Dottorato/PhD in
Matematica Pura e Applicata /
Pure and Applied Mathematics

(in convenzione con Università degli Studi di Torino e il Politecnico di Torino / jointly activated by Università degli Studi di Torino and Politecnico di Torino)

XXXIV ciclo

Elenco delle tematiche per specifiche borse di Dottorato, posti in apprendistato, assegni di ricerca / List of research topics bound to PhD scholarships, positions with apprenticeship contract, positions with research fellowships

(Aggiornato al 21 giugno 2018)
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1) Modeling, Simulation, Prediction, and Control in Networks. *(borse Politecnico),*

(supervisors: Giacomo Como, Davide Ambrosi, Stefano Berrone, Enrico Bibbona)

2) Topological methods for dimensionality reduction with application to simulation and privacy. *(borsa Politecnico di Torino), (supervisors: Giovanni Petri, Francesco Vaccarino)*

3)Apprendimento automatico per l'automazione avanzata. *(posto in apprendistato Politecnico di Torino - Addfor S.p.A.), (supervisors: Francesco Vaccarino, Enrico Busto)*

4) Mathematical multi-scale modeling of biological tissues. *(assegno di ricerca, Politecnico di Torino), (supervisor: Alfio Grillo)*

PhD in Pure and Applied Mathematics

(jointly activated by Università degli Studi di Torino and Politecnico di Torino)

Research Title: Modeling, Simulation, Prediction, and Control in Networks

Funded by	Politecnico di Torino With fund of Italian Ministry of Education, University and Research (MIUR) DISMA – Department of Excellence 2018-2022

Supervisor	Giacomo Como: giacomo.como@polito.it Davide Ambrosi: davide.ambrosi@polito.it Stefano Berrone: stefano.berrone@polito.it Enrico Bibbona: enrico.bibbona@polito.it

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Context of the research activity	The Department of Mathematical Sciences (DISMA) of the Politecnico di Torino has been designated as a department of excellence based on a competitive selection process carried out by the Italian Ministry of Education, University and Research (MIUR). Thanks to this achievement, the department will receive considerable funds, which will be devoted on new job appointments, infrastructures, and high level education during the period 2018-2022. Within this project, DISMA supports two PhD positions in the XXXIV cycle of the PhD program in Pure and Applied Mathematics. These positions are aimed at attracting exceptionally talented and motivated students that will conduct research on the theses of the Department of Excellence's scientific project.

Objectives	The DISMA Department of Excellence's scientific project is conceived around a paradigm for modelling, simulation, prediction, and control with a strong focus on the mathematics of complex

networks. The selected PhD students will work within one of the following main research topics:

T1. Resilient control for network systems

It is well known that the malfunctioning of big infrastructural networks can cause major social effects limiting the access to essential services like mobility and energy, influencing the outcome of electoral polls and possibly destabilizing large economic systems. A central feature of such networked systems is the role that interconnections play in propagating and amplifying perturbations even if small or localized (systemic risk). The term "resilience" refers to the capability of a system to limit the propagation and the effect of such disturbances, thus maintaining an acceptable functionality. The ambitious goal of this project is to develop notions of dynamic resilience, through which one can easily predict the effect of perturbations on a large-scale network and optimize its behavior.

T2. Nested mathematical models in biomedicine

In biology and medicine, the macroscopic behavior of a living system is intrinsically related to phenomena that take place at a microscopic level. Mathematical models must, therefore, incorporate the dynamics of events that occur at different spatial and temporal scales, making them intrinsically multi-scale (multi-level) mathematical problems. For example, to study phenomena that operate at the tissue or cellular scale, one must take into account and model processes that take place at the sub-cellular level. This project will explore, in various contexts, the interaction of systems operating at different scales. The idea is, therefore, to use mathematical models as a sort of virtual microscope, focusing on the cellular or sub-cellular levels to extract the key features of their role at a macro-scale in a formally precise averaged form.

