Educational program 2021/22

PhD Program in Mathematics, Physics and Applications to Engineering

XXXVII cycle

Courses

University Training activities

Research and intellectual property enhancement activities

Patent as an inventive research activity (4 ECTS – 24 hours)

The course focuses on patenting principles, practices and strategies in the processes of intellectual property management and enhancement and technology transfer at national and international level.
The lessons aim to promote the exploitation of research results through the protection of Intellectual Property (IP), providing tools and methods on procedural forms and steps to structure patent applications.
Specifically, they will concern the principles of Intellectual Property protection, patent submission and evaluation procedures, information on how to retrieve data on existing patents (anteriority search) and the necessary bibliographical tools.

Syllabus

1. *Patent Making* - Theories – Laboratory

- The Patent between Invention and Innovation
- Forms and types of patents
- Definition and practice of the patent for industrial invention
- Patentability requirements
- Good practices for structuring a patent application for an industrial invention
- Procedure for depositing and/or extending the patent
- Patent searches and classification codes
- Definition and practice of the utility model
- Comparison between patent for industrial invention and utility model patent
- Registration of designs and models

- Rights on inventions
- Practical laboratory on Intellectual Property: use of databases and setting up patent proposals

2. *Processes, tools and best practices to structure patents and models* - Theories – Laboratory

- Impact of Intellectual Property on Research
- Overview of industrial invention patents examples
- Overview of designs and models examples
- Practical laboratory on intellectual property: simulation of patent research proposals
- Presentation and explanation of patent proposals
- Round table to discuss the proposed patent files

3. *Strategies and forms of patent valorisation* - Theories – Laboratory

- Tools and opportunities for Intellectual Property valorisation
- Presentation of Innovation Awards and Competitions: Start Cup Campania, National Award for Innovation
- Overview of examples and mock-ups of Business model and Business plan
- Spin off as a tool for research valorisation
- Overview of academic spin-off examples
- Facilitated finance instruments
- Practical laboratory on Intellectual Property: patent valorisation and technology transfer
- Structuring business models to simulate start cup and spin off creation

Language and computer training activities

English Language (4/6 ECTS - 24/32 hours)

Introduction to modern computing infrastructures (4 ECTS – 24 hours)
Lecturer: M. Iacono (UniCampania)

The course aims at providing students of Dottorato di Ricerca in Matematica, Fisica e applicazioni per l'Ingegneria the basic knowledge related to modern computing infrastructures, presenting the main issues on a small and large scale, to allow an appropriate and wise use for the needs of usage and development of specialized computing applications for research problems. After an introduction about the characteristics of modern computing nodes and computer networks, the course presents the main themes related to architecture, organization and software support offered by contemporary large scale computing systems, with special reference to massively distributed architectures and cloud applications. Finally, the course includes a primer on the issues related to performance evaluation for these systems and related modeling techniques. The course includes references to related research activities about research topics.

Specialistic courses

Python Programming Fundamentals - Basics of Deep Learning and Neural Networks in Python (4 ECTS - 24 hours)

Lecturers: E.Bellini (UniCampania) - F. Marulli (UniCampania)

Module 1 (12 hours): Python Programming Basic

The objective of this module is to provide to the PhD students an initial set of knowledge of the Python 3 programming language. The course will have a pragmatic cut focusing on the practical use of Python as a tool in research rather than discovering the internal mechanisms of this language. This notwithstanding, the course will present the "pythonic" way of programming, i.e. the use of specific Python features that allow the ease construction of complex programs.

The course will also present libraries and packages devoted to the scientific computing (e.g., NumPy).

Module 2 (12 hours): Basics of Deep Learning and Neural Networks in Python

Deep learning represents the machine learning technique actually behind lots of exciting capabilities in several areas like robotics, natural language processing, image recognition, and artificial intelligence, including the famous AlphaGo. In this course, ph.D. students will gain hands-on, practical knowledge of how to use deep learning with very useful and popular Python based frameworks, as Tensorflow and Keras. This latter represents the latest version of a cutting-edge library for deep learning in Python.

Prerequisites:

Attendants should previously be able to program into a procedural programming language (e.g., C, Fortran) and computer architecture basics.

Syllabus:

1. Introduction to machine learning and deep learning
2. Introduction to Neural Networks and Deep Neural Networks
3. Comparing neural network models to classical regression models
4. Activation functions: The Rectified Linear Activation Function
5. Applying the network to many observations/rows of data
6. Deeper networks and Multi-layer neural networks
7. Forward propagation in a deeper network
8. Creating a model in Keras
9. Preparing data set
10. Choosing and compiling a model
11. Fitting and tuning a model
12. Classification models
13. Understanding results from classification.

