization of the Chebyschev norm (Remez algorithm).
4. IIR filter design using the bilinear transformation method; Butterworth, Chebyschev and
Cauer filters; frequency transformations.
5. Multirate linear systems: interpolation and decimation; Efficient realizations; Examples of
application.

Examination:
The course has the following methods of examination:
DIGITAL SIGNAL PROCESSING module:
The grading of the expected knowledge and skills is based on two contributions:
1. a closed book WRITTEN EXAM, where the student must solve four problems, needed to
verify that a good knowledge of the theoretical aspects and of the fundamental characteristics
of the various digital signal processing systems analyzed during the course has been acquired;
2. the development of a simple HOMEWORK consisting in a computer simulation project using
Matlab, to check the ability of the student to apply the theoretical concepts to a practical
implementation. Each student must write a short report describing the methodologies used to
solve the assigned homework and the obtained results.

MACHINE LEARNING module:
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/2019/LM/SC/SC2443/000ZZ/SCP8082710/N0
GAME THEORY (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics Of Data, First semester
Lecturer: Elvina Gindullina
Credits: 6 ECTS

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

Short program:
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons
Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle
Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization
Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value
Resource allocation
Utilities, choices, and paradoxes
Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems

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/2019/LM/SC/SC2443/000ZZ/SCP7079401/N0

GENERAL RELATIVITY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)
Master degree in Physics Of Data, First semester
Lecturer: Marco Peloso
Credits: 6 ECTS

Prerequisites:
Knowledge of Special Relativity

Short program:
1. Preliminaries
3. Gravity as Geometry
4. The Einstein equations
Parallel transport and curvature. Covariant derivative, Riemann, Ricci, and Einstein tensor. The source of curvature. Einstein equations and weak field approximation.
5. Geodesics
The geodesic equation. Symmetries and Killing vectors. Local inertial frames and freely falling frames.
6. Schwarzschild Geometry
7. Horizons and Coordinate Systems
8. Rotations and Kerr Geometry
Geodetic precession around a non-rotating, and a slowly rotating body. Kerr metric and the ergosphere.
9. Cosmology
10. Gravitational waves (if time permits)

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

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081661/N0
INFORMATION THEORY AND INFERENCE
Master degree in Physics Of Data, Annual
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
Prerequisites:
Basics of Probability Theory. Models of Theoretical Physics or Theoretical Physics

Short program:
• The program can be summarized as follow
  Basic Principles
  o Bayesian Statistics: prior, likelihood, posterior.
  o The Monte Carlo Paradigm: noise vs. bias.
  o Basic building blocks of samplers: transformations, weighting (importance sampling), acceptance/rejection.
  Exploring a high-dimensional potential
  o The Metropolis algorithm (Markov Chain Monte Carlo)
  o Gibbs sampling: local interactions.
  o Adaptive (non-Markov) algorithms
  o Ensemble methods
  Information Theory
  o Information Bottleneck, and predictive information.
  o Diffusion and Information theory: Machine learning kernels and the Green's function of the Diffusion equation
  • The program can be summarized as follow
  Basic Principles
  o Bayesian Statistics: prior, likelihood, posterior.
  o The Monte Carlo Paradigm: noise vs. bias.
  o Basic building blocks of samplers: transformations, weighting (importance sampling), acceptance/rejection.
  Exploring a high-dimensional potential
  o The Metropolis algorithm (Markov Chain Monte Carlo)
  o Gibbs sampling: local interactions.
  o Adaptive (non-Markov) algorithms
  o Ensemble methods
  Information Theory
  o Information Bottleneck, and predictive information.
  o Diffusion and Information theory: Machine learning kernels and the Green's function of the Diffusion equation
  o Partially Observed Markov Decision Processes
  o Example: application to time series data.
  Bayesian inference: Letting the model fluctuate around the data
  o Gaussian Process (GP): Using a path integral to fit data
  o GP Example: Fitting spherical harmonics to data
  o GP Example: Gaussian Process for Time Series
  o Dirichlet Process and Information Theory (DP): The probability over probability distributions
  o Example: Computing the uncertainty in the density estimation of a gas
  o Example: Unsupervised Clustering of data points
  Information Geometry
  o Using Entropy to Understand Probability
  o Comparing probability distributions: From KL divergence to information geometry
  o Local structure versus Global symmetries: Hamiltonians or Green’s functions
The manifold of multivariate Gaussian probability distributions.

Diffusion on a Manifold: Parametric approximation.

The Estimation of the Gradient of a Density Function

Example: manifold learning from time series data.

Example: clustering data

The statistics of high-dimensional point clouds

Estimating the dimensionality of the data

Manifold Learning and Local Models in high dimension.

Mixture of Probabilistic PCA

Divide and conquer the manifold: Estimating tangent spaces in high-d data.

Stitching together the tangent spaces: Interpolating between tangent spaces

Example: Application to data

Hamiltonian Dynamics: Beyond random search.

Hamiltonian Monte Carlo (HMC)

HMC for stochastic differential equations: path-integrals and separation of time.

THERMODYNAMICS: Entropy and learning.

Approximate Bayesian Computation (ABC)

Simulated Annealing ABC: learning with minimal entropy production [Albert et al. 2014].


Statistical Mechanics: Interacting particle systems as inference tool.

Field-theoretic description: Doi-Peliti formalism.

Inference: particle filters and path-integral methods.

Examination:
The first part of the verification of the acquired knowledge will be evaluated through homeworks and the participation of the students in the class discussions. The second part will take place through presentation of a small project or exercises and open questions to test the knowledge on basic concepts, the scientific vocabulary, the ability to synthesis and critical discussion on the various topics discussed during the course.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCQ0093479/N0

LABORATORY OF COMPUTATIONAL PHYSICS (C.I.)

Master degree in Physics of Data, Annual

Credits: 12 ECTS

Modules of the integrated course unit:
- LABORATORY OF COMPUTATIONAL PHYSICS (MOD. A)
- LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)

Common characteristics of the Integrated Course unit:

Prerequisites:
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/2020/LM/SC/SC2443/000ZZ/SCP8082524/N0

LABORATORY OF COMPUTATIONAL PHYSICS (MOD. A)
**Specific characteristics of the Module**
Lecturer: Marco Zanetti

**Prerequisites:**
Even though not strictly required, the development of the class assumes the attendance of at least two physics laboratory classes during the bachelor degree

**Short program:**
- The working principles and logic schemes of a modern computer and its main components.
- Review of the available hardware solutions to face problems in various areas of scientific computing: parallel computing, cluster/cloud computing, distributed computing
- 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.)
- 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

**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/2020/LM/SC/SC2443/000ZZ/SCP8082525/N0

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**LABORATORY OF COMPUTATIONAL PHYSICS (MOD. B)**

**Specific characteristics of the Module**
Lecturer: Marco Baiesi

**Short program:**
* Gradient descent methods
* Ridge and LASSO regularization
* Deep neural networks and convolutional version
* Clustering
* Data visualization
* Energy-based models
* Restricted Boltzmann machines
* Combination of models

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP8082526/N0

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**LIFE DATA EPIDEMIOLOGY (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics Of Data, First semester
Lecturer: No lecturer assigned to this course unit
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:**
The exam will consist of two parts.
1) an individual written exam with exercises on mathematical evaluations and practical applications of concepts explained during the course
2) a (group) project developed throughout the course and discussed after the written exam
The two parts of the exam can be sustained separately, although it is advised that the students perform them together (typically, exam sessions will have both parts in the order above)

**More information:**

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**MACHINE LEARNING (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)**
Master degree in **Physics Of Data**, First semester
Lecturer: Pietro Zanuttigh
Credits: 6 ECTS

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

**Short program:**
Motivation; components of the learning problem and applications of Machine Learning.
Supervised and unsupervised learning.

**PART I: Supervised Learning**
1. Introduction: Data, Classes of models, Losses.
2. Probabilistic models and assumptions on the data. The regression function. Regression and Classification.
3. When is a model good? Model complexity, bias variance tradeoff/generalization (VC dimension, generalization error).
5. Classes of nonlinear models: Sigmoids, Neural Networks.
6. Kernel Methods: SVM.
8. Validation and Model Selection: Generalization Error, Bias-Variance Tradeoff, Cross Validation. Model complexity determination.

**PART II: Unsupervised learning**
2. Dimensionality reduction: Principal Component Analysis (PCA).

**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/2020/LM/SC/SC2443/000ZZ/SCP8082660/N0

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (C.I.)
Master degree in Physics of Data, Annual
Credits: 12 ECTS

Modules of the integrated course unit:
- MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)
- MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)

Common characteristics of the Integrated Course unit:
Prerequisites:
Elements of analysis and algebra.
General physics.
Statistics.
Basic programming elements.

Examination:
Development of a project assigned at the end of the course. Presentation and discussion of the project, questions on the material presented in class.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP8082533/N0

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. A)
Specific characteristics of the Module
Lecturer: Gianmaria Collazuol

Prerequisites:
Elements of analysis and algebra.
General physics.
Statistics.
Basic programming elements.

Short program:
PART I - Electronics for real-time data management systems
1) Data Sources
   - signal generation in sensors/detectors
   - early (analog) data processing (amplification, filtering, ...)
   - digitization (A/D, ADC, TDC,...)
   - timing, sync and control signals distribution systems
2) Data Transport
   - Data Transport Architectures
   - Physical layers for data streams
- Interconnections and buses
3) Real Time Data Processing
- Digital ports and logics
- Storage units - Memories
- Processing units - focusing on FPGA
- Parallel data streams
4) Real Time Data Filtering and System Control
- Trigger generation and distribution
- Transducers and System Control

PART II - Hands-on Laboratory of data management with FPGA
1) Introduction to FPGA and intro to the ARTY A7 board
2) FPGA Programming framework, Simulation and Test-Bench
3) Combinational Logic Circuits
4) Sequential Logic Circuits
5) Virtual Input Output and Integrated Logic Analyzer
6) Arithmetic Operations
- case study: DAC/ADC and FIR Filter
7) Finite State Machines
8) Memories
9) Buses and Protocols
- case study: SPI interface for accessing Flash memory
- case study: IPBUS - communication FPGA-PC via Ethernet interface
NOTE - Examples and Case studies will be chosen in various fields: from High Energy Physics to Astro-particle and Space Physics Systems on satellites; from Nuclear Imaging Medicine to Low-Latency Market Data Feed Processing; from Biomedical and Neuro Sciences to Gravitational Wave Physics.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP8082534/N0

MANAGEMENT AND ANALYSIS OF PHYSICS DATASET (MOD. B)

Specific characteristics of the Module
Lecturer: Jacopo Pazzini

Prerequisites:
Elements of analysis and algebra.
General physics.
Statistics.
Basic programming elements.

Short program:
Part 1) Distributed computing
Distributed Computing systems and the Grid paradigm
Computing Models
Dask principles
Setup of a cluster with Dask
Data movement and analysis on dask cluster
Machine learning on a dask cluster
Part 2) Data Management
Data Workflows in scientific computing
Storage Models
Data management components:
- Name Servers and databases
- Data Access protocols
- Reliability
- Availability
- Access Control and Security
- Cryptography
- Authentication, Authorization, Accounting
- Scalability
- Cloud storage
- Block storage
- Analytics
- Data Replication
- Data Caching
- Monitoring, Alarms
- Quota

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP8082535/N0

### MODELS OF THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)

**Master degree in Physics Of Data**, First semester

Lecturer: 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 steepest descent
distributions/measures

Brownian paths and polymer physics biopolymer elasticity. The random walk
generating function, the Gaussian field theory and coupled quantum harmonic
oscillators.

Levy walks.

Field theories as models of interacting systems

$O(n)$ symmetric Phi$^4$ theory. The large n limit: Spherical (Berlin-Kac) model.

Perturbative expansion. Introduction to renormalization group techniques and universality.

Generalized diffusion and stochastic differential equations. The Feynman-Kac formula

Feynman path integrals and the quantum version of the Feynman-Kac formula.

Quantum mechanics (solvable model: free particle, harmonic oscillator)

Stochastic amplification and stochastic resonance

Non-perturbative methods: instantons

Statistical physics of random spin systems and the machine-learning problem.

Sherrington-Kirkpatrick model

Random energy model, replica trick

**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 various 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/2020/LM/SC/SC2443/000ZZ/SCP8083597/N0
NETWORK SCIENCE (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics Of Data, First semester
Lecturer: 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 (e.g., MatLab, Python, C, Java, Linux). Moreover: 1. for the INTERNET module: to be familiar with the most basic networking and communication concepts and terms (ISO/OSI model, packet-based networks, routing); 2. for the NETWORK SCIENCE module: 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; Evolving networks.
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 - Dendrograms; Girvan Newman method and betweenness; Louvain modularity optimisation; Spectral clustering; Consensus clustering; Measuring similarities in clustering outcomes; 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 course has the following methods of examination:
INTERNET module:
The final exam will be the same for both ATTENDING and NON-ATTENDING students since it does not rely on in-class activities. The exam consists of two parts, namely: 1. a WRITTEN EXAM at the computer, 2. a LAB TEST. Students will be offered four attempts to pass the written and the lab tests. During in-class lectures, the students may be offered to participate to some (in class or at home) activities, such as peer-reviewing of other students’ reports, participating in-class discussion and taking part to problem-solving competitions. The active participation to such initiatives may bring a few extra points (up to 3) to the students.
NETWORK SCIENCE module:
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 project is foreseen in two ways: 1. for ATTENDING students in which the students are guided towards intermediate project objectives (HOMEWORKS) coherently with the development of the lessons, and complete the project at the end of the course; 2. for NON-ATTENDING students, in which the development of the project takes place in a single solution and is discussed in an oral exam in one of the four institutional dates. 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. The final grade is expressed as a combination of the judgments in the two modules (50%+50%).

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2443/000ZZ/SCP8082723/N0

NEURAL NETWORKS AND DEEP LEARNING (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics Of Data, First semester
Lecturer: Alberto Testolin
Credits: 6 ECTS

Prerequisites:
The course relies on preliminary knowledge of mathematical analysis, linear algebra and probability theory. Familiarity with machine learning concepts is desired, though not mandatory. Python programming skills are required.