T3. Numerical methods for models with high geometric complexity

A source of serious complexity in numerical modeling and simulation is the presence of dimensionally inhomogeneous geometric structures, which play a fundamental role in many physical phenomena. Examples are: reinforcing fibers in homogeneous materials, networks of (possibly evolving) fractures in the subsoil, capillaries or fibrous structures in biological tissues. Their numerical treatment with standard approaches is often unfeasible or prohibitively expensive; for instance, the process of

	mesh generation to conform to small geometrical structures may yield a vast number of elements. The project aims to explore recently proposed alternatives to classical approaches. They have been successfully applied to some of these problems and are based on constrained optimization techniques that provide flexibility and computational efficiency. Furthermore, in this context, we will develop uncertainty quantification methods to perform stochastic analyses when there is substantial uncertainty on the geometry or the material properties. To achieve these goals, it will be crucial to investigate geometrical and algebraic theoretical issues. **T4. Approximation and statistical inference in random reaction networks** Several phenomena in biology, finance, telecommunications, economy and the social sciences can be modeled with interconnected Markov chains. The complexity of such phenomena is caused by a large number of interacting agents, which may render the corresponding mathematical models hardly applicable in practice. The project aims to a) find effective approximated models, and b) calibrate stochastic models against experimental data by extracting information from the noise and not only from the mean signal.

Skills and competencies for the development of the activity	The candidates are expected to have a solid mathematical background with a strong interest both in methodological and applied aspects of the research topics of the project.

PhD program in Pure and Applied Mathematics

(jointly activated by Università degli Studi di Torino and Politecnico di Torino)

Research Title: Topological methods for dimensionality reduction with application to simulation and privacy

Funded by	Politecnico di Torino

Supervisor	Giovanni Petri – giovanni.petri@isi.it Francesco Vaccarino – francesco.vaccarino@polito.it

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Context of the research activity	One of the characteristic of the so called Big Data is the occurrence of high dimensional data. The analysis of high dimensional data is affected by the so-called *curse of dimensionality*. As an example, one of the aspects of this phenomenon is the impossibility of sampling efficiently point from neighborhood of a data set. There are several methods used to overcome this difficulty, many of them based on projecting data onto smaller dimensional subspaces. Besides deterministic methods, as e.g. PCA, there techniques based on random matrices and the Johnson-Lindenstrauss Theorem which have become quite popular both for their computational efficiency and also because it has been recently shown that they can be efficiently used in *differential privacy*. Furthermore, very recently it has been started the study of the use of topological data analysis to understand the behavior of data under random projections from a topological point of view. The research activity fits in the SmartData@PoliTo interdepartmental center, that brings together competences from different fields, ranging from modeling to computer programming, from communications to statistics. The candidate will join this interdisciplinary team of experts and collaborate with them, and in the context of the joint PhD between Politecnico di Torino and University of Turin.

Objectives	To study the behavior of data, real or generated in silico, under random projections by means of techniques of topological data analysis. To apply the mathematical findings, also by developing ad-hoc algorithms and codes, to high dimensional data and structures arisng in simulations and privacy issues, in particular

	those one coming from **Progetto DISMA, Dipartimento di eccellenza 2018-2022 (https://areeweb.polito.it/disma-excellence/project.html).**

Skills and competencies for the development of the activity	The candidate is required to have very good competences in basic machine learning, topology/geometry, experience in algorithm design/analysis and good programming skills.

In consideration of the determination of the Regione Piemonte – Direzione Coesione sociale No. 503 of June 12, 2018 which approved the following apprenticeship position for the PhD project proposal submitted by the Politecnico di Torino in the framework of a specific regional call for proposals (Apprendistato di Alta Formazione e Ricerca 2016-2018 - Avviso Pubblico per la realizzazione dei percorsi formativi di: Laurea triennale e magistrale, Diploma Accademico di primo e secondo livello, Master di primo e secondo livello Universitario, Dottorato di ricerca e Diploma accademico di formazione alla ricerca, Attività di ricerca approvato con Determinazione 537 del 3/8/2016):

PhD in Pure and Applied Mathematics

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Research project "Apprendimento automatico per l'automazione avanzata"

Politecnico di Torino - Addfor S.p.A.

Supervisor	Prof. Francesco Vaccarino – Politecnico di Torino francesco.vaccarino@polito.it Ing. Enrico Busto – Addfor S.p.A. enrico.busto@add-for.com

Contact	https://smartdata.polito.it/ https://www.add-for.com/

Context of the research activity	The advent of IOT and Industry 4.0 is fostering new exciting research areas. One of the most interesting tool to be used within the above frameworks is a kind of machine learning methodology which goes under the name of Reinforcement Learning (RL). RL is quite different from other forms of machine learning being not classifiable as supervised nor unsupervised. Indeed, the main objective of RL is the mimesis of the learning process per se via a sophisticated paradigm whose cornerstones are: agent, environment, reward function, value function and a policy.