Fundamentals of linear programming, numerical methods and applications

Lecturer: R. Campagna (UniCampania) (4 ECTS - 20 hours)

Linear Programming is a form of optimization. Optimization is a mathematical branch which methods are used to solve complex everyday problems. It provides the tools that are at the heart of Operations Research, the discipline that provides analytical methods to help make better decisions.

The focus of linear and integer programming is on resource-constrained optimization problems that can be described by linear inequalities and a linear objective function. These problems can arise in all decision-making contexts, such as manufacturing, logistics, healthcare, education, finance, energy supply and many others.

The aim of the course is to allow the student to use mathematical modeling to solve practical optimization problems and to work with a mathematical software system to find numerical solutions to the proposed applications. To achieve these objectives, the course will provide the student with knowledge on the fundamentals of linear programming and the theory of duality and on the main solution techniques for linear and integer programming, such as the simplex method.

Also included is an interactive hands-on session in which students will apply the methods studied for solving economic problems, also by product mix strategies.

<u>Syllabus</u>

1. Preliminaries

Basics of linear algebra and geometry in space and methods for solving linear systems.

2. Introduction to optimization and decision problems

Models, examples, how to move from a concrete problem to the abstract model.

Algorithm definition, implementation, and analysis of results.

3. Linear Programming (LP)

- Graphic resolution of a LP problem.

- Geometry of the LP (vertices, facets and faces of the polyhedron).

- Fundamental theorem of LP.

- Duality.

- Sensitivity analysis and economic interpretation of shadow prices.

4. Basics on Convex optimization

Lagrange multipliers; Karush-Kuhn-Tucker conditions.

Applications of Kinetic Theory to Non-mechanical Systems (4 ECTS - 20 hours)

Lecturer: B. Carbonaro (UniCampania)

Origin, motivation and meaning of the Boltzmann Equation - Generalization of the Boltzmann Equation to probability density function on non-mechanical variables: Vlasov equation - The case of continuous Variables - The case of discrete variables – Interaction rates and transition probabilities - Well-posedness problems - Stability and instability of solutions.

Self-adjointness for unbounded operators on Hilbert spaces: perturbation theory and self-adjoint extensions (4 ECTS – 20 hours)
Lecturer: B. Cassano (UniCampania)

The course focuses on the theory of unbounded self-adjoint operators in Hilbert spaces, addressing the question: given a self-adjoint operator, how does this property change adding perturbations? Such question is fundamental in Mathematical Analysis, in Physics and in applications.
Prerequisites of the course are unbounded self-adjoint operators on Hilbert spaces, Lebesgue and Sobolev spaces. In the course, first, the basic definitions and properties of unbounded

operators are recalled and the property of self-adjointness is described. Then, we address some results of perturbation theory (Kato-Rellich-Wust theorem). Finally, some results on extensions for symmetric operators are given (Friedrichs extension, Von Neumann theory, boundary triples). Constant attention will be given to applications, with focus on the Laplace and Dirac operators and to the necessary mathematical tools.

Pyro-electrohrdrodynamics and advanced technologies for soft-matter manipulation (4 ECTS - 20 hours)
Lecturers: S. Coppola (ISASI)

The course provides the description and exploitation of innovative fabrication methods for the manipulation of liquids, polymers, and high viscous materials. In particular, the method based on the pyro-electrohrdrodynamic (pyro-EHD) effect will be presented focusing on different materials, high resolution printing and patterning properties. The main feature of the method discussed stands in the non-contact and nozzle free modality that allows to manipulate starting drops of the material of interest in a direct way. The course will be focused on the theory of the pyroelectric effect and its experimental exploitation for the manipulation of soft matter, opening towards its feasible application in different field of technologies. A cross-overview with the advanced conventional technologies will be provided while the main properties and advantages of the pyro-EHD will be discussed for biomedical application, additive manufacturing of 3D microstructures and for functionalization of microfluidic lab-on-chip devices.

Theory of nuclear forces (4 ECTS - 20 hours)
Lecturer: L. Coraggio (UniCampania)

The goal of this course is to introduce PhD students to our present knowledge of the theory of nuclear forces. First, the basic phenomenological features of the nuclear potential are presented, and their connection to the main aspects of strong force. Then, we start to follow the path that from the Yukawa potential, through models based on the meson theory, historically leads to the present approach to the derivation of two- and three-body nuclear forces which are rooted in the QCD by way of the effective field theory. Last section is devoted to study the nuclear environment that is considered the best testing ground for models of nuclear forces, that is the infinite nuclear matter. To this end, basic knowledge of the derivation of the equation of state of nuclear matter in terms of the Brueckner theory will be provided to the students.

