Stefano Vignolo

DOCTORATE COURSE, 25-30 hours, 6 CFU

Academic year 2024/2025 (September 2024 - January 2025)

**Introduction to differential geometry**

The course aims to provide students with elements of differential geometry and illustrate some applications of it.

1. **Multilinear algebra**

Multilinear algebra, universality theorem, tensor algebra of a vector space, group of permutations and its action on tensors, symmetric and antisymmetric tensors, exterior algebra, exterior and interior products, scalar densities and pseudo-tensors, metric tensor, raising and lowering indices process, Levi-Civita tensor, Hodge operator.

1. **Tensor calculus on differentiable manifolds**

Topological preliminaries, topological manifolds, differentiable manifolds, tangent bundle, cotangent bundle, tensor bundles, differentiable maps, partitions of unity.

1. **Differential operators on manifolds**

Tensor fields on manifolds, push-forward and pullback maps, Lie derivative, exterior derivative, interior product.

Vincenzo Vitagliano

DOCTORATE COURSE, 30 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**Introduction to QFT in curved spacetime**

The course gives an overview on the application of quantum field theory methods to gravitational physics, in both semiclassical and full quantum frameworks, through a careful formulation of the fundamental base of quantum theory, with special attention to issues such as renormalization, the quantum theory of gauge theories and effective action formalism.

* Canonical quantization and particle production
* Driven harmonic oscillator
* From harmonic oscillator to fields
* Quantum fields in expanding universe
* Quantum fields in the de Sitter universe
* Unruh effect
* Hawking effect
* Casimir effect
* Path integral and vacuum polarization
* Effective action formalism
* Calculation of heat kernel
* Renormalization of the effective action
* Conformal anomaly

Patrizia Bagnerini

DOCTORATE COURSE, 25 hours, 5 CFU

Academic year 2024/2025 (Second Semester)

**Numerical methods for the solution of partial differential equations**

Many engineering and physics applications involve solving both ordinary differential equations (ODEs) and partial derivative equations (PDEs). Although many solving software programs are available, it can occur that the solutions exhibit oscillations, numerical instabilities, or that the methods do not converge, due to the inherent complexity of the equations, particularly those at partial derivatives. It is also often unclear how to base the choice of the most appropriate type of method according to the typology of equation.

The purpose of the course is to provide an overview of the main methods of solving PDEs, i.e., finite differences, finite volumes, and finite elements, providing the basis for choosing the most suitable method, the reason for lack of convergence, and the appearance of numerical instabilities, avoiding or at least mitigating their effects. The lectures are supplemented with practical solving of PDEs using Matlab and Comsol Multiphysics.

Lucia Cassettari

DOCTORATE COURSE, 30 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**Response Surface Methodology applied to Stochastic Simulation Models**

The course aims to provide the student with the statistical techniques and methodologies of Response Surface Methodology applied to discrete and stochastic simulation models.

* Experimental Error Measurement in Stochastic Simulations
* Principles of linear regression
* Design of Experiments
* Two-level factorial designs to fit first order metamodels
* Orthogonality, optimal variance, and rotatability
* Confidence intervals on the mean response and prediction intervals
* Central Composite Design to fit second order metamodels
* Limits of Response Surface Methodology

Upon student interests, more specific and advanced topics can be explored individually.

Bibliography

1. R.H.Myers, D.C. Montgomery, “Response Surface Methodology”, John Wiley & Sons, 1995

2. R.J. Freund, W.J. Wilson, "Regression Analysis”, Academic Press, 1998

3. J.E.P.Box, N.R.Draper, “Empirical Model-Building and Response Surfaces”, John Wiley & Sons, 1987.

Sante Carloni

DOCTORATE COURSE, 15-20 hours, 4 CFU

Academic year 2024/2025 (Second semester)

**Transformational metamaterials and their applications**

The course aims to give an overview of the state of the art of metamaterial design with emphasis on the transformational techniques.

* The concept of metamaterial and its applications
* Electromagnetic metamaterials
* Acoustic metamaterials
* Transformational metamaterials and their design
* Analogue Transformation Acoustics

Sante Carloni

DOCTORATE COURSE, 15-20 hours, 4 CFU

Academic year 2024/2025 (Second semester)

**Positioning systems for Earth and Space Navigation (non-relativistic and relativistic)**

The course aims to give an overview of relativistic positioning systems and their application to real positioning systems.