	Oversimplifying, the main objective of RL is to find an optimal policy, where optimal stands for maximization of the value. Well known examples are those application of RL, enabled by Deep Neural Networks (DNN), as Alpha Go and the Atari simulator. Finding the optimal policy is a very challenging optimization problem, also in computational terms. Indeed, the Bellman's equation is formally solvable only in the thermodynamic limit of the configuration space of the system. From this the challenge, but also the opportunity, to use DNN for a collateral training process to learn the solutions in an approximate form. The Company Addfor has planned for the winner of this position a collaboration within a contract of high apprenticeship according to the Italian Legislative Decree 81/2015, art. 45.

Objectives	The final goal of this project is the development of new methodologies in the area of machine learning and their application to Industry 4.0. More specifically the research activity will focus on Reinforcement Learning (RL) and will constitute the backbone of the training by research plan hereby presented. The PhD student will be involved in advancing the current knowledge in using Deep Neural Network (DNN) in the RL context and to apply this knowledge, deeply based on mathematical rigor in the area of Industry 4.0 and IOT. A quite new and interesting approach to the questions raised by the RL approach to robotics or control grid embedded in stochastic environment is provided by the so-called topological Q-learning (TQL). In TQL the state space is organized via a topological sorting which is used instead of a randomized trial and error approach. This promising technique has already been shown to overperform the previous techniques, at least for a randomized, unmodeled or partially unknow environment. On the other hand, by classical results, the introduction of a partial order is equivalent to give a simplicial structure to the sate space thus paving the way to the entrance of topological data analysis (TDA) in this setting. The final objective will be, therefore, to study the integration of DNN in RL via TQL and TDA with application to automated management of energy systems based on renewables and

	autonomous driving systems. This project will be jointly developed by Addfor S.p.A. and the interdepartmental center Smartdatalab@polito of Politecnico di Torino.

Skills and competencies for the development of the activity	The candidate should have solid competences in computational mathematics. In particular: optimization, mathematical foundation of machine learning, statistics, linear algebra, topology. In computer science: databases, neural networks, programming, big data handling. Programming: C++, matlab, python, R, tensor flow. Team working capability is required as well. The candidate must also be less than 30 years old at the moment of the hiring from the company.

PhD in Pure and Applied Mathematics

(jointly activated by Università degli Studi di Torino and Politecnico di Torino)

Research Title: Mathematical multi-scale modeling of biological tissues

Funded by	Politecnico di Torino

Supervisor	Alfio Grillo (E-mail: alfio.grillo@polito.it , Dipartimento di Scienze Matematiche (DISMA) "G.L. Lagrange", Politecnico di Torino

Contact	http://www.disma.polito.it/en/; http://www.disma.polito.it/en/research/topics/bio_medicine

Context of the research activity	**Generalities.** The research activity proposed hereafter sets itself in the context of Mathematical Physics, and is devoted to the Biomechanics of biological systems, such as tumors and tissues, e.g. articular cartilage, bones, blood vessels, brain, and skin. The main objective of the research is the description of the growth, i.e., variation of mass, and remodelling, i.e., variation of material properties, of the biological systems under study. **Multi-scale properties of biological systems.** A relevant property of biological systems is that they are characterized by several length and time scales, and that each of these scales is associated with one or more processes. These can be, for example, of chemical, mechanical, or electromagnetic nature, thereby giving rise to what is usually referred to a "multi-physics" environment. Moreover, biological tissues can be regarded as media with a *"nested"* microstructure, which can be characterized by *"complex geometries"*, as is the case in fiber-reinforced materials in which the fibers are oriented statistically. Even when the above-mentioned scales are well-separated, they influence each other. For instance, in the case of two scales –a fine and a coarse one–, a phenomenon or a material property pertaining to the fine scale of a tissue can be brought up to the coarse scale through appropriate procedures known as up-scaling techniques.