Physics for Space Application (4 ECTS - 24 hours)
Lecturer: M. De Cesare (CIRA)

The course provides the basis of the experimental methodologies concerning the problems of measurement applications, diagnostic and theoretical-experimental characterization in aerospace application, typical of the re-entry phase (terrestrial and planetary). The need to qualify and measure on large on-ground laboratories for the development of modern diagnostic aerospace technologies is underline.

Research in mathematics education (4 ECTS - 20 hours)
Lecturer: U. Dello Iacono (UniCampania)

The course aims at supplying PhD students with the main theoretical frameworks in mathematics education and the main methodologies, by setting they in the historical context and in the national and international researches and by dealing the conceptual questions by an epistemological point of view.
In addition, the course aims to stimulate a critical analysis of the main teaching methodologies, also referring to the specific role of the teacher, to the conceptual, epistemological, linguistic and didactic aspects for the mathematics teaching and learning.
Teaching methods: multimedia lessons, laboratory activities, discussion of scientific papers.

Introduction to Partial Differential Equations and Calculus of Variations (4 ECTS - 20 hours)

Lecturers: G. Di Blasio (UniCampania) - G. Pisante (UniCampania)

The course aims to introduce some of the aspects of the wide world of Partial differential equations. The course is divided into two parts.

<u>Modulo I – PDEs</u>

Partial differential equations are often used to construct models of the most basic theories underlying physics and engineering. Our goal in this course is to give a brief introduction to this field. We first focus our attention on the solvability of uniformly elliptic second-order PDE and we give the notion of weak solutions. To this end, using the well-known Lebesgue spaces, we introduce the Sobolev spaces and their properties. The basic Hilbert space theory will allow us to study the existence and the regularity of weak solutions to the boundary value problem of elliptic PDE.

<u>Modulo II – Calculus of Variations</u>

The theory of Calculus of Variation enables us to study a quite important class of nonlinear PDEs, namely the ones having a variational structure, using relatively simple techniques from nonlinear functional analysis. The basic idea is to recast the problem of solving a PDE in terms of the existence of minimizers of a related abstract functional and subsequently to study the minimization problem.

The course aims to present the main ideas underlying this theory mainly focusing on the existence and regularity results for minimizers of integral functionals defined in Sobolev Spaces.

Syllabus

Modulo I – PDEs

1. Introduction to partial differential equations: weak derivatives and properties, Sobolev spaces, Sobolev inequalities.
2. Compactness.
3. Existence and regularity of weak solutions.
4. Maximum principles.
5. Eigenvalues of symmetric elliptic operators and notes on eigenvalues of nonsymmetric elliptic operators.

Modulo II – Calculus of Variations

1. Introduction to basic ideas on Calculus of Variations: Integral functionals, first variation and Euler-Lagrange equations, second variation.
2. Existence of minima: coercivity, semicontinuity, convexity, polyconvexity.
3. An overview on the regularity properties of minimizers.
4. Constrained problems.

Advanced constitutive and structural models, and shape and topology optimization strategies (4 CFU - 24 hours)
Lecturer: L. Esposito (4 ECTS - UniCampania)

The course aims to provide students with the essential tools for modeling and computational analysis in the thermo-mechanical field of continuum and structures, and optimization strategies used in mechanics. By recalling continuum mechanics and fundamentals of modeling based on the Finite Element Method (FEM), the objective of the course is to illustrate the main approaches to modeling and numerical strategies for determining stress and strain in one, two, and three-dimensional structures, also considering examples of materials that exhibit geometrical and/or constitutive nonlinearities, in steady-state or transient regime.
Finally, the optimization strategies used in mechanics will be illustrated and implemented.

Contents:
-Reviews of continuum mechanics (equilibrium equations and kinematic models of continuum; constitutive equations; variational problem and discrete form of partial differential equations in elasticity; matrix analysis of reticular structures; the displacements approach; formulation of the

minimum potential energy problem in the FEM; elastic analysis; high order and isoparametric elements; non-linear materials).

-Applications to one, two, and three-dimensional systems by means of FEM codes.