Short program:
1. Introduction: computational and mathematical modeling of neural systems; levels of analysis in system neuroscience; historical perspectives in cognitive science and artificial intelligence.
3. Principles of neural encoding: spike trains, firing rates, local field potentials; tuning functions and receptive fields; efficient encoding principles and information compression.
4. Neural network modeling: types of architectures; localistic, distributed, and sparse coding; examples from the visual system.
5. Learning, memory and plasticity: synaptic plasticity in biological and artificial neural networks; quick overview of machine learning basics.
7. Supervised deep learning: advanced optimization methods for training deep networks; convolutional architectures; transfer learning; adversarial attacks.
10. Generative models: Boltzmann machines; Deep Belief Networks; Variational Autoencoders; Generative Adversarial Networks.
11. Reinforcement learning: exploration-exploitation dilemma; temporal-difference learning; on-policy and off-policy methods; deep reinforcement learning.
12. Research frontiers: complementary learning systems theory, hippocampus and experience replay; sample-efficient reinforcement learning; curiosity-driven learning; neuromorphic hardware for deep learning.

Examination:
Evaluation of knowledge and abilities acquired will consist on 3 individual assignments, which will be discussed during the oral exam. The assignments will require a software implementation of one or more computational models and analyses discussed during the course, along with a short essay in which the student will describe and discuss the results. The oral exam will also include general theoretical questions related to the course content.

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2443/000ZZ/SCP9087899/N0
NUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)
Master degree in Physics Of Data, First semester
Lecturer: Silvia Monica Lenzi
Credits: 6 ECTS
Prerequisites:
Quantum mechanics
Short program:
Program of Nuclear Physics 2017/2018
First part: Nuclear Structure and Nuclear Models
• Introduction: The nucleus as a laboratory of Quantum Mechanics
• Symmetries and the Nuclear Force
• Experimental methods
• Theoretical Models:
1) Collective Models:
The nuclear deformation
Surface vibrations, Rotating nuclei
2) Microscopic Models: Mean-field Models,
Interacting Shell Model
The Nilsson Model
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 with eventual presentation of a research work on
one of the several subjects proposed by the professors.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081658/N0

QUANTITATIVE LIFE SCIENCE (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET
AND MULTIMEDIA)
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Physics Of Data, First semester
Lecturer: 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 me.
Short program:
The program can be summarized as follow
Theoretical Neuroscience
- Basics in Neuroscience
- Neural circuits & structure and function of brain networks
- Wilson Cowan models
- Stochastic whole brain models
- Mean field approaches
- Criticality in the brain
- Controllability in brain networks

2. Statistical Mechanics of Ecological Systems
- Neutral theory and emergent patterns in ecology
- Dynamical Evolution of Ecosystems
- Upscaling and Downscaling biodiversity
- Species Interaction Networks
- Consumer-Resource Models

3. Physical Models in Biology
- Virus Dynamics
- Bacterial Genetics
- Molecular Population Dynamics
- Gene expressions
- Criticality in gene-regulation networks
- Robustness and Adaptability in Living Systems.

Please note that some topics may vary.

**Examination:**
The first part of the verification of the acquired knowledge will be through homework exercises (to do in groups) 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 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/2019/LM/SC/SC2443/000ZZ/SCP8082720/N0

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**QUANTUM INFORMATION AND COMPUTING (OFFERED IN THE MASTER DEGREE IN PHYSICS EXAM OF QUANTUM INFORMATION)**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Physics Of Data, First semester
Lecturer: Simone Montangero
Credits: 6 ECTS

**Prerequisites:**
Quantum mechanics and elements of programming.

**Short program:**
Basics in computational physics
1. Large matrix diagonalization
2. Numerical integration, optimizations, and solutions of PDE
3. Elements of Gnuplot, modern FORTRAN, python
4. Elements of object-oriented programming
5. Schrödinger equation (exact diagonalization, Split operator method, Suzuki-trotter decomposition, ...)

Basics of quantum information:
1. Density matrices and Liouville operators
2. Many-body Hamiltonians and states (Tensor products, Liouville representation, ...)
3. Entanglement measures
4. Entanglement in many-body quantum systems
Theory:
1. Numerical Renormalization Group
2. Density Matrix Renormalization group
3. Introduction to tensor networks
4. Tensor network properties
5. Symmetric tensor networks
6. Algorithms for tensor networks optimization
7. Exact solutions of benchmarking models

Applications:
1. Critical systems
2. Topological order and its characterization
3. Adiabatic quantum computation
4. Quantum annealing of classical hard problems
5. Kibble-Zurek mechanism
6. Optimal control of many-body quantum systems
7. Open quantum systems (quantum trajectories, MPDO, LPTN, ...)

Examination:
The exam will be a final project composed of programming, data acquisition, and analysis, which will be discussed orally.

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC2443/000ZZ/SCP8082721/N0

SOLID STATE PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)
Master degree in Physics Of Data, First semester
Lecturer: 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/2020/LM/SC/SC2443/000ZZ/SCP7081660/N0

STATISTICAL MECHANICS (OFFERED IN THE MASTER DEGREE IN PHYSICS) 

Master degree in Physics Of Data, First semester 
Lecturer: 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 criterium and upper critical dimension. Scaling theory and Kadanoff block spin argument. 
Renormalisation group in real space. Universality. 
Please note that some topics may vary 
Spontaneous symmetry breaking for continuous symmetry. Goldstone's theorem. 

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/2020/LM/SC/SC2443/000ZZ/SCP7081659/N0

THE PHYSICAL UNIVERSE (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY – EXAM OF FUNDAMENTALS OF ASTROPHYSICS AND COSMOLOGY)

Master degree in Physics Of Data, First semester
Lecturer: 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.
* Shortcomings of the standard cosmological model: horizon, flatness problems, etc.
• 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.
* 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.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081677/N0

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**THEORETICAL PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS EXAM OF THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. A))**

Master degree in **Physics Of Data**, First semester
Lecturer: Pierpaolo Mastrolia
Credits: 6 ECTS

**Prerequisites:**
Principle of Theoretical Physics

**Short program:**
Outline:
Lorentz-Poincare' Group and Representations.
Relativistic Wave Equations. Introduction to Classical Field Theory: Lagrangian and Stationary Principle, Noether Theorem.
Canonical Quantization for: Schroedinger field, Klein-Gordon field, Electromagnetic field.
Interacting Quantum Fields: S-matrix and Feynman rules.
Basic applications to QED.

**Examination:**
Written and oral exams

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081638/N0

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**THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (OFFERED IN THE MASTER DEGREE IN PHYSICS EXAM OF THEORETICAL PHYSICS OF THE FUNDAMENTAL INTERACTIONS (MOD. B))**

Master degree in **Physics Of Data**, First semester
Lecturer: Stefano Rigolin
Credits: 6 ECTS

**Prerequisites:**
Principle of Theoretical Physics

**Short program:**
Programme:
1. Quantum Electrodynamics: Feynman rules, tree level processes (Rutherford, Compton and
Bhabha scattering, Bremsstrahlung).
3. Quantum Chromodynamics: The "colour" algebra, Feynman rules and scattering amplitudes for gluons and quarks at tree level.
4. Electroweak gauge theory. The Fermi effective Lagrangian: Feynman rules and muon decay. SU(2)xU(1) gauge theory and Electroweak unification.
7. The electroweak Lagrangian for one and three families.

**Examination:**
Written and oral exams

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081657/N0

**ADVANCED STATISTICS FOR PHYSICS ANALYSIS (OFFERED IN THE MASTER DEGREE IN GEOPHYSICS FOR NATURAL RISKS AND RESOURCES)**

Master degree in **Physics Of Data**, Second semester
Lecturer: Alberto Garfagnini
Credits: 6 ECTS

**Prerequisites:**
None

**Short program:**
- 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:**
The exam consists of a written test where students (individually) are requested to solve analytically statistical exercises and the presentation of a research project carried out in group; such research project focuses on modern physics topics where statistical tools and concepts described in course play a major role.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP8082557/N0

**BIOLOGICAL DATASETS FOR COMPUTATIONAL PHYSICS**

Master degree in **Physics Of Data**, Second semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS

**Prerequisites:**
Unix and experience in programming is advised. Basic (high-school) chemistry and statistics can be helpful, but not obligatory.

**Short program:**
- 1st week:
Lecture: Defining problems in biology - the information flow
Introduction to biological questions. How biological information is encoded and finding the right level to answer the question. Method selection to approach the problem.
Practical: problem solving in biology - phrases and flowcharts

- 2nd week
Lecture: Datasets versus physical approaches
Physics-based simulation approaches versus bioinformatics, pro’s and con’s. Connections between these approaches. Making the right choice when and what to apply? Data assessment.
Practical: computer simulations and libraries

- 3rd week
Lecture: Understanding proteins through data
Information available from databases and the links in between them. How to combine the information, biological read-outs. How to identify missing data? Assembling data for analysis.
Practical: general protein datasets, establishing comprehensive information

- 4th week
Lecture: Interaction networks
Understanding different aspects of protein interactions and how they are represented in different databases. Overlaps and differences between databases, how to find pieces of information for a model systems? Interpretation of data conflicts.
Practical: analysis of PPI networks, metadata

- 5th week
Lecture: Structure and disorder in proteins
Basis of protein structure, and how it is encoded in sequence. Structure prediction methods for globular and disordered proteins. Deriving structure-function relationships from datasets.
Practical: structure prediction from sequence

- 6th week
Lecture: Mutations and disease
Disease-related mutation databases. Molecular mechanisms how mutations can cause disease. How to analyze mutation data, what can we learn?
Practical: analysis of disease mutations via datasets and predictions

- 7th week
Lecture: Tracing evolution
Key concepts in protein evolution. How evolutionary data is utilized in modern biotechnology? Construction of phylogeny and points for improvements.
Practical: ancestral reconstruction

- 8th week
Lecture: Comparison of organisms
Local and global sequence alignment algorithms. Challenges in comparative sequence analysis. Assessing sequence similarities.
Practical: sequence alignment

- 9th week
Lecture: What is conserved in a protein?
Practical: functional annotations

- 10th week
Lecture: Different levels of protein organisation
Practical: analysis of protein assemblies

- 11th week
Lecture: Tissues and cells
Practical: analysis of tissue-specific networks
- 12th week
Lecture: Proteins and small molecules
Specific target recognition by proteins. The complementarity in interaction interfaces.
Practical: docking
- 13th week
Lecture: What about drugs?
Practical: analysis of drug datasets
- 14th week
Lecture: Pathogen-related transcriptomics
Examination:
In the practicals the students receive a project, which can be solved by independent work. These projects have to be submitted in the middle and at the end of the semester.

These projects require independent thinking and usage of the information, which was given in lectures and practicals. It will show whether the student understood the material. As they do not have to submit each week, they have an opportunity to discuss in case a problem is encountered or something has not been clarified sufficiently. They can also contact the teacher by email in case of an urgent problem.

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.

In some cases oral presentations in the form of flash-talks can be given, but this is not obligatory. It will only be used if the project is excellent, or concerns arise due to originality.

The students will only have to do oral exams if the project performance has not been satisfactory. Oral exams will consist of two parts: i) description of a method ii) proposal to solve a biological problem.

More information: https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCQ0093478/N0

COSMOLOGY (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY – EXAM OF THEORETICAL COSMOLOGY)
Master degree in Physics Of Data, Second semester
Lecturer: Sabino Matarrese
Credits: 6 ECTS
Prerequisites:
Fundamentals of Cosmology and Astrophysics
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 gravitazional 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/2020/LM/SC/SC2443/000ZZ/SCN1035989/N0

NETWORK MODELLING (OFFERED IN THE MASTER DEGREE IN ICT FOR INTERNET AND MULTIMEDIA – EXAM OF STOCHASTIC PROCESSES)

Master degree in Physics Of Data, Second semester
Lecturer: 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/2020/LM/SC/SC2443/000ZZ/SCP8082659/N0

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**RELATIVISTIC ASTROPHYSICS (OFFERED IN THE MASTER DEGREE IN ASTROPHYSICS AND COSMOLOGY)**
Master degree in Physics Of Data, Second semester
Lecturer: Giacomo Ciani
Credits: 6 ECTS

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

**Short program:**
Elements of general relativity. Gravitational waves (GW) in linearized theory; TT-gauge and detector frame; interaction with free falling masses and rigid bodies.
Generation of GW. Quadrupole and post-newtonian approximations. Energy and momentum loss by gravitational wave emission. Examples of GW sources: stable and coalescing binary systems, rotating rigid bodies, extreme mass-ratio inspirals.

**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/2020/LM/SC/SC2443/000ZZ/SCP7081738/N0

**STATISTICAL MECHANICS OF COMPLEX SYSTEMS (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING)**

Master degree in **Physics Of Data**, Second semester
Lecturer: 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 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/2020/LM/SC/SC2443/000ZZ/SCP8082536/N0

**STRUCTURE OF MATTER (OFFERED IN THE MASTER DEGREE IN PHYSICS)**

Master degree in **Physics Of Data**, Second semester
Lecturer: Luca Salasnich
Credits: 6 ECTS

Prerequisites:
All the exams of the B.Sc. in Physics.

Short program:
2. Electromagnetic transitions. An atom in the presence of the electromagnetic field. Fermi golden rule. Dipole approximation. Absorption, stimulated and spontaneous emission of radiation:


5. Second quantization of the Schrodinger field. Field operators for bosons and fermions. Fock and coherent states of the bosonic field operator. Schrodinger field at finite temperature. Matter field for interacting bosons and fermions. Bosons in a double-well potential and the two-site Bose-Hubbard model.