* Positioning systems and their realization
* GNSS, GLONASS, GALILEO, BeiDou
* The relevance of relativity in positioning systems
* Models of RPS
* RPS applied to GALILEO

Sante Carloni

DOCTORATE COURSE, 25-30 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**Dynamical systems**

The course aims to give an overview of dynamical systems theory and several applications in engineering and applied sciences.

* Basic definitions
* Equilibrium Solutions, Stability, and Linearized Stability
* Liapunov Functions
* Invariant Manifolds: Linear and Nonlinear Systems
* Periodic Orbits
* Principles of Chaos and Strange Attractors

Examples :

* Mechanics of rigid bodies,
* Population dynamics and ecosystems,
* Financial mathematics and time series,
* Cosmology,
* To be decided together with the students.

Sante Carloni

DOCTORATE COURSE, 25-35 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**Lagrangian and Hamiltonian theory**

The course aims to give an introduction to Lagrangian and Hamiltonian mechanics and their application to engineering problems.

* Mechanics of point masses (free and constrained)
* Olonomic Systems and Lagrange Equations
* Mechanics of the rigid body Kirchoff equations
* Lagrangian Statics and small oscillations
* Applications (To be decided with the students)
* Legendre Transformations and the Hamilton Equations of Motion
* Cyclic Coordinates and Conservation Theorems
* Canonical Transformations
* The Equations of Canonical Transformation
* Examples of Canonical Transformations
* The Harmonic Oscillator
* Liouville's Theorem
* The Hamilton-Jacobi Equation for Hamilton's Principal
* Function
* The Harmonic Oscillator Problem as an Example of the
* Hamilton-Jacobi Method
* Action-angle Variables

Examples:

* The Kepler Problem in Action-angle Variables
* To be decided with the students

Sante Carloni

DOCTORATE COURSE, 25-30 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**Non-relativistic and relativistic fluid mechanics**

The course aims to give an overview of fluid dynamics and its application to engineering and astrophysics:

* The Physical Properties of Fluids
* Kinematics of the Flow Field
* Equations Governing the Motion of a Fluid
* Flow of Viscous fluids
* Irrotational Flow Theory and its Applications
* Flow of Effectively Inviscid Fluid with Vorticity
* Applications:
  + Two-dimensional aerofoils
  + Cavitation in a liquid
  + To be decided with the students
* Relativistic Fluids: Definitions and Properties
* Four-dimensional Extension of the Equations Governing the Motion of a Fluid
* Ehlers’ Covariant Representation of Relativistic Fluids
* Relativistic Fluid Mechanics and Magnetohydrodynamics
* Thermodynamics of Relativistic Fluids in and out of Equilibrium
* Applications:
  + Plasmas
  + Nuclear collisions
  + Cosmology
  + Neutron stars

Luca Fabbri

DOCTORATE COURSE, 30 hours, 6 CFU

Academic year 2024/2025 (Second semester)

**An introduction to physical spinors**

The course aims to give an introduction to physical spinors in kinematics and dynamics.

A - KINEMATICS: ALGEBRA  
    1. Properties of the Clifford algebra  
    2. Spinor Fields  
    3. Adjunction and bi-linear quantities  
    4. Fierz identities  
  
B - KINEMATICS: DIFFERENTIATION

    1. Spinorial connection and covariant derivative  
    2. Compatibility conditions and differential decomposition  
    3. Spinor curvature and Bianchi identities  
  
C - DYNAMICS

    1. Dirac spinor field equation  
    2. Gordon decompositions

Edoardo Mainini

DOCTORATE COURSE, 25-30 hours, 6 CFU

Academic year 2024/2025 (second semester)

**Calculus of variations and applications**

Basic Theory:

Classic examples in the calculus of variations. Compactness and lower semicontinuity, the direct method of the Calculus of Variations. First variation, Euler-Lagrange equations.  Sobolev spaces and convex variational integrals.

Applications:

-Sets of finite perimeter, isoperimetric problems. Geometric variational problems.

-Elasticity theory. Hyperelastic materials, quasiconvexity and polyconvexity. Equilibrium problem of place and traction in finite and linearized elasticity.

-Gamma-convergence. Phase transitions, sharp interface limits, Modica-Mortola theorem. From finite to linearized elasticity via Gamma-convergence.