-Numerical simulations in ANSYS Multiphisics environment: 1) pre-processing phase: geometrical modeling; setting of the constitutive properties of the materials; choice of the finite element and discretization of the model (mesh); initial and boundary conditions settings; 2) solution phase: choice of the solver; 3) post-processing phase: analysis of the results.

-Ansys Parametric Design Language (APDL) programming language: the batch mode in ANSYS Multiphisics environment.

-Mechanical optimization strategies: design optimization; topological optimization; custom-made optimization. Applications.

Optics and Photonics for advanced multimodal metrology (4 ECTS - 20 hours)
Lecturer: P. Ferraro (CNR-ISASI)

Optical and photonic methods (interferometry, spectroscopy, holography, 3D imaging, IR, etc.) have the inherent advantage of being non-invasive, full-field and often based on image output. The course will address the fields of modern metrology based on optical and photonic approaches and methods for the characterization of materials, processes and components in the new paradigm of Industry 4.0. It will be given the groundwork for understanding the basic operating principles of the most advanced technology currently available for inspection and testing. Particular emphasis will be given to the interpretation and analysis of the measurements. Examples of applications in different fields (automotive, aerospace, cultural heritage, biotech, etc.) will be illustrated and discussed to understand the significant role of these methods today and in the next years considering the emerging "multimodal" approach in metrology. Finally will be discussed also the importance of exploiting Deep Learning in metrology connected to the aforementioned tools.

Quantum sensing and applications (4 ECTS - 24 hours)
Lecturers: C. Granata – A. Vettoliere (ISASI)

Direct current Superconducting Quantum Interference Device (dc SQUID) is the most sensitive magnetic flux and field detector known so far. Due to the low operating temperature and the quantum working principle, a SQUID exhibits an equivalent energy sensitivity that approaches the quantum limit. In this course, the topic of nano-SQUID will be addressed. Starting from the underlying principles, the main characteristics on these quantum devices will be highlighted. The many configurations and arrangements will be also addressed together with the motivations, the theoretical aspects and the fabrication techniques. An overview of many nanoscale applications including the investigation of the magnetic properties of nanoparticles, magnetic molecules, cold atom clouds, nanowires or single electronic spin will be given.

Label free phase contrast microscopy: principles and applications - (4 ECTS - 24 hours)
Lecturers: L. Miccio (ISASI) - V. Bianco (ISASI)

Label-free microscopy techniques exploiting quantitative phase-contrast paradigm will be presented. In particular the methods based on interferometry and digital holography will be treated extensively. Physical principles will be reviewed and great attention will be given on the more efficient experimental arrangements and the most upgraded image processing procedures. The main feature of interferometric methods stands in the quantitative evaluation of the phase shift introduced in the wavefront due to the presence of sample. This is the reason of the great range of applications of such techniques from macroscopic length scale to microscopic world. The course will be mainly focused on microscopy and, in particular, on recent developments in bio-medical field.

Model theory of separably closed valued fields (4 ECTS - 16 hours)
Lecturer: M. Hills (Universität Münster, Germany)

The course will cover fundamental results in the model theory of separably closed non-trivially valued fields, from a point of view of classical algebraic model theory (quantifier elimination, description of the completions etc.) and also from a more modern point of view, considering important properties from combinatorial/geometric model theory (NIP, classification of imaginaries, stable domination etc.)

Overview of the course:

- Algebraic preliminaries, in particular around p-independence .
- Model theory of separably closed fields, including quantifier elimination, stability and, in finite
degree of imperfection, elimination of imaginaries.
- Quick review of the model theory of algebraically closed non-trivially valued fields, starting with quantifier elimination in the three-sorted language and then sketching Johnson's proof of the classification of imaginaries by the geometric sorts, a result due to Haskell-Hrushovski-Macpherson.
- The theory SCVF of separably closed non-trivially valued fields: completions of SCVF, Hong's proof of quantifier elimination in the language with parametrized lambda-functions

and variants in finite degree of imperfection, proof that all completions are NIP (a result due to Delon).
- Classification of imaginaries in SCVF, in finite degree of imperfection, by the geometric sorts (in a language with a p-basis or with Hasse derivations), proved via a reduction to the algebraically closed case (result due to Kamensky, Rideau and myself).
- A glimpse on further notions in SCVF (in finite degree of imperfection): stable part, stable domination, metastability.