**Examination:**
Colloquium of about 30 minutes.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC2443/000ZZ/SCP7081438/N0

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**SUBNUCLEAR PHYSICS (OFFERED IN THE MASTER DEGREE IN PHYSICS)**

Master degree in **Physics Of Data**, Second semester  
Lecturer: 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:**  
Introduction and recap  
Tools for calculation  
Detectors for particle physics experiments  
Cross section $e+e-\rightarrow\mu+\mu-$ and $e+e-\rightarrow hh$  
Deep Inelastic Scattering  
The Gluon  
QCD, Partons and jets  
Electroweak interaction:introduction  
Experimental tests of Electroweak interaction  
Cabibbo Theory and Cabibbo-Kobayashi-Maskawa Matrix  
CP and T violation, the B meson system. Tests of CKM  
Neutrino and Standard Model  
Higgs Properties  

**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/2020/LM/SC/SC2443/000ZZ/SCP7081697/N0

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**VISION AND COGNITIVE SERVICES (OFFERED IN THE MASTER DEGREE IN COMPUTER SCIENCE)**

Master degree in **Physics Of Data**, Second semester  
Lecturer: Lamberto Ballan
Credits: 6 ECTS

**Prerequisites:**
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

**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 teacher, 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:**
SECOND CYCLE DEGREES WITH SOME COURSE UNITS HELD IN ENGLISH:

CHEMISTRY

PHYSICAL CHEMISTRY OF FLUIDS
Master degree in Chemistry, First semester
Lecturer: Alberta Ferrarini
Credits: 6 ECTS
Prerequisites:
Concept of mathematics: power series expansion, derivatives, integrals.
Thermodynamics: principles, thermodynamic potentials and their properties.
Quantum mechanics: Schroedinger equation, wavefunction, model of particle in a box.
Short program:
The first part of the course will introduce concepts and methods of statistical thermodynamics (distribution functions, partition functions and thermodynamic properties). These will be used to examine fluctuations on the microscopic and molecular scale, intermolecular correlations and thermodynamic properties of simple liquids.
In the second part of the course, the concepts and methods developed in the first part will be applied to topics such as:
- Colloids and dispersed/supramolecular systems: effective interactions (van der Waals and entropic forces, Poisson-Boltzmann theory, DLVO theory), tuning of attractive interactions (phase diagrams of colloids and of protein solutions).
- Polymers: conformational and elastic properties of polymers (freely-jointed and worm-like chain models) and their experimental determination (measure of shape fluctuations and stretching of single polymers); liquid-liquid phase separation (Flory-Huggins theory); coil-globule transition.
- Anisotropic systems: liquid crystals, lipid membranes.
The course includes also some mention of experimental methods for the investigation of the structure and order of fluids, in particular scattering and microscopy techniques and single molecule experiments.
Examination:
Oral exam with at least three open questions, which allow students to use the concepts and methods acquired in the two parts of the course.

PRINCIPLES AND APPLICATIONS OF ORGANOMETALLIC CHEMISTRY
Master degree in Chemistry, First semester
Lecturer: 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 of the main group elements
The preparation methods, the properties and the applications of the most important organometallic compounds of the main group metals, of the group 12 metals and of boron will be illustrated.
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 carbynyls, metal carbenes, metal olefin and metal alkyne 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/2019/LM/SC/SC1169/000ZZ/SCP9087645/N0

PROTEIN STRUCTURE AND DYNAMICS
Master degree in Chemistry, First semester
Lecturer: Massimo Bellanda
Credits: 6 ECTS

Prerequisites:
Basic knowledge of physical-chemistry and biochemistry

Short program:
1. Basic concepts in NMR: introduction to nuclear spin physics, chemical shift, scalar coupling.
2. Relaxation, dipolar coupling, nuclear Overhauser effect (NOE).
3. Practical aspects in the acquisition of NMR spectra: principal components of NMR spectrometer, acquisition and processing of NMR signals, preparation of samples suitable for the NMR analysis.
4. Principle of FT-NMR; Product Operator formalism to describe NMR experiments.
5. Homonuclear 2D NMR experiments (COSY, TOCSY, NOESY).
7. Triple resonance NMR experiments for the study of proteins.
8. Use of NMR data for the structural characterization of peptides and proteins: secondary structure from NMR parameters, high resolution tertiary fold from NOE data. Structure validation.
9. Spin relaxation measurements to evaluate protein dynamics
10. Strategies to study large proteins: TROSY experiments and deuteration.
11. Residual Dipolar Couplings in structural biology.
12. Protein-and protein-ligands interactions by NMR.
13. Production of recombinant labeled proteins.

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/2019/LM/SC/SC1169/000ZZ/SCP9087646/N0

CHEMISTRY OF ORGANIC MATERIALS
Master degree in Chemistry, Second semester
Lecturer: Enzo Menna
Credits: 6 ECTS

Prerequisites:
General Organic Chemistry.

Short program:
The course program covers main application fields for advanced organic materials. Each application will be discussed with regard to:
- theoretical bases required to understand how the material works
- different chemical classes of materials
- different kind of structures (polymers, oligomers, molecules, supramolecular systems and nanostructures)
- synthesis and characterization of structures
- structure-property relationships (e.g. effect of the substituent, of the supramolecular organization, ...)
- device fabrication techniques (e.g. thin layer deposition, self assembly of systems, ...)
- example of application both at research and commercial level.

According to such scheme, the following topics will be considered in particular:
- Fullerenes, nanotubes and other carbon nanostructures
- Organic photovoltaic devices
- Organic electroluminescent materials (OLED)
- Supramolecular polymers
- Self assembled layers of organic molecules
- Organic molecules for non-linear optics
- Advanced biomimetic materials: dry adhesives (gecko effect) and self healing materials.
- Structural organic materials: main classes of plastic and engineering polymers, their application, synthesis and properties.

Examination:
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/2020/LM/SC/SC1169/000ZZ/SCP9087639/N0

MAGNETIC SPECTROSCOPIES
Master degree in Chemistry, Second semester
Lecturer: Lorenzo Franco
Credits: 6 ECTS

Prerequisites:
Physics and quantum chemistry basics.

Short program:

Examination: Oral examination.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1169/000ZZ/SCP9087644/N0
OPTICAL PROPERTIES OF MOLECULAR SYSTEMS
Master degree in Chemistry, Second semester
Lecturer: Elisabetta Collini
Credits: 6 ECTS

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

Short program:
1. Electromagnetic fields (Maxwell's equations)
2. Dielectric properties of materials and molecules (linear and nonlinear regime)
3. Time dependent perturbation theory of spectroscopy in frequency and time domain
4. Interaction with the bath: time correlation functions
5. Absorption, emission and scattering a reinterpretation of well-known spectroscopic observables in terms of correlation functions (lineshape function)
6. Electronic and vibronic transitions: absorption and emission
7. Photochemistry and photochemistry of molecular aggregate systems
   a Frenkel excitons
8. Time resolved spectroscopy for the study of the dynamics and photophysics of molecular systems. Response theory applied to linear and non linear optical spectroscopies
9. Elements of non linear optical spectroscopy in the time and in the frequency domain.

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/2020/LM/SC/SC1169/000ZZ/SCP9087642/N0

PHYSICAL CHEMISTRY OF THE SOLID STATE AND OF MATERIALS
Master degree in Chemistry, Second semester
Lecturer: 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:
1. Basics. Classification of solids
2. Structure and Symmetry in Crystals
3. Local order in fluids and amorphous solids
4. Polymers
5. Lattice dynamics
6. Phonons and thermal properties
7. Electrons in crystals
8. Metals and semiconductors
9. Physical properties of crystals. General principles
10. Dielectric and optical properties of insulators
11. Magnetic materials
12. Devices based on inorganic and organic semiconductors.
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/2020/LM/SC/SC1169/000ZZ/SCP9087640/N0

PHYSICAL METHODS IN ORGANIC CHEMISTRY (OFFERED IN THE MASTER DEGREE IN INDUSTRIAL CHEMISTRY)
Master degree in Chemistry, Second semester
Lecturer: 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/2019/LM/SC/SC1169/000ZZ/SCP9087647/N0

THEORETICAL CHEMISTRY
Master degree in Chemistry, Second semester
Lecturer: 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/2020/LM/SC/SC1169/000ZZ/SCP9087641/N0

COMPUTER SCIENCE

ADVANCED TOPICS IN COMPUTER SCIENCE
Master degree in Computer Science, Annual
Lecturers: Giovanni Da San Martino
Credits: 6 ECTS
Prerequisites: Basic knowledge of linear algebra, probability, machine learning and Python is recommended.
Short program:
- Introduction to machine learning: a practical perspective
- Basic text processing: sentence splitting, tokenisation, Part of Speech tagging, Named Entity Recognition, Coreference Resolution
- Syntactic Parsing, Semantic Role Labeling
- Vectorial representation of texts: n-grams, word2vec, representation of sentences.
- Text Generation: language models, sequence-to-sequence models
- Applications: machine translation, sentiment analysis, (community) question answering, news analysis.
Examination:
Oral exam or development of a project (to be decided with the professor)

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCP6076301/N0

ARTIFICIAL INTELLIGENCE
Master degree in Computer Science, First semester
Lecturer: 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/2020/LM/SC/SC1176/000ZZ/SCQ0093639/N0
**BIOINFORMATICS (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE)**

Master degree in Computer Science, First semester  
Lecturer: 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.

**More information:**


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**COMPUTER AND NETWORK SECURITY (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE AND IN CYBERSECURITY) EXAM OF COMPUTER AND NETWORK SECURITY: ADVANCED TOPICS)**

Master degree in Computer Science, First semester  
Lecturer: 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/2020/LM/SC/SC1176/000ZZ/SCP6076342/N0

**CRYPTOGRAPHY (OFFERED IN THE MASTER DEGREE IN CYBERSECURITY EXAM OF CYBERSECURITY AND CRYPTOGRAPHY: PRINCIPLES AND PRACTICES)**

Master degree in **Computer Science**, First semester
Lecturer: 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. Migliardi; 6 credits): OS, Programming.

**Short program:**

For the second part (Prof. Conti and Prof. Migliardi; 6 credits):

**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.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCQ0093658/N0

**FORMAL METHODS FOR CYBER-PHYSICAL SYSTEMS**
Master degree in **Computer Science**, First semester
Lecturer: 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:**
Cyber-Physical Systems: definition and key features.
Formal models for cyber-physical systems: synchronous and asynchronous models, timed and hybrid models.
Analysis of cyber-physical systems: safety and liveness properties, dynamical systems and control properties.

**Examination:**
Oral exam and/or project

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCQ0089514/N0

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**FUNCTIONAL LANGUAGES**
Master degree in **Computer Science**, First semester
Lecturer: Gilberto File'
Credits: 6 ECTS

**Prerequisites:**
Imperative and object oriented programming

**Short program:**
The course introduced the functional language Haskell. In particular the following aspects are studied:
Pattern matching.
Curryfied and higher-order functions.
Type inference: what it is and how it is done.
I/O.
Parametric polymorphism.
Lazy evaluation.
Functors, applied functors and monads.
Run-time support.
Parsing with Monads

**Examination:**
The exam has a written and an oral part. The written part counts for 80% of the final grade and concerns the concepts and exercises studied during the course. The oral part is a discussion about the project that consists of a parser for a functional language.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCP6076299/N0

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**GAME THEORY (OFFERED IN THE MASTER DEGREE IN INGEGNERIA INFORMATICA)**
Master degree in **Computer Science**, First semester
Lecturer: Elvina Gindullina
Credits: 6 ECTS

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

**Short program:**
Basic concepts of game theory
Utility, market, discount factor
Static games in normal form
Dominance, Nash equilibrium
Efficiency, price of anarchy
Zero-sum games, minmax games
Mixed strategies, mixed equilibria
Nash theorem, minmax theorem
The tragedy of the commons

Dynamic games
Strategy and subgames
Backward utility
Stackelberg equilibria
Repeated games and cooperation
Dynamic duopolies, collusion
Cooperation, pricing
Imperfect/incomplete information
Bayesian games, signaling, beliefs
Revelation principle

Axiomatic game theory
Fictitious play
Best response dynamics
Distributed optimization
Algorithmic game theory
Computation, complexity, and completeness of equilibria
Auctions, bargaining
First-price and second-price auctions
VCG principle
Cooperative games: the core, the Shapley value

Resource allocation
Utilities, choices, and paradoxes
Potential games, coordination
Bio-inspired algorithms
Evolutionary games
Cognitive networks
Selfish routing
Game-theory enabled multiple-input systems

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/2020/LM/SC/SC1176/000ZZ/SCP7079401/N0
**METHODS AND MODELS FOR COMBINATORIAL OPTIMIZATION (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING AND DATA SCIENCE)**

Master degree in **Computer Science**, First semester  
Lecturer: Luigi De Giovanni  
Credits: 6 ECTS  

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

**Short program:**  
1. Advanced linear programming and duality with applications: primal-dual simplex, column generation, applications to network optimization.  
2. Advanced methods for Integer Linear Programming (ILP): Branch & Bound and relaxation techniques, alternative ILP formulations, cutting planes method and Branch & Cut, application to relevant examples (Traveling Salesman Problem, location, network design etc.).  
4. Application of graph modeling and optimization.  
5. Labs: optimization software packages and libraries.  

**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:**  

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**PROCESS MINING (OFFERED IN THE MASTER DEGREE IN DATA SCIENCE)**

Master degree in **Computer Science**, First semester  
Lecturer: Massimiliano De Leoni  
Credits: 6 ECTS  

**Prerequisites:**  
Basic notions of algorithms, data structures and programming, as acquired in course "Fundamental of Information Systems".  

**Short program:**  
The course will cover the topics listed below:  
1. **MODELING AND ANALYSIS VIA THE BPMN LANGUAGE**  
   - Essential and Advanced Process Modeling in BPMN  
   - Qualitative Analysis  
   - Quantitative Analysis  
   - Simulation-based analysis  
2. **MODELING AND ANALYSIS VIA PETRI NETS**  
   - Basic Concepts of Petri Nets  
   - Usage of Petri Nets to model business processes  
   - Structural Analysis of Petri Nets  
   - Soundness of Business Processes: Basic Principles and Checking  
3. **PROCESS MINING**  
   - Introduction to Process Mining and Event Logs  
   - Basic Techniques for Process Discovery and Limitations  
   - Advanced Techniques for Process Discovery: Heuristic Miner and Inductive Miner  
   - Conformance checking based on token replay  
   - Conformance checking based on alignments
- Mining the Additional Perspectives on Decision, Time and Resource
- Social Network Analysis

4. PREDICTIVE PROCESS MONITORING
- Basic Predictive Process Monitoring Techniques
- Advanced Predictive Process Monitoring Techniques

Examination:
Written exam, and a mandatory project.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCP7079235/N0

RUNTIMES FOR CONCURRENCY AND DISTRIBUTION
Master degree in Computer Science, First semester
Lecturer: 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.
However, the class does not place explicit prerequisites for admission: the class activities is designed to aid students to refresh and deepen their prior knowledge in that regard.

Short program:
Concurrency
- Introduction: 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/2020/LM/SC/SC1176/000ZZ/SCQ0093640/N0

SOFTWARE VERIFICATION
Master degree in Computer Science, First semester
Lecturer: 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/2020/LM/SC/SC1176/000ZZ/SCQ0089515/N0

WIRELESS NETWORKS FOR MOBILE APPLICATIONS
Master degree in Computer Science, First semester
Lecturer: Claudio Enrico Palazzi
Credits: 6 ECTS
Prerequisites:
Computer Networks

Short program:
Introduction to Wireless Networks.