Agostino Bruzzone

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Modelling & Simulation Foundations**

This PhD Course is in English and is dedicated to people interested in Modeling & Simulation (M&S) activities.

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in statistics and computer use; audience is usually mostly composed by Engineers, Computer Scientists.

Topics:

* Simulation Concepts
* M&S Definitions & Classifications
* Simulation Paradigms
* Continuous Simulation
* Discrete Simulation
* Virtual, Constructive & Live Simulation
* M&S Development Processes
* Case Studies
* Exercises
* Bursting (Ballistic Unified Rockets Simulation Testing and Interactive Numerical Grinder) Exercise

Evaluation Modes: Discussion of a Simulation Project to be presented

March 18,2024,14:00-18:00, March 25,2024,14:00-18:00, April 1, 2024, 14:00-18:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom Infal 1, Via Opera Pia 15a, 16145 Genova, Italy

Agostino Bruzzone

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Strategic Engineering for Complex Systems**

This PhD Course is in English focused on Strategic Engineering discipline that combines

Modeling and Simulation (M&S), Artificial Intelligence (AI), Intelligent Agents (IA) and Data Analytics in closed loop with Big Data to support Strategic Decision Making.

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in statistics and ICT Solutions; audience is usually mostly composed by Engineers, Computer Scientists.

Topics:

* Strategic Engineering Definitions
* Challenges and Needs of Decision Makers
* Strategic Engineering Architecture
* Data Analytics Components
* M&S Components
* AI/IA Components
* Specific Advances supported by Strategic Engineering

Case Studies

Exercises

WETRAS demonstrates Strategic Engineering Concept in a realistic case of illegal traffic by combining Multisource & Multiplatform Data Fusion (e.g. AIS, Radar, ESM, EO/IR, OSINT, COMINT, SIGINT, CYBINT, HUMINT) with M&S & AI.

Evaluation Modes: Discussion of a Strategic Engineering Project to be presented

March 18,2024,9:00-13:00, March 25,2024,9:00-13:00, April 1, 2024, 9:00-13:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom B4, Via Opera Pia 15a, 16145 Genova, Italy

Agostino Bruzzone

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Interoperable Simulation**

This PhD Course is in English and is dedicated to people interested in interoperability issues about Modeling and Simulation (M&S).

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in computer use and programming; audience is usually mostly composed by Engineers, Computer Scientists.

Topics:

* Interoperability Definitions
* Past and Current Challenges in Interoperability
* Distributed Interactive Simulation (DIS) Overview
* High Level Architecture (HLA) Intensive Course
* Other Standards
* Case Studies
* Exercise Pasife on Interoperabiity

Evaluation Modes: Discussion over an Interoperable Simulation Project to be presented

April 8,2024,14:00-18:00, April 15,2024,14:00-18:00, April 22, 2024, 14:00-18:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom Infal 1, Via Opera Pia 15a, 16145 Genova, Italy

Agostino Bruzzone

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Verification, Validation and Accreditaton (VV&A)**

This PhD Course is in English and is dedicated to people interested in VV&A over Simulation Projects.

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in computer use and programming; audience is usually mostly composed by Engineers, Computer Scientists.

Topics:

* VV&A Definition and Foundations
* VV&A Processes and Deliverables
* VV&A Methodologies
* Case Studies
* SOAVE Experience on VV&A

Evaluation Modes: Discussion on VV&A over an Simulation Project to be presented

April 8,2024,14:00-18:00, April 15,2024,14:00-18:00, April 22, 2024, 14:00-18:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom Infal 1, Via Opera Pia 15a, 16145 Genova, Italy

Agostino Bruzzone

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Project Management (PM) & Concurrent Engineering (CE) in R&D Projects**

This PhD Course is in English and is dedicated to people interested in PM in R&D Projects with special attention to Modeling and Simulation Projects.

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in statistics; audience is usually mostly composed by Engineers, Computer Scientists, Economists.

Topics:

* PM & CE Definition and Foundations
* Challenges in R&D Projects
* R&D Project Development Process
* PM Methodologies and CE Approaches for R&D Initiatives
* Case Studies
* J20 Experience on VV&A

Evaluation Modes: Discussion on PM & Ce applied to a R&D Project to be presented

May 2,2024, 9:00-13:00, May 9,2024,9:00-13:00, May 16, 2024, 9:00-13:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom Tiger, Delfino Building, Savona Campus, Via Magliotto 2, 17100 Savona, Italy (to be confirmed with possible visit to Company Labs)

Agostino Bruzzone, Marco Fascio

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (second semester)

**Artificial Intelligence and Modelling & Simulation (M&S) for Biomedical Systems**

This PhD Course is in English and is dedicated to people interested in specific use of Artificial Intelligence (AI) and Modeling and Simulation (M&S) in support of Medicine, Health Care and Biomedical Systems.