Stability analysis of open-channel flows with Newtonian and non-Newtonian fluids (4 ECTS - 24 hours)
Lecturer: M. Iervolino (UniCampania)

The course concerns the basic concepts of hydrodynamic instabilities, with application to a class of one-dimensional free surface flows which are encountered in both environmental and industrial applications. The governing equations for the one-dimensional free surface flow of thin layers are preliminarily discussed, with special reference to the rheological behavior of the considered fluid, i.e. Newtonian or non-Newtonian. Subsequently, the standard method of normal-mode analysis is applied to the investigation of the stability of the equilibrium flow of a thin-layer of fluid. The main features of unstable-free surface perturbations are evaluated based on the results of the normal mode analysis and their implication in practical applications is discussed. The theory of near-front wave expansion is then introduced to analysis the stability of flow influenced by the boundary conditions or the non-linear growth of the fronts of unstable perturbations, in a rather general framework that allows the application of this method to an even wider class of flows. In the last part of the course, PhD students are guided to the application of these techniques to examples from their own research field.

New Concepts and Materials for Applications in Electronics, Photovoltaics and Energy Storage (4 ECTS - 24 hours)
Lecturer: G. Landi (ENEA)

The course introduces:

- **new concepts and materials** for the next generation of **photovoltaics**: multijunction solar cells, multiple excitation solar cells, intermediate band solar cells and related technologies (for quantum dots, thin films, organic and perovskite).

- an **overview** of the latest advancements in **different types of batteries** (including rechargeable lithium and lithium-ion batteries, metal-air batteries) and supercapacitors with a comprehensive review of materials and technologies. Particular attention to environmentally friendly energy storage devices is given.

- **new biodegradable, polymeric and organic materials** that can be used as alternative systems to the inorganic materials for biodegradable/transient **electronics applications** (which can physically disappear after a period of stable operation with harmless end products).

Biophotonics for clinics and environment (4 ECTS - 24 hours)

Lecturer: M. Lepore (UniCampania)

The course will deal with the application of optical techniques to the development of new diagnostic strategies and environment monitoring tools. Vibrational and fluorescence spectroscopies will be used for investigating biofluids, human tissues, radioesposed cells and enzymes in order to monitor biological processes and to develop sensor devices.

Numerical Methods for Data Analysis in Optical Spectroscopy (4 ECTS - 24 hours)

Lecturers: M. Lepore (UniCampania) - I. Delfino (Università della Tuscia) - C. Camerlingo (CNR)

The course aims to introduce numerical methods particularly useful for the analysis of spectral data with particular attention to background subtraction, noise reduction and quantitative applications (chemometrics). Univariate and multivariate analysis (PCA, Principal Component Analysis), wavelet algorithms will be discussed and applied in the analysis of practical cases of students' interest.

Biophysical mechanisms and therapeutic implications of human exposure to ionising radiation (4 ECTS - 20 hours)
Lecturer: L. Manti (Università di Napoli Federico II)

Human exposure to ionizing radiation (IR), as a result of both naturally occurring sources as well as from diagnostic and therapeutic applications, is ubiquitous and entails well-known risks along evident benefits. The aim of the course is to provide the basic knowledge of the mechanisms that govern the biological action of IR, starting from the strong link between the patterns with which energy is deposited within the biological target and the consequences these might have at cellular, tissutal and organismal level. In fact, IR is unique among all the mutagenic and carcinogenic agents because it gives rise to a peculiar distribution of ionization clusters at the nanometer level, whose spatio-temporal proximity determines the severity of the damage incurred by the most important macrobiomolecule, the DNA. A cascade of complex pathway is then triggered that process such damage, driving the cell towards restoration of its genomic integrity or to death by several modes or, towards transmission of heritable damage. The latter is the most hazardous scenario for long-term effects such as cancer onset. The course will then illustrate the main biophysical models currently describing and quantifying the biological action of IR and the experimental work that has allowed to lay the foundations for modern radiotherapy (RT), such as the concepts of dose fractionation, together with novel phenomena that have questioned the central dogma of DNA as the sole target of radiation action. Special attention will be also devoted to illustrate the most advanced frontiers of novel radiation-based strategies to improve cancer control and minimize damage to the ineludibly exposed normal tissue, thereby reducing the risk of secondary cancers. Specifically, hadrontherapy (the use of accelerated particle beams), FLASH-RT, laser-driven particle acceleratiorn, and radioimmunotherapy and the exploitation of nuclear physics reactions to locally enhance the effectiveness of external particle therapy will be discussed.