	The Asymptotic Homogenization Technique (AHT). Among various up-scaling methods, this proposal focuses on the Asymptotic Homogenization Technique (AHT). The reason for this choice is twofold: First, it gives a direct insight on how, and to which extent, the information available at the fine scale of a tissue, e.g. the information about its internal structure, contributes to determine the information observable at the coarse scale; secondly, it offers a powerful mathematical tool for solving a given class of multi-scale problems in an effective, yet computationally cheap, way. However, the prize to pay for applying AHT is that the medium under study must comply with some technical hypotheses, such as the periodicity of its microstructure. **Matching with the Department's research policy.** The Department of Mathematical Sciences (DISMA) "G. L. Lagrange" of the *Politecnico di Torino* has been recently conferred the honor of *"Department of Excellence"* by the Italian Ministry of Education, University and Research (MIUR), and has received a grant that supports financially the research project *"Modeling, Simulation, Prediction, Control"* (see https://areeweb.polito.it/disma-excellence/project.html). This project is articulated in four tasks: (T1) *"Resilient control for network systems"*; (T2) *"Nested mathematical models in biomedicine"*; (T3) *"Numerical methods for models with high geometric complexity"*; (T4) *"Approximation and statistical inference in random reaction (and interaction) networks"*. In the opinion of the proposer, the PhD position associated with the present research plan fits very well with the scientific policy of DISMA. This can be inferred by the comparing the context of the research activity of this proposal with the contents of the project available on line at https://areeweb.polito.it/disma-excellence/project.html. In addition, it is emphasized that the present proposal, with its fully interdisciplinary research spirit, matches very well with the tasks T2 and T3.

Objectives	**General Objectives.** The proposed research aims at studying the growth and remodelling of biological tissues with the aid of the Asymptotic Homogenization Technique (AHT). The scope of this approach is to detect the principal heterogeneities that characterize the internal structure and morphology of a given tissue, resolve them in space and time, and describe their evolution. The latter is modelled as a sequence of inelastic processes, and is thus assumed to result into the production of inelastic distortions.

	Within the general framework sketched above, the proposal sets itself the scope of providing mathematical models and numerical algorithms capable of resolving the inhomogeneities introduced by growth and remodeling at the most relevant scales of a tissue. Note that, while the *"inhomogeneities"* pertain to the structural reorganization brought about by the processes under study, the *heterogeneities* of a tissue are intrinsically related to the fact that the tissue consists of material with different properties. **Specific objectives.** The milestones of this proposal can be summarized as follows: 1. *Determination of evolution laws describing the inelastic distortions that accompany growth and remodeling.* Giving for granted that growth and remodeling are accompanied by inelastic distortions that occur at different tissue scales, the goal is to write, at each scale of interest, biologically sound evolution laws for the inelastic distortions. This requires to go beyond the assignment of evolution laws on the basis of phenomenological observations, and to look for a theoretical justification for each proposed law. 2. *Homogenization of the evolution laws of the inelastic distortions.* Through dedicated averaging procedures, the evolution laws describing the inelastic distortions must be brought up to the tissue scale, and solved together with the other equations determining the tissue's dynamics. In this respect, it is crucial to assess whether or not, and at which scales, the considered evolution law resolves explicitly the spatial inhomogeneities of the tissue. To further investigate this aspect, the proposal aims at developing constitutive theories that depend explicitly on the gradients of the tensors describing the inelastic distortions. 3. *Formulation of dedicated numerical algorithms.* The proposal puts emphasis on the formulation of numerical algorithms capable of solving efficiently the boundary value problems that arise from the application of the AHT to the problems outlined above. This task necessitates a solid knowledge of the standard algorithms employed in computational inelasticity, and the ability to modify them in order to match the needs of the mathematical models that will be elaborated.

Skills and competencies for the development of the activity	To be able to develop the proposed research project, and to reach the objectives listed above, the Candidate should possess the following competencies:

	1. Strong knowledge of modern Continuum Mechanics, especially of solid and porous materials, with emphasis on the theoretical and computational aspects of both elastic and inelastic processes (e.g. Finite Strain Elastoplasticity, and Mechanics of Growth and Remodelling). 2. Strong knowledge of the theoretical and computational aspects of the Asymptotic Homogenization technique, as applied heterogeneous materials characterized by multiple length and time scales and evolving microstructure. 3. Good knowledge of Tensor Algebra and of the fundamentals of Differential Geometry. 4. Good knowledge of the fundamental biological aspects characterizing soft tissues, such as articular cartilage and tumours.