Scholarship A

**Topic:** Advanced numerical methods and control problems for multiscale models in self-organizing systems

**Financier:** University of Verona (Department of Computer Science)

**Synthetic description of the activity and expected research outcome**

Nowadays the mathematical modeling of interacting particle systems has risen large interest in several fields of applications, in physics: vortex patterns in Bose-Einstein condensate, galaxies formation; in biology: swarms of animals, cell aggregation; and in socio-economics: opinion formation in social groups, financial markets [8]. These models consist of large system of particles, whose dynamics are characterized by the superposition of binary interactions, and whose evolution exhibits the emergence of self-organized phenomena and/or the persistence of some coherent structures.

From the mathematical view point, we are interested in understanding the fundamental mechanisms which rule their dynamics, in particular their long-time behaviour, the geometrical and structural properties of their solutions, and possible control strategies.

Hence, the aim of this project is twofold. First we want to address the theoretical study of interacting particle systems, deriving consistent mesoscopic, or macroscopic approximation, described by nonlinear PDEs, possibly coupled with optimal control problems. Second, we want to develop novel numerical schemes capable of reducing considerably the computational cost arising in this high-dimensional setting.

From the numerical view point, this second step will require the combination of three main directions: the study of large time step schemes to solve stiff scales [2]; the study of fast algorithms for the evaluation of non-local interaction kernels, [7]; and implementation of optimization algorithms [3].

Moreover, we aim to develop such modeling and numerical framework thanks to the support of the novel HPC facilities at disposal of the Computer Science Department of Verona.

**Ideal candidate** (skills and competencies):

- Knowledge of the following topics, at a level of a master degree in Mathematics: advanced numerical methods for PDE and dynamical systems, numerical optimization and control, differential geometry and mechanics
- Very good coding skills
- Good English level (written and spoken)
### Scholarship B

**Topic:** Blockchain algorithms for scientific reproducibility and privacy-by-design in machine learning

**Financier:** Fondazione Bruno Kessler (Trento)

**Synthetic description of the activity and expected research outcome**

The aim of this thesis project is to identify an interdisciplinary data science approach to problem of scientific reproducibility, focusing on privacy-by-design machine learning for healthcare data. In particular, the candidate will explore the application of recent advances in the blockchain technology for massive data (e.g. bioimaging and omics). Both mathematical and implementative aspects will be explored, in collaboration with major national clinical medical centers and the international MAQC initiative. The research activity will take place at the Fondazione Kessler, Data Science Area, Predictive Models for Biomedicine & Environment Lab (FBK/MPBA [http://mpbalab.fbk.eu/]), and it will include strong interdisciplinary aspects, including collaboration with leading clinical research centers and participation to the new initiative for DataScience jointly developed by FBK and UnitTN. Skills requested include working knowledge of machine learning, previous studies in cryptography and/or blockchain, good working knowledge of data science tools (Python, R, and *NIX operating systems).

**Ideal candidate (skills and competencies):**

- Knowledge of the following topics, at a level of a master degree in Mathematics, Data Science, Statistics, or Computer Science: working knowledge of machine learning, previous studies in cryptography and/or blockchain.
- Good working knowledge of data science tools (Python, R, and *NIX operating systems).
- Fluent English (written/spoken).

### Scholarship C

**Topic:** Modeling geometry of complex networks

**Financier:** Fondazione Bruno Kessler (Trento)

**Synthetic description of the activity and expected research outcome**

A variety of complex systems, from biological to social ones, share a common feature: they exhibit multiple types of relations among their units that can be encoded into multilayer networks. A challenging problem in network science is the understanding of the relationship between the topology of empirical systems and their function. The candidate will develop a novel mathematical framework for: i) mapping such networks to metric spaces; ii) exploiting geometric tools for network analysis. The research activity will take place at the Fondazione Bruno Kessler, Complex Multilayer Networks Lab (FBK/CoMuNe [http://comunelab.fbk.eu/]) and will include international collaborations with leading Labs in the field of Network Science.

**Ideal candidate (skills and competencies):**

- Knowledge of the following topics, at a level of a master degree in Mathematics: functional and real analysis, geometric measure theory, pde’s theory, calculus of variations.
- Good computer skills and advanced knowledge of both R and python environments, with special focus on packages/libraries such as igraph and networkx.
- Proven experience in analysis of complex networks, with special attention to embedding techniques based on structural and dynamical measures of distance.
- Strong plus: formation and/or academic experience in data science and data visualization.
- Fluent English (written and spoken).
### Scholarship D

**Topic:** Network models for digital humanities: a multilayer approach

**Financier:** Fondazione Bruno Kessler (Trento)

**Synthetic description of the activity and expected research outcome**

Mathematics is revolutionising the study of history in an unprecedented way, creating the conditions for new research opportunities and the emergence of new perspectives. The candidate will develop novel mathematical models, mostly based on multilayer networks, to explain how ideas and knowledge change from a social and historical perspective. The project will be developed at the Fondazione Bruno Kessler in collaboration with the Max Planck Institute for the History of Science (MPIWG) in Berlin, with additional funding for mobility and for spending research periods in their headquarters.

**Ideal candidate (skills and competencies):**
- Knowledge of the following topics, at a level of a master degree in Mathematics: functional and real analysis, statistics.
- Good computer skills and experience with R/python environments
- Plus: Previous experience in modeling and analysis of complex networks, multilayer networks
- Fluent English (written and spoken)

### Scholarship E

**Topic:** Network science of human mobility: modelling and prediction

**Financier:** Fondazione Bruno Kessler (Trento)

**Synthetic description of the activity and expected research outcome**

Understanding and modeling human mobility patterns is of paramount importance for a variety of applications (e.g., modeling of epidemics spreading). Emblematic examples include migration flows at regional scale and mobility within cities. The candidate will develop novel (network) models of human movements with the ultimate goal of i) improving our understanding of local and global mobility patterns; ii) enhancing the prediction accuracy for real-world applications. The research activity will take place at the Fondazione Bruno Kessler, Complex Multilayer Networks Lab (FBK/CoMuNe [http://comunelab.fbk.eu/](http://comunelab.fbk.eu/)) and will include international collaborations with leading Labs in the field of Network Science.

**Ideal candidate (skills and competencies):**
- Knowledge of the following topics, at a level of a master degree in Mathematics: functional and real analysis, pde’s theory
- Good computer skills and experience with R/python environments
- Knowledge of nonlinear dynamical systems theory
- Plus: Previous experience in modeling and analysis of complex networks; modeling of coupled socio-ecological systems
- Fluent English (written and spoken)