Petri Nets and their applications in science and engineering (4 ECTS - 24 hours)
Lecturer: S. Marrone (UniCampania)

Petri Nets is a formal language introduced in 1962 in the PhD thesis of Carl Adam Petri. Starting from this date, they proved their capability of modelling both discrete and continuous systems, being able to create a wide scientific literature, a meaningful set of industrial applications and the consequent releasing of a huge number of tools for their modelling and analysis.
Using Petri Nets, it is possible not only to obtain qualitative information on the modelled system as liveness, presence of deadlock and stability but also to get quantitative information as the probability of staying into a particular state of the system.
Up to now, Petri Nets are an assessed modelling formalism that can be used by the scientists to model the system under their study. Since their introduction, different variants and dialects of such a formalism have been introduced to raise the expressive power and to ease the modelling task.
Among such derived formalisms: the Generalized Stochastic Petri Nets (where activities can cost stochastically distributed times), the Fluid Stochastic Petri Nets (where resources can be continuous as well as discrete) and the Stochastic Well-formed Nets (adding “colours” to the tokens).
The objective of the course is twofold. On one hand, it introduces such this formalism since its mathematical foundations showing both the syntax and the semantics of the language as well as the main methods for the qualitative and quantitative analysis. On the other hand, it fills the gap between theory and practice of the application showing pragmatic application cases of the formalism in different aspects of science and engineering: from the security of computer-based systems to performance of industrial plants, to the modelling of continuous physical phenomena.

Data Management (4 ECTS – 24 hours)

Lecturer: Michele Mastroianni (UniCampania)

Data are now recognized as a major organizational resource to be attained and managed like other assets such as land, labour and capital. The ability to structure, access, manage and leverage this valuable resource is becoming more and more critical to all organizations, large or small, public or private.

This course is designed to present the fundamental concepts and theories in data management, in order to promote their application to research activities and professional practice. An examination of Database Management Systems, database architectures, the role of data in decisional processes and the processes that guide the data lifecycle will be a focus of the course. Due to the importance of personal data in scientific research, it is mandatory to include in the course the main concepts about personal data protection regulation.

<u>Contents:</u>

1. Data Management basics: Information need, sources and users; data attributes; relationship among data; the data life cycle.
2. The conceptual database models utilizing entity-relationship model: design of data structures that will limit redundancy and enforce data integrity.
3. The logical database model as the second step of database design: the relational data model in terms of data structure, data integrity, and data manipulation. Notes on data definition, manipulation and query languages (SQL).
4. The role of data in Decision Support Systems: multidimensional data model; operational and informational systems; Data warehousing systems and OLAP analysis; Data Mining.
5. Introduction to Big Data and large database and unstructured databases for scientific applications.
6. Data management and personal data protection regulation: ethics of privacy; basics on GDPR regulation: general principles, right of users, accountability and policies; GDPR rules on personal data in the scientific research.

Principle of non-Newtonian Fluid Mechanics (4 ECTS - 20 hours)

Lecturers: M. Minale (UniCampania) - C. Carotenuto (UniCampania)

The aim of the course is to teach the first concepts of the mechanics of non-Newtonian fluids and their characterization so to be able to choose the best constitutive equation for each material, homogeneous or heterogeneous. These skills are necessary for the analysis and design of conventional and innovative materials and related production processes.

Short introduction to rheology and its various field of application.

Constitutive equations. Newtonian and non-Newtonian fluids. Classification of non-Newtonian behaviours: dilatant, pseudo-plastic and plastic.

Modelling: Principles of continuous mechanics. Pure viscous fluids: Reiner-Rivlin fluid, Generalized Newtonian fluid; Viscoelastic Fluids: Maxwell Fluid, Simple Fluid, Coleman and Noll Second Order Fluid, Fading Memory.

Rheometry: Classification of rheometers. Rotational and capillary rheometers. Equation of rheometers: Simple Shear, Small-gap Couette, Cone-Plate, Plate-Plate, Large-gap Couette, Capillary Viscometer.

Experimental techniques, time-temperature superposition. Dynamic-Mechanical Spectroscopy: Analysis of viscoelastic properties of materials with oscillatory experiments.

Heterogeneous materials: Overview of the constitutive properties of emulsions (cosmetic creams, mayonnaise, polymer blends, etc.), suspensions (slurries, peanuts butter, etc.), gel (gelatin) and foams (expanded polystyrene, shaving foam, cream, etc.).