Wireless network issues: error and collision losses, fairness and transmission delays, handoffs.

MAC layer standards: 802.11 a/b/g/n/p/s

Transport protocols in wireless environments: TCP Vegas, TCP Westwood, TCP Hybla, CUBIC.

Ad hoc networks and routing protocols: MANET, VANET, DSDV, AODV, DSR.

Applications and services on mobile networks.

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/2020/LM/SC/SC1176/000ZZ/SCQ0093642/N0

BIG DATA COMPUTING (OFFERED IN THE MASTER DEGREE IN COMPUTER ENGINEERING)
Master degree in Computer Science, Second semester
Lecturer: Andrea Alberto Pietracaprina
Credits: 6 ECTS
**Prerequisites:**
The course has the following prerequisites: competences regarding the designing 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
Programming frameworks: MapReduce/Hadoop, Spark
Clustering
Association Analysis
Graph Analytics (metriche di centralità, scale-free/Power-law graphs, fenomeno dello small world, uncertain graphs)
Similarity and diversity search

**Examination:**
The exam consists of a number of programming homeworks, assigned approximately every 2-3 weeks and to be carried out in groups of 3-4 students, and of an individual written test comprising both theory questions and exercises.

**More information:**
[Links to course details]

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**DEEP LEARNING (OFFERED IN THE MASTER DEGREE IN CYBERSECURITY; DATA SCIENCE; COMPUTER ENGINEERING; DATA SCIENCE EXAM OF MACHINE AND DEEP LEARNING (MOD. B))**

Master degree in **Computer Science**, Second semester

Lecturer: 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 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:**
[Links to course details]

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**KNOWLEDGE REPRESENTATION AND LEARNING (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN DATA SCIENCE EXAM KNOWLEDGE AND DATA MINING))**

Master degree in **Computer Science**, Second semester

Lecturer: Luciano Serafini

Credits: 6 ECTS

**Prerequisites:**
Suggested basic knowledge of logics and statistics.
MATHEMATICAL MODELS AND NUMERICAL METHODS FOR BIG DATA (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN DATA SCIENCE)

Master degree in Computer Science, Second semester
Lecturer: DA DEFINIRE
Credits: 6 ECTS

Prerequisites:
Background on Matrix Theory: Type of matrices: Diagonal, Symmetric, Normal, Positive Definite; Matrix canonical forms: Diagonal, Schur; Matrix spectrum: Kernel, Range, Eigenvalues, Eigenvectors and Eigenspaces Matrix Factorizations: LU, Cholesky, QR, SVD

Short program:
Numerical methods for large eigenvalue problems
- The power method
- Subspace Iterations
- Krylov-type methods: Arnoldi (and sketches of Lanczos + Non-Hermitian Lanczos)
- (Optional) Sketches of their block implementation
- Singular values VS Eigenvalues
- Best rank-k approximation
2. Network centrality
- Perron-Frobenius Theorem
- Centrality based on eigenvectors ((HITS and Pagerank)
- Centrality based on matrix functions
3. Data and network clustering
- (Sketches) K-Means algorithm
- Principal component analysis and dimensionality reduction
- Laplacian matrices, Cheeger constant, nodal domains
- (Optional) Lovasz extension, exact relaxations
4. Multiway Data Analysis
- Tensors Decompositions: Tucker Decomposition, Multilinear Singular Value Decomposition, Canonical Poliadic Decomposition.
- Numerical Methods for tensor decomposition
- Applications: Face Recognition Using Tensor SVD and Tensor Data Fusion
- Tensor eigenproblems: hypergraph Eigenvector Centralities
- (Sketches) Higher order power method

Examination:
Written examination
MOBILE AND IOT SECURITY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN CYBERSECURITY)
Master degree in Computer Science, Second semester
Lecturer: Eleonora Losiouk
Credits: 6 ECTS
Prerequisites:
No strict prerequisites on previous exams.
Short program:
Examination:
Written
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCP7079406/N0

REAL-TIME KERNELS AND SYSTEMS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN COMPUTER SCIENCE)
Master degree in Computer Science, Second semester
Lecturer: 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/2020/LM/SC/SC1176/000ZZ/SCQ0089502/N0
Structural Bioinformatics (also offered for students of the Master Degree in Data Science and Computer Engineering)

Master degree in Computer Science, Second semester
Lecturer: Damiano Piovesan
Credits: 6 ECTS

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

Short program:
The course consists of two parts:

1) Introduction to living matter (2 credits):
   1.1) Introduction to organic chemistry, weak interactions and energy
   1.2) Structure and function of DNA and proteins
   1.3) Lipids, membranes and cellular transport
   1.4) Experimental methods for structure determination

2) Computational Biochemistry (4 credits):
   2.1) Biological Databases
   2.2) Software libraries and concepts for sequence alignments and database searches
   2.3) Sequence - structure relationship in proteins and structural classification
   2.4) Methods for the prediction of protein structure from sequence, the CASP experiment
   2.5) Methods for the prediction of protein function and interactions, the CAFA experiment
   2.6) Non-globular proteins, disorder and structural repeats

Examination:
The exam covers three separate parts, which have to be all passed: (relative weights in parenthesis)

1) Written test of the biochemistry concepts (ca. 30%)
2) Software project (ca. 40%)
3) Project presentation and critical evaluation (ca. 30%)

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1176/000ZZ/SCP7079278/N0

Vision and Cognitive Services (also offered for students of the Master Degree in Computer Engineering; Physics of Data; Data Science; Cybersecurity)

Master degree in Computer Science, Second semester
Lecturer: Lamberto Ballan
Credits: 6 ECTS

Prerequisites:
The student should have basic knowledge of programming and algorithms. It is also advisable to be familiar with basic concepts in probability and analysis of multivariate functions.

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 teacher, 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 to a few questions about the topics addressed in class.

**More information:**

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**EVOLUTIONARY BIOLOGY**

**COMPARATIVE PHYSIOLOGY**
Master degree in **Evolutionary Biology**, First semester
Lecturer: 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. Mechanoreception; electoreception; thermoception; photoreception; 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; Malpighi tubules of insects; osmotic balance and volume regulation; nervous and endocrine regulation.

**Examination:**
The evaluation will be a written test with 6 open questions followed by an oral exam if necessary.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1179/000ZZ/SCP8084977/N0

ETHOLOGY
Master degree in Evolutionary Biology, First semester
Lecturer: 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 behavior 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 behavior, kin selection.

Examination:
Written test (multiple choice questions, open questions)

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1179/000ZZ/SCN1031442/N0

EVOLUTION AND CONSERVATION
Master degree in Evolutionary Biology, First semester
Lecturer: Leonardo Congiu
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, 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/2019/LM/SC/SC1179/000ZZ/SCO2043741/N0
Master degree in **Evolutionary Biology**, First semester

Lecturer: Dietelmo Pievani

**Credits:** 8 ECTS

**Prerequisites:**

Prior knowledge needed for the classes in Philosophy of Biological Sciences is that normally provided for students at the third year of the first degree (mainly in Biology, but not only). Particularly, the basic understanding of Evolutionary Biology, in its 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. The classes (in English) are primarily intended for students from the Department of Biology, but the involvement of students from other careers, such as particularly Philosophy and History, is not precluded. The construction of a heterogeneous class of students every year is indeed an asset, given the interactive teaching provided in the classes. Class attendance is mandatory due to the interactive nature of lessons.

**Short program:**

The course aims at deepening the fundamental concepts, principles and analytical methods of the philosophy of biology, according to current International debates, namely: types of explanation and inferences in biological sciences; notions of theory, hypothesis, empirical basis, model, falsifiability, parsimony, prediction; biological terminology; biological ontology; selection of models and probability; research protocols; logic of scientific discovery in life sciences; scientific controversies; defensive and argumentative strategies. These general objectives are addressed through critical discussion of case-studies - both historical and taken from primary scientific literature - in particular about Evolutionary Biology and the structure of evolutionary theory.

The general themes in philosophy of life science will also be developed through the analysis of the logic of scientific discovery in Charles Darwin's work, extrapolated from his unpublished private texts, such as the Notebooks of Transmutation, and the working papers that led to the peculiar argumentative structure of the Origin of Species in its six editions. Darwin's thoughts, assumptions and insights, in their typical theoretical pluralism, will become another starting point to discuss evolutionary issues debated in the scientific literature today. Among the others:

- Notions of "species";
- Tempo and mode of speciation (gradualism and punctuationism);
- Variation and inheritance;
- Genetics and epigenetics;
- Evolution, ecology and biogeography;
- Functional factors and structural factors (adaptations and constraints) in evolutionary change;
- Common descent (Tree Thinking) and natural selection;
- Explanatory power of selective mechanisms;
- Units of evolution and levels of selection (the debate about the evolution of altruism);
- Relationships between ontogeny and phylogeny;
- The role of "chance" in evolution;
- Teleology and contingency;
- Darwin's risky predictions;
- Extended Evolutionary Synthesis.

**Examination:**

Examination is oral and aims at the evaluation of both scientific and philosophical skills acquired, through open-ended questions and requests for argumentation and comparison of
different theses and models. The examination (in Italian or in English) is divided into a common part and a monographic part. The common part includes textbooks, books and articles that provide a general overview of the contents of the discipline. The examination also provides the monographic choice, by the students, of one of the cases discussed during the classes, on which a specific study with further bibliography (usually two chapters of books or additional papers) is required. Attendance is mandatory, due to the teaching by interactive methods and case-studies. Students unable to attend a percentage of classes (anyway no more than 50%) have to agree the attendance with the teacher.


MOLECULAR PHYLOGENY
Master degree in Evolutionary Biology, Second semester
Lecturer: 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).

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:
  - chromatogram reading and analysis; use of GenBank and the barcode database BOLD to identify species;
  - phylogenetic reconstruction with the main algorithms using MEGA, MrBayes and Fasttree.
  - Use of the software BEAST to date with molecular data evolutionary events.

Examination:
The student assessment will be achieved by a written examination on a PC using the e-learning platform. The test will consist of 6 questions:

4 questions with open answer to assess the acquired knowledge, comprehension and ability to synthetize the concepts developed during the course

2 more focused questions on the interpretation of examples of phylogenetic relationships of specific taxonomic groups and the methods to reconstruct the tree.
GEOMETRY AND TECHNICAL GEOLOGY

APPLIED GEOCHEMISTRY
Master degree in Geology and technical Geology, First semester
Lecturer: 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:
Isotope geochemistry plays an increasingly important role in a wide variety of geological, environmental, medical, forensic and archeological investigations. Isotope methods allow to determine the age of the Earth, reconstruct the climate of the past, detect adulterated foods and beverages, detect and monitor the progress of diseases in human and explain the formation of the chemical elements in the universe. This course is designed to provide an introduction to the principles and applications of isotope geochemistry. Systems discussed include the classic radiogenic systems (Rb-Sr, Sm-Nd, Lu-Hf and U-Th-Pb), traditional stable isotope systems (e.g. H and O) and extinct radioactivities. Applications as chronometers or tracers will be 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 CONTENT:
1. Introduction
2. Nuclear physics and nuclear stability
3. Radioactivity
4. Nucleosynthesis: when, where and how chemical elements are formed?
5. Principles of stable isotope geochemistry
6. Mass-balance calculations
7. Tracing the hydrologic cycle with stable isotopes
8. Radioactive decay and geochronometry
9. The Rb-Sr method
10. The Sm-Nd method
11. The Lu-Hf method
12. The U-Pb, Th-Pb and Pb-Pb methods
Examination:
Course learning goals will be assessed by written examinations.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1179/000ZZ/SCP8084997/N0

APPLIED SEDIMENTARY GEOLOGY
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Geology and technical Geology, First semester
Lecturer: Massimiliano Ghinassi
Credits: 6 ECTS
Prerequisites:  
Basic concepts of geology (structural geology, geodynamic settings, lithology (different types of rocks) and geomorphology (geomorphic configuration of the main depositional environments). Complete view of the main geological processes and main basics of geology, geomorphology, sedimentary geology and paleontology. Comprehensive knowledge of sedimentology (depositional dynamics and stratal architecture of different depositional environments), lithology and sedimentary petrography (sedimentary rocks and sediments, optical microscope analyses), paleoecology and biostratigraphy (fossil determination and biostratigraphic meaning), carbonate petrography and geochemistry (biomineralizations, geochemistry of stable isotopes)

Short program:  
The course will be based on a multidisciplinary approach and will be developed on the analyses of data collected in the frame of a 3-days excursion, which will be held within the first two weeks of the course.

Content of the course will be as follows:
Introduction to the main geomorphological, geological and stratigraphic features of the selected study area (credits 0.25)
Introduction to the research program (goal of the study and schedule) and summary of the main research methodologies (credits 0.5)
Field activities and data collection (credit 1)
Sedimentology (credit 1): facies analyses and reconstruction of depositional dynamics, architectural analyses and definition of 3D sedimentary bodies, summary
Sedimentary petrography (credit 1): sediment characterization, provenance analyses, summary
Paleoecology and biostratigraphy (credit 1): determination of fossil content, biostratigraphy and ecobiostatigraphy, paleoenvironmental reconstruction, summary
Carbonate petrography and geochemistry (credit 1): biomineralizations, sclerochronology, trace elements and stable isotope geochemistry, summary
Integration of the acquired datasets and final summary (credits 0.25)

Examination:
Witten test. The test will be based on interpretation and elaboration (written report) of specific datasets, which will be provided consistently with the topics of the course.

More information:

CARBONATE SEDIMENTOLOGY

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Geology and technical Geology, First semester
Lecturer: Nereo Preto
Credits: 6 ECTS

Prerequisites:
Knowledge of sedimentary geology and clastic sedimentology; base notions of chemistry. Having taken, or being taking "Sedimentology" is recommended.

Short program:
- The carbon cycle in the oceans, and some notions of physical oceanography;
- the precipitation of carbonates as a chemical and biological process;
- origin of carbonate platforms and deep-water carbonates;
- types of carbonate platforms, their depositional architectures, and their dynamic stratigraphy;
- diagenesis of carbonates and reconstruction of diagenetic histories;
- dolomitization processes;
- sequence stratigraphy of carbonates.