The course includes lecturing and exercises to be completed.

The attendees are expected to have some basic background in computer use and statistics; audience is usually mostly composed by Medical Doctors, Engineers, Computer Scientists.

Topics:

* Health Care and Biomedical Systems as Complex Systems
* Needs and Challenges of Health Care and Biomedical Systems
* Foundations of M&S and AI
* Case Studies of using M&S and AI in Medical Sector
* Experience on M&S and AI applied in Medical Sectors

Evaluation Modes: Discussion on use of M&S and AI in a Medical Project to be presented

May 13,2024,14:00-18:00, May 20,2024,14:00-18:00, May 27, 2024, 14:00-18:00

Lectures on MS-Teams STRATEGOS Webinars, www.simulationteam.com/strategos/webinstructions

Classroom Infal 1, Via Opera Pia 15a, 16145 Genova, Italy (TBC with potential visits to Medical Simulation Center)

Giovanni TANDA

DOCTORATE COURSE, 12 hours, 3 CFU

Academic year 2024/2025 (January/February 2025)

**Thermal imagery for remote sensing: principles, methods, and engineering applications**

**Part 1) Foundations of radiant heat transfer**

The blackbody definition and laws

The solar radiation

The radiant heat transfer among blackbodies and real surfaces

The radiant properties of materials

**Part 2) Detectors of thermal radiation**

Infrared thermal cameras: measurement principles, thermal and quantum detectors, main performance parameters

Multispectral and hyperspectral cameras: measurement principles, sensors, and performance parameters

Examples of applications of infrared, multi- and hyper-spectral cameras

**Part 3) Remote sensing platforms and procedures**

Implementation of thermal radiation cameras for remote sensing: performance parameters and inspection requirements

Image processing (overlapping, mosaicking, etc.) and georeferencing

Remote platforms: UAV (drone), aircraft, and satellite

**Part 4) Applications**

Monitoring of photovoltaic plants

Applications in forestry, agriculture, and environment (marine pollution)

Monitoring of landfills

Estimation of heat leakages from buildings

Dellacasagrande, Lengani, Simoni

DOCTORATE COURSE, 18 hours, 4 CFU

Academic year 2024/2025 (January/February 2025)

**Data-driven transition modelling in the era of data**

**Part 1) RANS equation and the need for closure schemes (6H)**

The Reynolds stress tensor: anisotropic properties and empirically observed properties of the tensor;

Eddy viscosity concept: physical constrains wall limit values, deviatoric part in fully turbulent flows;

Transition schemes for boundary layer flows and the role of data for tuning;

Gamma-Re\_theta model, LKE concept, Algebraic models;

**Part 2) Data reduction and regression (Theory and Practice, 12H)**

Machine Learning for data reduction;

Lasso algorithm for the identification of sparse models;

Gaussian process based on sparse library of candidate predictors;

Identification of the best model for the Reynolds stress closure based on cross-validation criteria;

Each argument will be complemented by practical application

Traverso, Sorce, Mantelli, Reggio

DOCTORATE COURSE, 24 hours, 6 CFU

Academic year 2024/2025 (January/February 2025)

**Advanced dynamic and diagnostic methods for the energy transition (24 H)**

**Part 1) Compressor surge (Theory and Practice)**

Fundamentals of compressor surge and semi-empirical modelling approaches

A simple compressor surge model: implementation experience with Matlab-Simulink

Challenges in predicting compressor instabilities in closed loop systems: the heat pump case

Experimental tests of compressor surge in closed loop systems

**Part 2) Thermal Energy Storage with Phase Change Materials (Theory and Practise)**

Technological fundamentals of phase-change materials

From the material specimen properties to the system behaviour: a real case study

Challenges in thermal energy storage dynamic modelling: implementation experience

**Part 3) Machine Learning applied to power plant monitoring and diagnostics (Theory)**

The power plant data acquisition system and data treatment/storage

Machine learning methods applied to power plant myriad data-sets

Diagnostics and Prediction: real case studies from operators.