Computational solid and structure mechanics: Finite elements and Boundary elements (4 ECTS - 24 hours)

Lecturer: V. Minutolo (UniCampania)

The noun structure designates the objects that in nature are responsible for bearing loads; every object, in a sense, is a structure even if some object has the structural ability as its main characteristic and other does not. For instance, bones of vertebrates, beams, and rods in machines and buildings are eminently structures. The Earth's surface, a mountain slope, the skin, and a blood vessel behave as structures when they are called to support loads even if their principal duty is somewhat else.

The course deals with the computational formulation of the mechanics of solids and structures.

After a brief introduction on the mechanics of structures within the framework of the continuum mechanics, the discretization techniques with finite elements are described. First, the one-dimensional problem is treated; furthermore, two and three-dimensional description f the structure is afforded.

The fundamentals of the variational approach and Galerkin formulation are addressed.

Betti reciprocal theorem constitutes the base of the Boundary Element formulation for linearly elastic structures. The feasibility of the method with respect to the two-dimensional and the three-dimensional structures is highlighted. The property of self-adjointness of the elastic equilibrium operator is described as the principal protagonist of the derivation of the Boundary Integral Equations of linear elasticity. Moreover, the extension of the formulation to non-linear elasticity, anisotropy, and plasticity is addressed.

Several examples using Matlab coding are discussed and implemented.

The application of linear elasticity, limit analysis of structures, fracture mechanics, and elastic instability form the core of the course.

Numerical Methods for Physics and Engineering (4 ECTS - 24 hours)

Lecturer: B. Morrone (UniCampania)

Scientists and engineers investigate the physical world. The measurement and tracking of every value of every variable in the real world is an impossible task. Consequently, they use different models for the physical world, which track every natural phenomenon, considered to be important for the given task to some desired level of accuracy. This implies that different professionals will work using different models, while describing the same physical world.

Since many problems to cope with are very difficult to solve analytically or would require loads of computations, the numerical methods come to help us representing an invaluable assistance for scientists. In addition, the problem given should be solved in the most efficient manner. If the solution is less efficient than another, there is a price to pay for this inefficiency.

This course will focus on Numerical methods, and the algorithms presented in this course are also evaluated in terms of efficiency.

Numerical methods are a set of mathematical modelling tools each of which allows to solve a specific type of problem. Massive use of Matlab or Octave programmes is accomplished to test the different methods and their programming methods during the course interactively.

Syllabus:

- Short introduction to floating-point numerical type, significant digits, round errors and Taylor series. Introduction to Matlab/Octave programs.
- Function interpolation and data set approximation. Lagrange interpolation, Newton method. Least square method for experimental data. Numerical examples.

- Equations and non-linear Root Finding methods: bisection, false position, secant method. Newton-Raphson method.
- Numerical integration: Trapezoidal rule. Simpson's rule. Gaussian Quadrature. Short note on adaptive Integration
- Ordinary differential equations. Introduction and motivations. Euler's method explicit and implicit, Runge-Kutta methods, predictor-corrector method. Examples for engineering applications. Initial Value Problems (IVP) vs. Boundary Value Problems (BVP).

Discrete Mathematics (4 ECTS – 20 hours)
Lecturer: V. Napolitano (Unicampania)

Graph theory is an important tool in a wide variety of subjects, ranging from operational research and chemistry to genetics and linguistics, and from electrical engineering and geography to sociology and architecture. The course will consider some topics in graph theory and their links with finite geometries.

Syllabus

- Definitions and examples of graphs, connectedness, Eulerian and Hamiltonian paths and cycles, and trees.
- Matching in graphs.
- Connectivity.
- Graphs and finite incidence structure.
- Moore graphs.

Cohomological Methods in Group Theory (4 ECTS - 20 hours)
Lecturer: A. Russo (UniCampania)

One of the most important topic in Group Theory is the *Extension Theory*. Roughly speaking the object of extension theory is to show how a group can be constructed from a normal subgroup and its quotient. In this subject concepts from homological algebra (in particular, the first and the second cohomology groups) arise naturally and contribute greatly to our understanding of it. The classical theory of group extensions was developed by *O. Holder* (1895) and *O. Schreier* (1926) while the homological implications of the theory were first recognized by *S. Eilenberg* and *S. MacLane* (1947). The aim of the course is to give an introduction to this topic. Moreover, some applications to finite groups (as the famous splitting theorem of *Schur-Zassenhaus*) and to isomorphisms of groups will be investigated.

Lectures on Elasticity (4 ECTS - 20 hours)
Lecturer: A. Tartaglione (UniCampania)

The course aims to introduce the participants to the analysis of the properties of the solutions of the PDEs governing the deformations of the elastic bodies with infinite size. The interest lies in the huge quantity of applications the theory refers to, as the wave propagation phenomena, the scattering theory, the deformations of bodies with defects, etc.