Examination:
The marking is based on two documents: a mid-term report based on class exercises and a final exam.
The report is the interpretation of a carbonate depositional system, presented as a idealized geological cross section of a carbonate platform, which is being studied during the course.
The final exam is a written test, which requires to answer briefly, with a short text or with geological sketches, to open questions.
More information:

GEOLOGY AND EXPLORATION OF PLANETARY BODIES
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Geology and technical Geology, First semester
Lecturer: Matteo Massironi
Credits: 6 ECTS
Prerequisites:
none
Short program:
Course contents:
- Physical parameters of the terrestrial planets
- Impact cratering
- Crate Chronology- Classification of the Meteorites
- 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.
- Venus: topography, tectonism and volcanism, evolution.
- Mars: topography, internal structure, tectonism and volcanism, water and water related morphologies, surface evolution.
- Geology, structure and composition of comets and asteroids
- Geology of the Medicean satellites
- Planetary space mission and related payloads
Examination:
Oral examination will be related to the geology of the solar system bodies, space missions and payload dedicated to the explorations of planetary bodies
More information:

MICROPALEONTOLOGY
Master degree in Geology and technical Geology, First semester
Lecturer: Claudia Agnini
Credits: 6 ECTS
Prerequisites:
Basic of Stratigraphy and Paleontology
Short program:
The course can be subdivided in three main parts:
- History of micropaleontology and its position in the context of the geological sciences. Its developments and the importance of deep-sea drilling projects. (0.5 CFU)
- “Pure” micropaleontology. An overview of the various microfossil groups of botanical and zoological origin, that are widely used both in academic research and oil and gas industry, by presenting their morphology, taxonomy, mode of life, environments and stratigraphic distribution. In this context, preparation- and research techniques of main microfossil groups
and their geological importance in terms of dating, correlation, facies interpretation, paleoenvironomental and paleoclimatic reconstruction is introduced to the students. (3.5 CFU)
 - practical microscope excercitations on micropaleontological samples which contain the main microfossil groups presented in the general theoretical part (e.g., calcareous nannofossils, foraminifera, radiolarians, diatoms, ...). A daily field excursion is also proposed (2 CFU).

**Examination:**
The knownledge/skills acquired during the course is checked by means of
 - a practical test in which the students analyse a micropaleontological sample.
 - an oral examination during which the concepts, the scientific terminology, the syntesis ability and the critical spirit are evaluated.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCP7077717/N0

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**MINERAL RESOURCES**
Master degree in **Geology and technical Geology**, First semester
Lecturer: Paolo Nimis
Credits: 6 ECTS

**Prerequisites:**
Solid knowledge of basic geology, mineralogy and geochemistry.

**Short program:**
2. Magmatic metallic and non-metallic ore deposits.
6. Other industrial mineral/rock deposits (fluorite, zeolites, kaolin, bentonite, refractories, fluxes, fillers, abrasives, dimension and ornamental stones).
7. Underground and surface extraction methods (notes).
9. Macroscopic and microscopic identification of the main metallic and industrial ore minerals and of their textures.

**Examination:**
Interview

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCQ0094198/N0

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**NUMERICAL MODELING IN GEOSCIENCES**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in **Geology and technical Geology**, First semester
Lecturer: 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) ir direct (Gauss elimination) methods.

**Examination:**
Oral and practical test.

**More information:**

**PALEOCLIMATOLOGY AND PALEOCEANOGRAPHY**

**Information concerning the students who enrolled in A.Y. 2019/20**

Master degree in **Geology and technical Geology**, First semester

Lecturer: Luca Capraro

Credits: 6 ECTS

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

**Short program:**

- **Systems theory:** linear and chaotic systems. The Poincaré problem and Lorenz attractor. Lyapunov time and the stability of the solar system. The minkovavian theory of climate.
Great Oxygenation Event, the Snowball Earth, the Cretaceous hyperthermal period. Climate during the Cenozoic: from the Greenhouse world to the Quaternary glaciations. High-frequency climate variability: Dansgaard-Oeschger cycles, Bond cycles, Heinrich events. The "Climate surprises”.

**Examination:**
Students' preparation will be ascertained by means of an oral, open-question exam, in order to gauge their ability to engender connections between different subjects and to establish critical and original approaches to the matter in question.

**More information:**
https://en.didattica.unipd.it/off/2019/LM/SC/SC1180/000ZZ/SCM0018542/N0

**PETROLOGY**
Master degree in **Geology and technical Geology**, First semester
Lecturer: Bernardo Cesare
Credits: 6 ECTS

**Prerequisites:**
In order to take full advantage of the course and be able to fully follow the classes the student will already have basic knowledge of petrography, geochemistry and mineralogy, as well as of english.

**Short program:**
Focusing on the metapelitic system, and through extensive practice at the microscopic laboratory, the course will provide deep insight into the main aspects of metamorphic petrology, such as:
- metamorphic classification;
- equilibrium assemblages; metamorphic facies;
- chemographies and other graphical representations;
- metamorphic reactions and equilibria;
- thermodynamics applied to phase equilibria modelling;
- role of fluids in metamorphism, fluid inclusions;
- geothermobarometry and phase equilibria calculations;
- metamorphism of pelites;
- contact metamorphism; crustal anatexis;
- microstructures of anatectic rocks;
- melt inclusions in migmatites and granulites.

**Examination:**
The acquired knowledges and skills will be assessed through an oral examination in english

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCP8085000/N0

**BASIN ANALYSIS**
Master degree in **Geology and technical Geology**, Second semester
Lecturer: Massimiliano Zattin
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of some courses of the first semester (Applied geophysics, Micropaleontology, Applied geochemistry)

**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: foredeep, foreland, buckling.
4) Dynamic topography.
5) Strike-slip and pull-apart basins.
6) Subsidence and thermal history.
7) Application to petroleum industry.
8) Case-history: the Cretaceous-Eocene Tremp Basin (Spain)

**Examination:**
Evaluation is provided by a written examination with open questions on knowledge acquired during classes and the field-trip

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCP3051165/N0

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**PETROLEUM GEOLOGY**
Master degree in Geology and technical Geology, Second semester
Lecturer: Massimiliano Zattin
Credits: 6 ECTS

**Prerequisites:**
Basic knowledge of some courses of the first semester (Sedimentology, Applied geophysics, Micropaleontology, Applied geochemistry)

**Short program:**
The course will delivery the key-concepts of petroleum geology and is integrated by seminars on specific topics (to be defined during the semester).
- The origin of petroleum; physico-chemical properties of hydrocarbons (0.5 CFU)
- The source rock, maturity of organic matter and petroleum migration (1 CFU)
- The seal rock (0.5 CFU)
- Reservoir geology, stratigraphic traps, structural traps (2 CFU)
- Main exploration and production techniques (1 CFU)
- Hydrocarbon reserves in Italy and in the World (1 CFU)

**Examination:**
Written examination with essay questions.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCP3051098/N0

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**SEDIMENTOLOGY**
Master degree in Geology and technical Geology, Second semester
Lecturer: Massimiliano Ghinassi
Credits: 6 ECTS

**Prerequisites:**
Basic concepts of geology (structural geology, geodynamic settings, lithology (different types of rocks) and geomorphology (geomorphic configuration of the main depositional environments)
Basic knowledge concerning sedimentology (textural features of the main types of sediments and sedimentary rocks) and stratigraphy (temporal and spatial variability of depositional systems)

**Short program:**
Introduction to Sedimentology (credits: 0.2)
- facies and facies associations
- textural features of sediments, stratal geometries and terminology
Sediment transport/deposition and post-depositional modifications (credits: 1.8)
- tractional transport from unidirectional currents
- tractional transport from oscillatory currents
- mass transport
- soft-sediment deformations
- icnofossils
Depositional environment (credits: 2.5)
- continental depositional environments (alluvial fan, fluvial, lacustrine, eolian)
- coastal depositional environment (wave-dominated coasts, deltas, tidal flats/lagoons)
- deep marine depositional environment (turbidites, contourites)
Sequence stratigraphy (credits: 0.5)
- base level and accommodation space
- systems tracts
- sequences
- incised valleys
- non-marine sequence stratigraphy

**Examination:**
Written test with open questions on the main themes illustrated in the frame of the course (processes of sediment transport, depositional environments, sequence stratigraphy)

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1180/000ZZ/SCP3051016/N0

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**INDUSTRIAL BIOTECHNOLOGY**

**BIOENERGY PRODUCTION**

*Information concerning the students who enrolled in A.Y. 2019/20*

Master degree in **Industrial Biotechnology**, First semester
Lecturer: 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.
Because of the Covid-19 emergency, the laboratory that was originally planned will not take place. In its place, the programmed experiments will be described using virtual tools.

**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/2019/LM/SC/SC1731/000ZZ/SCP9088068/N0

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**BIOREMEDIATION**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Industrial Biotechnology, First semester
Lecturer: Paola Venier
Credits: 6 ECTS

Prerequisites:
The exam Biochemical reactors testing is a prerequisite. Essentials of environmental chemistry, biochemistry and microbiology are useful.

Short program:
PART A
Environmental contaminants by contamination size, hazard level and resistance to degradation. Contaminated sites of national concern in Italy. Biodegradation and bioremediation. Main strategies of restoration in situ and ex-situ (0.5 CFU).
Unifying features and variety of microorganisms. Main types of microbial metabolism, mixotrophy, syntrophy and extremophiles as a knowledge basis for understanding biodegradation and bioremediation processes. Gene-specific and genomic approaches for the study of communities of micro-organisms at contaminated sites or ex situ treatment facilities (1 CFU).
Study cases with a focus on the pathways of biotransformation of environmental contaminants (e.g., oil, plastics, polycyclic aromatic compounds, organohalogenated chemicals). What remediation strategies for metals and radioactive materials? (1 CFU).
Current limitations in bioremediation. Bioengineered microbes and enzymes or nature-inspired selection of extremophiles? Optimization and innovation of bioremediation processes via microorganism communities (0.5 CFU).

PART B
Technological aspects of bioremediation: from lab experiments to pilot scale. Introduction to bioremediation of water, soil and gases. The importance of modelling in bioremediation scaling-up (0.5 CFU).
Application of microalgae to wastewater treatment. Recovery of nitrogen from a circular perspective. Concept of bioaugmentation (0.5 CFU).
Bioremediation of soil and gaseous streams: technologies and physico-chemical properties. Role of mass transfer and desorption processes. Examples of pilot scale plants (0.5 CFU).

Examination:
Notice that the following mode of examination may change for major causes (e.g. COVID19).
The exam will be oral and will focus on Part A (BIO/19, 3 CFU) and Part B (ING-IND/25, 3 CFU).

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC1731/000ZZ/SCP9088082/N0

ENVIRONMENTAL PLANT BIOTECHNOLOGY
Master degree in Industrial Biotechnology, Second semester
Lecturer: 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/2020/LM/SC/SC1731/000ZZ/SCQ0093380/N0

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**GENETIC TOXICOLOGY AND ENVIRONMENTAL CHEMISTRY**

Master degree in **Industrial Biotechnology**, Second semester

Lecturer: Sara Bogialli

Credits: 6 ECTS

**Prerequisites:**
Knowledge of General, Inorganic and Organic Chemistry, Biology and Genetics

**Short program**
The following contents will be treated in more or less detail depending on the student’ starting skills and curiosity.

Part A (CHIM).
Chemico-physical properties and main descriptor parameters in environmental chemistry. Evaluation of the distribution of pollutants in air, water and soil. Chemical speciation and its influence on the distribution of contaminants in the environment and their toxicity. Examples and case studies (1.5 CFU).

Macro and micro-pollutants of the environment: organic compounds, metals, emerging pollutants. Radionuclides and sources of radioactive pollution. European regulatory aspects. Examples of pollutants and case studies (1.5 CFU).

Part B (BIO).
Variety of toxic agents and possible adverse effects at different levels of biological organization. Toxicokinetics and toxicodynamics (in general). Biological targets, exposure measurements, effect and susceptibility. Dose-response with/without threshold, hormesis. Hazard, risk, damage. Symbols and safety rules. Criteria and methods to identify toxic agents, with particular attention to genetic and reproductive toxicology (1.25 CFU).
Effects and responses induced by non-ionizing and ionizing radiations. Dose units. Adaptive response, bystander effect, radio-resistance in cancer cells and extremophilic bacteria. Effects and responses induced by toxic chemical agents: examples of metalloids, metals, organic compounds, toxins (1.5 CFU).
Biodegradations and bioremediation of contaminants. Microbial bioremediation in perspective (0.25 CFU).

**Examination:**
Notice that the following mode of examination may change for major causes (e.g. COVID19). The exam will be oral and will focus on Part A (CHIM, 3 CFU) and Part B (BIO, 3 CFU). For Part B, the student will also discuss a topic (toxic agent or biological process in terms of function and dysfunction or investigation method) chosen in agreement with the teacher during the course and based on the scientific literature. Effective reporting of biotechnological aspects will be positively evaluated.

**More information:**

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**NANOSYSTEMS**
Master degree in **Industrial Biotechnology**, Second semester
Lecturer: Sabrina Antonello
Credits: 6 ECTS

**Prerequisites:**
B.Sc. level knowledge of Physical Chemistry and Organic Chemistry.

**Short program:**
Part A: Physical chemistry and characterization of nanosystems.
Nanoscale dimension and quantum size confinement.
Intermolecular forces: electrostatic forces, dispersion forces, hydrogen bonds.
Physical Chemistry of interfaces.
Thermodynamics of self-assembly and self-organization.
Amphiphilic molecules: thermodynamics for aggregation of micelles, bilayers, vesicles, biological membranes.
Electron and charge transfers.
Electrochemical techniques.

Part B. Preparation, properties and application of nanosystems.
Bottom-up approaches to nanosystems production.
General concepts of solution synthesis: La Mer description of nucleation and growth process, Ostwald ripening, sintering.
Steric and electrostatic stabilization of nanosystems (DLVO theory, Z-potential, stealth behavior).
Aggregates of amphiphilic molecules and peptides.
Polymeric nanoparticles and dendrimers.
Stimuli-responsive nanosystems.
Carbon nanostructures (nanotubes, fullerenes, graphene).
Metal nanoparticles, nanoshells, nanorods and nanoclusters.
Plasmon resonance in metal nanostructures and surface enhanced Raman spectroscopy (SERS).
Semiconductive nanoparticles: quantum dots.
Oxides nanoparticles: silica, titania.
Magnetic nanoparticles.
Scanning probe microscopies, electronic microscopies and other surface characterization methods.