After a brief overview on the basics of the theory of linear elasticity, the differential system of elastodynamics will be analysed, exploring the possibility to extend to unbounded domains the classical properties of the solutions (work and energy theorem, Graffi's reciprocity relation, uniqueness for the initial-boundary value problems, etc.). The need to make hypotheses on the material properties of the body, i.e., on the density and on the elasticity tensor representing the material response function, will be clear.

The differential system of elastostatics governing the equilibrium of unbounded elastic bodies will be also analysed. The problem of existence and uniqueness for different boundary value problems will be investigated, in relation to more or less stringent hypotheses on the elasticity tensor and to different regularity requests on the data.

Statistical Methods in Experimental Sciences (4 ECTS - 24 hours)
Lecturer: F. Terrasi (UniCampania)

The course aims at providing the students with a deep understanding of the basic grounds of statistical methods used in the analysis of experimental data, allowing them to identify the most adequate to the problem under study and to correctly interpret the statistical meaning of the results of their application.

Syllabus

- The results of an experiment as samples of statistical populations
- Multidimensional statistical variables. Change of variables; correlation.
- Statistical estimators: bias; efficiency.
- Maximum likelihood estimators.
- Hypothesis testing
- Least squares. Linear and non linear fits.

Financial mathematics and behavioural finance (4 ECTS - 20 hours)
Lecturer: V.Ventre (Unicampania)

The course of lessons of Financial mathematics and behavioural finance in its parts deals with an introduction and development of financial mathematics and insurance.
The laws governing financial contracts are especially provided. In particular, the course covers the different types of interest to compute present and accumulated values for different streams of cash flows and the decomposability in the evaluation process. Applications include annuities, discrete versus continuous annuities and perpetuities, debt retirement methods, mortgages, bond and stock pricing, capital budgeting and the evaluation of contingent claims. Fairness condition as pillar for the evaluation, sinking fund, amortization of a debt, reevaluation and indexation logic will be described. The course will also cover the stochastic dynamics of asset prices assumed under the efficient market theory, the concept of arbitrage-free pricing and replicating strategies, leading to the PDE approach to pricing. The second part of the course starts with a brief introduction to the general models in Behavioural Finance (such as Prospect Theory, Ambiguity Aversion, Herding, Choice over time and Nonadditive Discount Functions). The purpose of this part is to provide a rationale of psychological biases which affect financial decision-making, consider the related empirical evidence and focus on the implications of behavioural biases for Corporate Finance.

Selected topics on algebraic curves over finite fields (4 ECTS - 20 hours)
Lecturer: G. Zini (UniCampania)

The course will consider some selected topics in the theory of algebraic curves over finite fields. Useful previous knowledge: elementary theory of algebraic curves. The topics will be selected among the following ones.

- Maximal curves over finite fields: properties, classical examples (Hermitian, Suzuki and Ree curves), recent families (GK curve, GGS curve, BM curve, Skabelund curves).
- Automorphism groups of curves, and quotient curves: bounds on the size, examples. Automorphism and quotients of the Hermitian curve: classification.
- Rational points of curves over finite fields: criteria and methods for the analysis of absolutely irreducible rational components of curves, in particular for what concerns plane curves.
- Applications of the study of rational points to some remarkable families of polynomials over finite fields which are of interest in cryptography.

Algebraic and geometric methods in Information theory (4 ECTS - 24 hours)
Lecturer: F. Zullo (Unicampania)

The mathematics of digital communications has never been as important as it is today. Recent predictions from Cisco and OECD Digital Economy Outlooks estimate that overall IP traffic in 2022 will reach over three times the 2017 rate. Therefore, it is crucial to find efficient ways of communicating, that is designing efficient and reliable data transmission methods.
The first part of this course provides an overview on the mathematical measures of information and their connection to practical problems in communication, compression, and inference (within entropy, mutual information, lossless data compression, channel capacity, Gaussian channels, rate distortion theory, Fisher information). This could turn out to be useful for PhD students in mathematics, signal processing, machine learning, statistics, and neuroscience.
The second part will be devoted to developing geometric and algebraic techniques to be applied in communication channels, which will regard linear algebra over finite fields, representation theory, Galois geometries and incidence structures.
Moreover, the last two lectures will be dedicated to some algebra software, such as MAGMA, GAP or SageMath, and the students will elaborate projects on some aspects of the developed theory supported by the use of such softwares.