**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:**
INDUSTRIAL CHEMISTRY

ANALYTICAL CHEMISTRY OF INDUSTRIAL PROCESSES
Master degree in Industrial Chemistry, Second semester
Lecturer: 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:
1) Introduction to Process Analytical Chemistry.
2) Sampling for analytical purposes. Process sampling systems.
3) Data domains and signal elaboration. Sources of noise in instrumental analysis and signal-to-noise optimization strategies.
4) Principles of chemical sensors. Types, preparation and properties of sensors for in-line analytical applications.
10) Optical spectroscopy for process analyses. Infrared and Raman spectroscopy: instrumentation design and sampling interface. Practical examples of IR and Raman analytical applications in the pharmaceutical industry.

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/2020/LM/SC/SC1170/000ZZ/SCP9087648/N0

PHYSICAL METHODS IN ORGANIC CHEMISTRY
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Industrial Chemistry, First semester
Lecturer: 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:

MARINE BIOLOGY

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS
Master degree in Marine Biology, First semester
Lecturer: Lorenzo Marangoni
Credits: 6 ECTS

Prerequisites:
No prerequisites are required to attend the course

Short program:
First part (2 CFU + 1 CFU practical): the scientific method; types of problem; how to develop a sampling design; preliminary sampling; scale of variation of phenomena; precision, accuracy and bias; sample size; concept of minimal area and volume; concept of replicate and pseudoreplicate; types of sampling: random, systematic, stratified; allocations of sampling effort: simple, proportional optimal. Sampling methods and techniques used in different habitats; direct sampling and remote sensing: water column, bottom; monitoring and BACI; examples of manipulative experiments: factorial, nested. Discussion of case studies. Sampling in the field.
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 two parts of the course.
The first part of the evaluation includes: a written exam with an open question on the topics presented during the course, a question on the application of the tools learnt during the course to a case study, and an oral presentation on case studies from scientific literature.
The second part is constituted by a practical exam in informatics lab.
The finale score is the average of the scores of the two parts.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093518/N0
MARINE BIODIVERSITY
Master degree in Marine Biology, First semester
Lecturer: Carlotta Mazzoldi
Credits: 6 ECTS
Prerequisites:
Knowledge of zoology, comparative anatomy, botany and systematic botany.
Short program:
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.
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.
Examination:
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.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093620/N0

MARINE ECOLOGY: PATTERNS AND PROCESSES
Master degree in Marine Biology, First semester
Lecturer: Laura Airoldi
Credits: 6 ECTS
Prerequisites:
Basic knowledge of ecology, and biology of marine organisms.
Short program:
The lectures will cover a variety of coastal ecosystems. For each ecosystem we will analyse:
- Main environmental characteristics
- Main communities, their structure and distribution
- Main ecological processes and functioning, with emphasis on experimental work focusing on some particularly well studied processes
- Human-induced changes, threats and conservation needs

The course is structured as follows:
1) Introduction
2) The physical environment
3) Marine biomes – focus on the concepts of ecosystem stability, habitat shifts and novel ecosystems
4) Intertidal rocky bottoms - experiments on the role of competition and predator-prey interactions
5) Subtidal rocky bottoms and canopy forming macroalgae & kelp forests - experiments on the role of disturbance, trophic cascades, and the effects of sedimentation
6) Estuarine environments, saltmarshes - experiments on the role of positive interactions and of the effects of excessive nutrient loads
7) Seagrasses – focus on productivity, trophic transfer and the role of microbial communities
8) Oyster reefs and other biogenic reefs
9) Soft-bottoms
10) Artificial man-made habitats – focus on the concept of ecosystem service and on the design of sustainable marine infrastructures and nature based solutions.

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:**
There will be 6 exam sessions during the year, two for each exam session: the first exam (which will take place immediately at the end of the course) will be written and will include about 20 questions both closed and open (the questions will cover all the topics of the course) while the next 5 session will be oral. The exam grade awarded may be refused up to a maximum of two times.

**More information:**
[https://en.didattica.unipd.it/off/2020/LM/SC/TF0360/000ZZ/SCQ0093552/N0](https://en.didattica.unipd.it/off/2020/LM/SC/TF0360/000ZZ/SCQ0093552/N0)

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**MOLECULAR METHODS FOR MANAGEMENT AND AQUACULTURE**
Master degree in *Marine Biology*, First semester
Lecturer: 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 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. The results of this laboratory and the biological problem will provide the starting background for the development of a group project.

**Examination:**
The exam entails two parts: written test with open questions and multiple choice quizes and a group project. The group project will allow to evaluate the ability to propose and describe a biological problem, to plan the execution of a project and to choose and apply a method that is suitable for achieving the project objectives. The group project will be based on the results and experience of the laboratory. This part is worth 10 points while the written assignment is
worth 20 points. All group members will get the same score for group work. The written exam will allow to evaluate the theoretical knowledge. The date of presentation of the group projects will be chosen by mutual agreement with the students, indicatively at the end of the semester or before the first official exam. The written exam will take place during the pre-scheduled exam sessions as published on the exams’ calendar.

Some changes to the evaluation plan and to the course general approaches may be agreed on with students. The exam grade is given by the sum of the scores obtained in all the parts. 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).

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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093553/N0

ECOLOGY AND PHYSIOLOGY OF GLOBAL CHANGES
Master degree in Marine Biology, Second semester
Lecturer: 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, pecilothermia 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 open 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 grade awarded may be refused up to a maximum of two times.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093618/N0

LIFE CYCLES AND ADAPTATIONS OF MARINE ORGANISMS
Master degree in Marine Biology, Second semester
Lecturer: 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:
Reproductive processes in aquatic photosynthetic organisms. Life cycles of marine algae belonging to different taxa.
Light in the marine environment: variation of the photosynthetic pigment pattern to face different light condition and impact of light on vertical zonation of seaweeds.
Nitrogen fixation mechanisms in marine cyanobacteria.
Adaptive strategies by photosynthetic organisms to live in different stress environmental conditions (desiccation, sea ice, high salinity, temperature, UV).
Biotic interactions in the sea ecosystem: symbioses, competition between algae, between algae and herbivore grazing, chemical protection by the production of allelopathic compounds and toxins.
Structure and function: size and shape cell on phytoplankton physiology.
Algae and man: cultures of algae for bioactive compound production.

Trade-off in life history traits: growth/reproduction; fecundity/offspring size.
Evolution of life history traits under fishery pressure. Life cycles and vulnerability of marine organisms to human activities.

The internal environment homeostasis: the regulation of internal environment; organization of regulation systems and organ systems.
The circulatory systems and the circulation of body fluids: circulating liquids; haemodynamics and organization of pumps and circulatory pathways; integrated cardiovascular functions; nervous and endocrine regulation; the lymphatic system and organization of lymphoid organs; hematopoiesis and hemostasis; the evolution of the circulatory system.
The respiratory systems: surfaces and mechanisms for exchange of respiratory gases; animals with aquatic and air breathing; respiratory mechanics; transportation of respiratory gases; control of respiration.
The osmoregulation and excretion: renal excretory organs; function of the nephron of mammals; urinary systems of other vertebrates and extrarenal organs; osmotic balance and volume control; nervous and endocrine regulation.

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/2020/LM/SC/IF0360/000ZZ/SCQ0093579/N0

MARINE CONSERVATION: PRINCIPLES AND APPLICATIONS
Master degree in **Marine Biology**, Second semester
Lecturer: Alberto Barausse
Credits: 8 ECTS
**Prerequisites:**
No one
**Short program:**
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
4) Citizen Science and NGOs

**Examination:**
Oral discussion

**More information:**
[https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093599/N0](https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093599/N0)

**PHARMACOLOGY, TOXICOLOGY AND WELFARE IN AQUACULTURE**
Master degree in **Marine Biology**, Second semester
Lecturer: 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) Algal-stocks preparation
   - Method for culturing the unicellular green alga Scenedesmus dimorphus
   - Algal cell count on Burker's chamber
   - Centrifugation, pellet resuspension and storage of algal stocks

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 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. Alternatively, if it is impossible to carry out the assessment in presence, the oral exam will be taken remotely, using the 'zoom' software.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093619/N0

PRACTICAL MARINE ECOLOGY
Master degree in Marine Biology, Second semester
Lecturer: Carlotta Mazzoldi
Credits: 2 ECTS
Prerequisites:
Basic knowledge of marine ecology, experimental design and data analyses, botany, and zoology of marine organisms.
Short program:
Use of different sampling techniques to collect qualitative and quantitative data on different marine organisms in the field and the lab. Sampling of beaches, hard and soft bottoms, water column. Estimation of richness and abundances of marine communities. Measurement of seawater abiotic parameters. Collection of marine litter data.

Examination:
The course has a qualifying examination. The exam will consist of a multiple-choice test on the activities carried out during the course and of a final presentation of the achieved results.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/IF0360/000ZZ/SCQ0093506/N0
SEAFOOD SUSTAINABILITY, PRODUCTION AND CONTROL
Master degree in Marine Biology, Second semester
Lecturer: 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, VET04, prof. Luca Fasolato).

AGR20
Aquaculture and fisheries. Fish production and consumption in Italy and all over the world, main problems and perspectives.
Definition and classification of aquaculture systems.
Water quality and management in aquaculture.
Mechanical and biological filters.
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 and laboratories, visits at commercial plants.

VET04
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/2020/LM/SC/IF0360/000ZZ/SCQ0093598/N0

MATERIALS SCIENCE

ELECTROCHEMISTRY OF MATERIALS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Materials Science, First semester
Lecturer: Christian Durante
Credits: 6 ECTS
Prerequisites:
Knowledge of general chemistry (General and inorganic Chemistry), thermodynamics (Physical Chemistry).
-ionic and electronic concution
Short Program:
2. Electrode; electrification of interphase, electrodic potential, different types of electrodes.
4. Voltammetric techniques; linear and cyclic voltammetry at stationary electrode; rotating disc electrode.
5. Basis of Electrochemical Impedance Spectroscopy; equivalent circuits; Nyquist’s and Bode’s plots.

Examination:
Oral examination generally based on three topics:
-electrochemical kinetic theory
-electrochemical techniques/ electrodeposition techniques
-energy conversion and storage devices/ properties of electrodic materials

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC1174/000ZZ/SCQ0090018/N0

MATERIALS TECHNOLOGY
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Materials Science, First semester
Lecturer: Alessandro Martucci
Credits: 6 ECTS

Prerequisites:
The course requires the knowledge of the Bachelor's Degree Fundamentals of Materials Science exam.

Short Program:
Ceramic materials: production processes, mechanical properties, defects.
Glass: production processes (flat glass, hollow glass, fibers), mechanical properties, chemical properties and degradation.
Composites: production processes of polymeric matrix composite materials and ceramics, mechanical properties.
Introduction to material selection and design.
Laboratory:
1. Sintering of a structural ceramic material and evaluation of its mechanical strength.
2. Process of melting a glass and characterization of its optical properties.

Examination:
Oral exam

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC1174/000ZZ/SCQ0090019/N0

NANOFABRICATION
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Materials Science, First semester
Lecturer: 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 nanofabrication laboratory in 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:  
https://en.didattica.unipd.it/off/2019/LM/SC/SC1174/000ZZ/SCP9087654/N0

OPTICS AND LASER PHYSICS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Materials Science, First semester
Lecturer: Tiziana Cesca
Credits: 6 ECTS

Prerequisites:
The exam is written and comprises two exercises and one open question.

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 properties 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
- bunching and antibunching;
- weak and strong coupling: Purcell effect and Rabi splitting.

OPTICS OF MATERIALS
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Materials Science, First semester
Lecturer: 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/2019/LM/SC/SC1174/000ZZ/SCP9087655/N0

ORGANIC FUNCTIONAL MATERIALS
Master degree in Materials Science, First semester
Lecturer: Miriam Mba Blazquez
Credits: 6 ECTS
Prerequisites:
Organic Chemistry courses of the 1st cycle Degree:
nomenclature of organic molecules, organic functional groups
electrofile and nucleofile
basicity and acidity
addition reactions (alkenes)
nucleophilic substitution (alcohols, halogenated compounds)
Electrophilic aromatic substitution (reactions of aromatic compounds)
Pericyclic reactions

Short program:
1. Carbon nanostructures: Synthesis, properties, characterization and applications of fullerenes, carbon nanotubes, graphene
2. Semiconducting organic polymers: synthesis, properties, characterization, electronic structure, charge generation and transport, bandgap engeneering
3. Small organic molecules for organic electronics
4. Organic light emitting diodes (OLEDs), organic solar cells (OSCs) and organic field effect transistors (OFET)
5. Supramolecular materials
Examination:
Written exam.
six questions
two hours time

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1174/000ZZ/SCP9087652/N0

PHYSIC AND TECHNOLOGY OF SEMICONDUCTORS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS)

Master degree in Materials Science, First semester
Lecturer: Davide De Salvador
Credits: 8 ECTS

Prerequisites:
Mathematical prerequisites:

Basic Physics Prerequisites
Quantum Physics Prerequisites:

Solid state physics Prerequisites

Short program:
Review of the crystal structure of the main semiconductors. Elementary semiconductors , compounds and alloys.
Review of solid state basic concepts ( Bloch theorem , effective mass , concept of hole ).
Origin and specificity of semiconductors band structure. The real bands (examples: GaAs , Si, Ge, AlGaAs ).
The envelope function method for the calculation of quantum states generated by aperiodic potential.
The mechanism of doping. The carriers in a homogeneous semiconductor as a function of doping and temperature ( semic. non-degenerate, intrinsic, ionized , partially ionized , in saturation). The compensation by deep level.
The semiconductor non-homogeneous equilibrium. The case of the p-n junction.
Charge transport in semiconductors. Drift-diffusion equation. Intraband scattering phenomena and mobility in a semiconductor.
The mechanisms of generation and recombination in a semiconductor.
The equation of continuity. The case of the p-n junction under polarization.
The heterojunction joins metal / semiconductor, metal / oxide / semiconductor.
The quantum confinement in semiconductor quantum well, quantum wire, quantum dot.
LEDs, GaN based LED, photodetectors. Solid state laser architectures, quantum confinement effect on lasering. Photovoltaic cells. Different architectures and materials for photovoltaics.
Productive. Transistor bipolar and FET technologies. MOS structure.
Doping techniques. Ion implantation. Diffusion and defects.
Insulation, thermal oxidation.

**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.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1174/000ZZ/SCP9087650/N0

**COMPUTATIONAL METHODS FOR MATERIALS SCIENCE (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MATHEMATICAL ENGINEERING - INGEGNERIA MATEMATICA AND PHYSICS)**

Master degree in Materials Science, Second semester
Lecturer: Francesco Ancillotto
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.
Intermolecular interactions: force-fields; atomistic 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/2020/LM/SC/SC1174/000ZZ/SCQ090918/N0
FUNDAMENTALS OF NANOSCIENCE (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN PHYSICS – EXAM OF INTRODUCTION TO NANOPHYSICS)

Master degree in Materials Science, Second semester
Lecturer: 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:
1) Fundamentals of NanoScience (MSc in Materials Science, 4 + 4 = 8 CFU)
MODULE A (4 CFU)
- Classification, characteristics and general properties of nanostructured materials: quantum confinement and electronic properties. Size Equations.
- Thermodynamic properties of nanostructured materials: thermodynamic size effect, nucleation (Gibbs-Thomson equation) and growth of nanostructures (Diffusion-Limited Aggregation and Ostwald Ripening regimes).
- Nanostructures embedded in solid matrices: ion implantation for the synthesis and processing of metallic nanostructures. Verification of the nucleation and growth models.
- Optical properties of nanostructured materials: (i) plasmonic properties of non-interacting metallic nanostructures (Mie theory and its extensions); (ii) interacting nanostructures
- Characterization techniques of nanostructures: transmission and scanning electron microscopy in transmission (TEM) and in scanning (SEM) mode.
MODULE B (4 CFU)
Recall of the fundamental equations for electron and photon dynamics. Material properties for electron and photon confinement. Density of states for confined systems in one, two or three dimensions.
Properties of low dimensional carbon nanostructures: graphene and nanotubes. Tight binding approach for the description of their conduction, optical properties (absorption and emission) and Raman scattering (Kataura plots).
Models for the electron confinement in quantum dots in the weak and strong regime.
Confinement of electrons in metallic nanoparticles and plasmonic properties. Froehlich conditions and far and near field optical properties. SERS effect with plasmonic nanostructures.
Hints on the confinement of photons in photonic crystals.

2) Introduction to NanoPhysics (MSc in PHYSICS, 4 + 2 = 6 CFU)
The first 4 CFUs are the same as for MODULE A, previously described, which will be borrowed by the students of the 'Introduction to NanoPhysics' of the MSc Degree in Physics.
The remaining 2 CFUs address the following topics:
- Fundamental description of the dynamics of electrons and photons
- Confinement of electrons and photons in nanostructured or periodic materials:
- 2D and 3D photonic crystals;
- Meta-materials: (i) with hyperbolic dispersion and (ii) with negative refractive index;
- Practical laboratory activities: (i) synthesis of Au spherical nanoparticles in solution; (ii) measurement of their UV-VIS transmittance spectrum; (iii) simulation of the experimental spectra with the Mie theory; (iv) electron microscopy characterization.
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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1174/000ZZ/SCP9087651/N0

SUPERCONDUCTING MATERIALS
Master degree in Materials Science, Second semester
Lecturer: No lecturer assigned to this course unit
Credits: 6 ECTS
Prerequisites:
Solid State Physics
Short program:
BASIC PRINCIPLES OF SUPERCONDUCTIVITY
Radiofrequency superconductivity.
SUPERCONDUCTING MATERIALS
Superconductivity in transition metals and Matthias’ empirical rules. B1 and A15 Compounds, the particular case of MgB2 and high Tc superconducting materials. Synthesis and surface treatments in superconducting materials, both thin film and bulk. Characterization of superconducting properties. Materials and applications in mixed phase and Meissner phase.
APPLICATIONS OF SUPERCONDUCTIVITY
Overview of different superconducting materials applications, with particular focus on: superconducting magnets, superconducting motors, radiofrequency cavities, SQUID and current transport.
Examination:
The evaluation exam on the knowledge and expected is based on an oral examination of about half an hour, structured as follows: a first part in which the student presents an application of superconductivity of his/her choice, and a second part in which open questions will be asked on all the topics covered in the course. In agreement with the students, the presentation of the applications can take place during the lectures’ semester.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1174/000ZZ/SCP9087678/N0

MATHEMATICS

ALGEBRAIC GEOMETRY 2
Master degree in Mathematics, First semester
Lecturer: Carla Novelli
Credits: 6 ECTS
Prerequisites:
Basics on topology and commutative algebra.
Short program:
Introduction to affine and projective varieties.
Morphisms, rational maps and birational maps.
Singularities and resolution of singularities. Blow-ups.
Introduction to sheaves and cohomology.
Rational curves and divisors on varieties.
Ampleness and cones of curves.
Extremal rays and extremal contractions.
Surfaces: Cone Theorem, birational classification and Minimal Model Program.
Higher dimensional varieties: Cone Theorem, Contraction Theorem, Extremal Rays, contractions associated with extremal rays, introduction to Minimal Model Program and Minimal Models.

**Examination:**
Seminar.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094305/N0

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**COMMUTATIVE ALGEBRA**

Master degree in Mathematics, First semester
Lecturer: Remke Nanne Kloosterman
Credits: 8 ECTS

**Prerequisites:**
Basic notions of algebra (groups, rings, ideals, fields, quotients, etc.), as acquired in the "Algebra 1" course.

**Short program:**
Rings of fractions and localisation. Exactness of localisation of rings and modules. Local properties.
Chain conditions, Artinian and Noetherian rings and modules. Hilbert's basis theorem. Normalization Lemma and Nullstellensatz.

**Examination:**
Written exam.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/001PD/SCQ0094309/N0
COMPLEX ANALYSIS
Master degree in Mathematics, First semester
Lecturer: Pietro Polesello
Credits: 6 ECTS
Prerequisites:
- Undergraduate courses in Calculus and Geometry
- Elementary notions on complex functions of one complex variable. In particular: Cauchy-Riemann identities and complex differentiation; holomorphic functions. Line integrals of complex functions and their homotopy invariance.
Logarithm of a path and winding number. Cauchy formula for a circle. Analitycity of holomorphic functions.
Zero-set of a holomorphic function; the identity theorem.
Laurent series and isolated singularities. Residue theorem and its use for the computation of integrals.
(All these notions will be recalled in the first lectures.)
Short program:
- The Argument principle and applications
- Conformal maps and the Riemann Mapping theorem
- The Schwarz reflection principle
- Runge’s theory and applications
- Infinite products and the Weierstrass factorization theorem
- Partial Fraction Decompositions and Mittag-Leffler’s theorem
- Principal ideals of holomorphic functions
- Some special functions (Gamma, Zeta)
- The Prime Number theorem
Examination:
Written exam (exercises, theoretical exercises, statements and proofs; duration: 2h30) with possible additional oral exam to improve the mark.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094308/N0

CRYPTOGRAPHY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN CYBERSECURITY)
Master degree in Mathematics, First semester
Lecturer: 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. Migliardi; 6 credits): OS, Programming.
Short program:
For the second part (Prof. Conti and Prof. Migliardi; 6 credits):

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. Migliardi; 6 credits): Written Exam, Homeworks, oral test.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/001PD/SCQ0093658/N0

DIFFERENTIAL GEOMETRY
Master degree in Mathematics, First semester
Lecturer: 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:
Differentiable manifolds, immersed and embedded submanifolds, smooth maps between manifolds.
Tangent space to a manifold, tangent vectors and derivations.
Connections on fiber bundles, linear connections. Curvature of a connection.
Linear connections compatible with a metric. Levi-Civita connection and Riemann curvature tensor.
Differential forms on a manifold, external algebra.
Orientable manifolds and manifolds with boundary.
Integration of differential forms. Stokes theorem.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0093963/N0

FUNCTIONS THEORY
Master degree in Mathematics, First semester
Lecturer: 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, [capacity and fine properties of Sobolev functions].

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 exercise sheet for each of the four parts of the course), according to which a mark will be proposed to the student. An oral examination is optional.


INTRODUCTION TO GROUP THEORY
Master degree in Mathematics, First semester
Lecturer: 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 finite index in profinite groups, Galois groups of 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.

INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS
Master degree in Mathematics, First semester
Lecturer: Laura Caravenna
Credits: 8 ECTS
Prerequisites:
Differential and integral calculus.
Elementary theory of ordinary differential equations.
Basic theory of complex analysis (functions of complex variables, holomorphic and analytic functions).
Short program:
Didactic plan:
- First order PDEs: transport equation with constant coefficients, conservation laws (classical
and weak solutions, Rankine-Hugoniot conditions, Riemann problem).
Weak solutions of Laplace equations on bounded domains are harmonic functions.

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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094080/N0

INTRODUCTION TO RING THEORY
Master degree in Mathematics, First semester
Lecturer: Alberto Facchini
Credits: 8 ECTS
Prerequisites:
Courses of “Algebra 1” and “Algebra 2”. That is, standard undergraduate Algebra.

Short program:

Examination:
Oral examination and/or evaluation of the exercises solved by the students during the course.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/001PD/SCQ0094304/N0

STOCHASTIC ANALYSIS
Master degree in Mathematics, First semester
Lecturer: David Barbato
Credits: 7 ECTS
Prerequisites:
Basic probability theory, basic analysis (differential calculus in R^d, ordinary differential equations), measure theory.

Short program:
Reasons. Stochastic processes (basics).
Probability calculus: notions of convergence, normal multivariate laws, conditional hope.
Brownian motion: construction and main properties.
Discrete and continuous time martingales.
Stochastic integral: construction and properties.
Itô calculation: Itô formula, first applications (e.g. Dirichlet problem), Girsanov’s theorem, martingale representation.
Stochastic differential equations: notions of existence and uniqueness, fundamental theorem of existence and uniqueness, examples, Markov properties and diffusions, Feynman-Kac formula.

**Examination:**
The exam consists of two partial parts, a written test and oral test.

**More information:**

**SYMPLECTIC MECHANICS**
Master degree in Mathematics, First semester
Lecturer: Franco Cardin
Credits: 6 ECTS

**Prerequisites:**
Elementary Calculus and Geometry

**Short program:**
Cohomology.
Riemannian manifolds:
Existence of metrics, Whitney theorem.
Symplectic Geometry:
Symplectic manifolds.
Introduction and developments of Hamiltonian Mechanics on symplectic manifolds.
Local and global parameterization of the Lagrangian submanifolds and their generating functions. Theorem of Maslov-H"ormander.
Hamilton-Jacobi equation, its geometrical solutions and links to the Calculus of Variations. Conjugate points theory in calculus of variations.
Relative cohomology and Lusternik-Schnirelman theory. Introduction to Symplectic Topology: existence and classification of critical points of functions and applications to generating functions of Lagrangian submanifolds.
The min-max solution of Hamilton-Jacobi equation. Symplectic Topology by Viterbo: towards the solution of the Arnol'd conjecture. Morse theory.

**Examination:**
Written.

**More information:**

**TOPOLOGY 2**
Master degree in Mathematics, First semester
Lecturer: 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/2020/LM/SC/SC1172/001PD/SCQ0094298/N0

### ADVANCED ANALYSIS

Master degree in **Mathematics**, Second semester

Lecturer: Giovanni Colombo

Credits: 8 ECTS

**Prerequisites:**
Basic real and functional analysis

**Short program:**
- Fixed point theorems by Brouwer and Schauder, with applications; the hairy ball theorem.
- Gateaux and Fréchet differentiability. The differential of the norm in $L^p$ spaces.
- Ekeland variational principle with some applications (Banach fixed point theorem; local inveribility of smooth functions in infinite dimensional spaces). Further applications to PDE and control theory.
- An introduction to Convex analysis: regularity of convex functions; subdifferential and normal vectors to convex sets; the convex conjugate; convex minimization problems and variational inequalities.
- An introduction to the mathematical Control Theory. Closedness of the set of trajectories under convexity assumptions; existence of optimal controls for minimum problems. Set separation and cone (non-)transversality as basic tools for abstract constrained minimization.
- Optimal Control.
- Nonlinear ordinary differential equations and transport of vectors and co-vectors.
- Necessary conditions for constrained minima. Pontryagin Maximum principle.
- Families of vector fields and controllability of control systems. An introduction to Rashewskii-Chow Theorem.

**Examination:**
An oral exam on the topics covered by the course, that will include some exercises, among those that will be assigned during the course.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0093998/N0

### ALGEBRAIC GEOMETRY 1

Master degree in **Mathematics**, Second semester

Lecturer: Orsola Tommasi

Credits: 8 ECTS

**Prerequisites:**
Many results are based on results from commutative algebra. Basic knowledge of commutative algebra (corresponding to roughly the first half of the commutative algebra course) is recommended.

**Short program:**
This course is intended as a foundational 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/2020/LM/SC/SC1172/010PD/SCQ0094306/N0

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**CALCULUS OF VARIATIONS**

Master degree in **Mathematics**, Second semester
Lecturer: Luca Massimo Andrea Martinazzi
Credits: 8 ECTS

**Prerequisites:**
The Analysis 1 and 2 and the Real Analysis course

**Short program:**
Introduction to the classical formalism of the Calculus of Variations: indirect methods, first variation, Euler-Lagrange equations, applications.

Some examples, including minimal surfaces.

The least action principle and the analytical mechanics of Lagrange.

First direct methods, working in spaces of Lipschitz functions, via a priori gradient estimates.


First questions of regularity theory. Regularity of elliptic equations via the Caccioppoli inequality, decay estimates, Campanato spaces.

Some more subtle questions in regularity theory: De Giorgi’s solution of the XIX problem of Hilbert. Partial regularity for elliptic systems.

**Examination:**
Homeworks and oral exam

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

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**DIFFERENTIAL EQUATIONS**

Master degree in **Mathematics**, Second semester
Lecturer: 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 Programming method; existence of solutions to H-J equations with convex Hamiltonians; synthesis of optimal feedbacks.

Part 2.
- 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/2020/LM/SC/SC1172/010PD/SCQ0093962/N0

DYNAMICAL SYSTEMS
Master degree in Mathematics, Second semester
Lecturer: No lecturer assigned to this course unit
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:
1. Continuous (ODEs, flows) and discrete (iteration of maps) Dynamical Systems. Linearization, variational equation. Linear dynamical systems; stabel, unstable and center subspace.
5. Hyperbolic systems and homoclinic phenomena; Smale horseshoe; symbolic dynamics; Melnikov integral; shadowing.
7. Numerical experiments on ODEs.

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 (recommended) in pairs, at their choice. During the examination, students may also be asked to solve some simple exercises.

This examination format allows to evaluate: 1) The level of the theoretical knowledge of the matter reached by the student. 2) The level of the mathematical comprehension of the matter reached by the student. 3) The abilities reached by the student in the numerical investigation of dynamical systems, and in particular in the analysis and comprehension of the numerical results.

More information:
HAMILTONIAN MECHANICS (OFFERED IN THE MASTER DEGREE IN PHYSICS – EXAM OF MATHEMATICAL PHYSICS)
Master degree in Mathematics, Second semester
Lecturer: Paolo Rossi
Credits: 6 ECTS
Prerequisites:
Basics of algebra and differential geometry (the very basics of differential geometry will be recalled at the beginning of the course, if needed).
Basic knowledge of Hamiltonian mechanics and/or quantum mechanics would help putting the course content into context, but is not strictly needed.
Short program:
Hamiltonian systems in Poisson manifolds
(Poisson algebras, deformation theory, Poisson manifolds and their geometry,...).
Integrability
(reminder of Arnold-Liouville integrability, Lax representations, bihamiltonian structures,...).
Elements of quantization
(basic ideas of quantum mechanics, elements of deformation quantization, quantum mechanics in phase space,...).
Evolutionary Hamiltonian PDEs
(as infinite dimensional Hamiltonian systems, modern theory of integrable PDEs,...).
Examination:
To be decided depending also on the number of students, but probably either a relatively simple written exam granting access to an oral exposition in the form of a short seminar plus some questions, or a written exam containing both simple exercises and questions on theory.
More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094084/N0

HARMONIC ANALYSIS
Master degree in Mathematics, Second semester
Lecturer: Massimo Lanza De Cristoforis
Credits: 6 ECTS
Prerequisites:
Analysis courses of the first two years, and preferably the following courses
Real Analysis
Mathematical Methods
Functional Analysis 1
and the basic properties of harmonic functions, which will be anyway brushed up.
Short program:
Preliminaries on function spaces
Integral operators with weakly singular and singular kernel
Applications to the analysis of potentials
Elements of potential theory
Applications to boundary value problems for harmonic functions.
Examination:
Partial tests and final oral exam
More information:

HOMOLOGY AND COHOMOLOGY
Master degree in Mathematics, Second semester
Lecturer: Bruno Chiarellotto
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. 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/2020/LM/SC/SC1172/001PD/SCQ0094302/N0

INTRODUCTION TO STOCHASTIC PROCESSES (OFFERED IN THE MASTER DEGREE IN STATISTICAL SCIENCES)

Master degree in Mathematics, Second semester
Lecturer: Marco Formentin
Credits: 8 ECTS
Prerequisites:
A basic course in Probability.

Short program:
Monte Carlo Simulation: Metropolis-Hastings algorithm.
Poisson process: main properties and applications.
Examination:

NUMBERS THEORY 1
Master degree in Mathematics, Second semester
Lecturer: Francesco Baldassarri
Credits: 8 ECTS
Prerequisites:
A standard Basic Algebra course; basic Linear Algebra; a basic course of Calculus; a short course in Galois Theory would be most useful; some familiarity with the theory of analytic functions of one complex variable would be useful.

Short program:
1. Basic algebra of commutative groups and rings.
2. Factorization of elements and ideals
3. Dedekind domains
5. Rings of integers. Factorization properties.
7. Frobenius automorphism, Artin map;
9. An introduction to Class Field Theory (from Kato-Kurokawa-Saito Vol. 2, Chap. 5)
10. Minkowski Theory (finiteness of class number and the unit theorem).
11. Dirichlet series, zeta function, special values and class number formula.

The whole material is to be found in the single textbook: Daniel A. Marcus "Number Theory", Springer-Verlag. The essential part of the program consists of Chapters 1 to 5, with those exercises which are used in the body of the textbook. Chapters 6 and 7 are required to get a higher grade. The lengthy real-analytic proofs in Chapters 5/6/7 are not essential. A good understanding of the complex-analytic strategy is necessary.

We recommend, for cultural reasons, reading through the two volumes of Kato-Kurokawa-Saito, possibly without studying proofs.

**Examination:**
The notes of classes will be posted weekly on the platform Moodle. Every week some exercises will be proposed as homework. Solutions will have to be surrendered by the next week. Papers will be graded weekly. The marks will contribute in an essential way to the final grades. During the second half of the course, each student will be offered the possibility to present in 30 minutes the solutions to 1 or 2 exercises of the week during the course. For those who attend classes and do the homework sufficiently well, the exam will be concluded without further checks.

(A final oral examination is reserved for those who aim at top grades.)

Alternatively, every student has the possibility of taking the exam in a traditional way as a conversation on the first 5 chapters of the textbook (Marcus), including the solutions of all exercises of that book.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094301/N0

**NUMBER THEORY 2**
Master degree in Mathematics, Second semester
Lecturer: 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/2020/LM/SC/SC1172/001PD/SCQ0094300/N0

**NUMERICAL METHODS FOR DIFFERENTIAL EQUATIONS**
Master degree in Mathematics, Second semester
Lecturer: 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:
Applications to nonlinear problems.
Examination:
Oral examination with discussion on the lab projects.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094083/N0

REPRESENTATION THEORY OF GROUPS
Master degree in Mathematics, Second semester
Lecturer: Giovanna Carnovale
Credits: 6 ECTS
Prerequisites:
Basic notions of 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.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/010PD/SCQ0094299/N0

RINGS AND MODULES
Master degree in Mathematics, Second semester
Lecturer: Silvana Bazzoni
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 consisting in answering to questions from the theory and in solving exercises. Discussion of the composition and possible oral exam.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1172/001PD/SCQ0094307/N0

STOCASTIC METHODS FOR FINANCE (OFFERED IN THE MASTER DEGREE IN MATHEMATICAL ENGINEERING)
Master degree in Mathematics, Second semester
Lecturer: Martino Grasselli
Credits: 7 ECTS
Prerequisites:
Stochastic analysis

Short program:
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.
Black&Scholes via PDE and via Girsanov.
Hedging and completeness in the Black&Scholes framework.
Feynman-Kac formula and risk neutral pricing in continuous time.
Pur Call parity, dividends and static vs dynamic hedging.
The Greeks and the Delta-Gamma hedging. Delta-Gamma-Vega neutral portfolios.
Barrier options pricing in the Black&Scholes model.
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.
Change of numeraire and Forward Risk Neutral measure.

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

More information:

NATURAL SCIENCE

ENVIRONMENTAL IMPACT ASSESSMENT (OFFERED IN THE MASTER DEGREE IN LOCAL DEVELOPMENT ORD.2018 EXAM OF ENVIRONMENTAL AND SOCIAL RESPONSIBILITY IN LOCAL DEVELOPMENT PROCESS)
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Natural Science, First semester
Lecturer: Massimo 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 Habitat 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/2019/LM/SC/SC1178/000ZZ/SCP4063900/N0

ANTHROPOLOGY
Master degree in Natural Science, Second semester
Lecturer: Luca Pagani
Credits: 6 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:
- early phases of human evolution with an overview on the available fossil remains (8h);
- genetic characterization of archaic humans (Neanderthals and Denisova) (4h);
- human expansions out of Africa and interactions with pre-existing archaic humans (4h);
- evidences of adaptive introgressions (genetic advantages derived from archaic genetic material) (2h);
- peopling of the continents (Eurasia, America, Oceania) (6h);
- dating of the divergence between various modern human populations (4h);
- genetic adaptation to the diverse environments encountered inside and outside of Africa (4h);
- how structured is the genetic diversity of our species (4h);
- demographic growth and expansion/admixture events following technological revolutions (i.e. Neolithic) (4h);
- patrilinar (Y chromosome) and matrilinar (mtDNA) perspectives on the diversification of modern populations (2h);
- 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 (6h)
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). If 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/2020/LM/SC/SC1178/000ZZ/SCP8085142/N0

**ENVIRONMENTAL MINERALOGY (OFFERED IN THE MASTER DEGREE IN LAND AND ENVIRONMENT SCIENCE AND TECHNOLOGY)**

**Information concerning the students who enrolled in A.Y. 2019/20**
Master degree in Natural Science, Second semester
Lecturer: Gilberto Artioli
Credits: 8 ECTS

**Prerequisites:**
Basic chemistry and chemical thermodynamics. Essentials of mineralogy and geology.

**Short program:**
Natural solid materials: basic concepts of mineralogy and crystal-chemistry.
Natural processes. Introduction on the distribution of the chemical elements on the Earth’s crust, on the geological processes, on the geochemical cycles. Processes and fluid-solid interactions at the mineral surfaces. Experimental techniques to study materials surfaces.

Case studies:
(1) Hazardous minerals in nature and in working places: asbestos, free silica. Environmental monitoring, assessment, mineral quantification, disposal.
(2) Microporous materials and inclusion compounds: clays, zeolites, clathrates, gas hydrates. Crystal structure, crystal chemistry, absorption properties, ionic exchange properties, catalysis. Their use in environmental, agricultural, and industrial applications.
(3) Mineral dust. Origin, characterization. Implications for the palaeoclimatic and environmental reconstructions of the investigations of mineral dust entrapped in polar ice and ocean sediments.
(5) Binders and cements. Their use in history and in present societies as building materials. Environmental applications in solidification and inertization processes of wastes and polluted soils.
(6) Rare Earth Elements. REE cycle and natural resources. Their role in technological products, recovery from e-waste.

**Examination:**
(1) mid-term presentation on an analytical technique selected by the teacher. The student will summarize: (a) the fundamentals of the technique, (b) the instrumental configuration, (c) the resulting information, (d) describe one application with environmental implications.
(2) The student will deliver a final presentation on a topic with environmental implications agreed with the teacher. The student will present: (a) the scientific problem, (b) the data
available in the literature, with critical discussion, (c) the prospected actions for a better definition or solution of the problem

More information:
https://en.didattica.unipd.it/off/2019/LM/SC/SC1178/000ZZ/SCP4065427/N0

SANITARY BIOLOGY

APPLIED STATISTICS (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MOLECULAR BIOLOGY)
Master degree in Sanitary Biology, First semester
Lecturer: 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:
- Elementary methods. Inference on a proportion and comparison of two proportions. Student's t: one sample, two samples, paired data. Large sample inference. Nonparametric methods: Wilcoxon (one and two samples) and Kruskal-Wallis tests. Correlation coefficient.

Examination:
Written exam. Students are required to answer a number of questions concerning the statistical analysis of a real data set.

More information:
https://en.didattica.unipd.it/off/2020/LM/SC/SC1177/000ZZ/SCN1028731/N0

BIOCHEMISTRY OF DISEASES (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MOLECULAR BIOLOGY)

Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Sanitary Biology, First semester
Lecturer: Luca Scorrano
Credits: 8 ECTS

Prerequisites:
Biochemistry, Physiology and Pathology.

Short program:
1. Introduction to the course
2. Mechanisms of protein homeostasis
3. Mechanisms of cellular ion homeostasis
4. Mechanisms of redox homeostasis and cellular bioenergetics
5. Biochemical mechanisms of reversible cellular damage
   a. atrophy
   b. hypertrophy
   c. Metaplasia (EMT)
6. Biochemical mechanisms of irreversible cellular damage
   a. apoptosis

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b. necrosis
c. necroptosis
d. Autosis
7. Biochemical mechanisms of senescence and aging
8. Biochemical mechanisms of cell transformation and oncogenesis
9. Role of biochemistry in mitochondrial disease
These topics will be covered in specific workshops, Journal Clubs, lectures held by the teacher and by ad-hoc invited international experts.

Tutorials
Laboratory tutorials on biochemical assays of cell death and autophagy and on the analysis of mitochondrial dysfunction.

**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:**

**HUMAN PHYSIOLOGY (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MOLECULAR BIOLOGY)**
Master degree in Sanitary Biology, First semester
Lecturer: 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 questions to be answered in two hours.

**More information:**
https://en.didattica.unipd.it/off/2020/LM/SC/SC1177/000ZZ/SCN1032657/N0

**MOLECULAR BIOLOGY AND GENETICS OF CANCER**
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Sanitary Biology, First semester
Lecturer Enrica Calura
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
2. Carcinogenesis and Cancer Genetics:
- Oncogenes and Signal Transduction
- Tumor Suppressor Genes
- DNA Repair Pathways and Human Cancer
- Epigenetics and Cancer
- Infectious Agents and Cancer
- Environmental Carcinogenesis

3. Cancer Biology:
- 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:
- Use of next-gen sequencing in cancer
- Cancer System Biology
- Introduction to Pan-Cancer Analysis

5. Molecular Pathology and Diagnostic:
- Biomarkers for diagnosis, risk and therapy assessment

6. Notes on the molecular basis of cancer therapy:
- Cancer Therapeutics
- Natural and Acquired Resistance to Cancer Therapies

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. Finally, seminars will be held by invited experts in molecular oncology.

Examination:
A written exam will be held. The journal club and activities in the bioinformatic laboratories will be also scored.

More information:
INTRODUCTION TO STOCHASTIC PROCESSES (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN MATHEMATICS)
Master degree in Statistical Sciences, Second Semester
Lecturer: Marco Formentin
Credits: 9 ECTS
Prerequisites:
A basic course in Probability.
Short program:
Examination: Written examination with exercises for solution similar to those solved in class. Statements and proofs of relevant theorems may be also asked.
More information: https://en.didattica.unipd.it/off/2020/LM/SC/SS1736/000ZZ/SCQ0093538/N0

THEORY AND METHODS FOR INFERENCE (ALSO OFFERED FOR STUDENTS OF THE MASTER DEGREE IN STATISTICAL SCIENCES)
Information concerning the students who enrolled in A.Y. 2019/20
Master degree in Statistical Sciences, Second Semester
Lecturer: Alessandra Salvan
Credits: 9 ECTS
Prerequisites:
First year Masters courses of the Department of Statistical Sciences, especially Probability Theory and Statistics (Advanced).
Short program:
Reparameterizations.
- Likelihood and Bayesian inference: numerical and graphical aspects in R. Scalar and vector parameter examples. EM algorithm.

**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/2019/LM/SC/SS1736/000ZZ/SCP4063246/N0](https://en.didattica.unipd.it/off/2019/LM/SC/SS1736/000ZZ/SCP4063246/N0)