

PhD Course

SUSTAINABLE AGRICULTURAL AND FORESTRY SYSTEMS AND FOOD SECURITY

Title

Mathematical Methods and Computational Tools for the Modeling and Analysis of Complex Biological Systems

Potential tutor

Francesco Giannino

Objectives of the research project and interdisciplinary collaborations

State of Art and general objectives

Modeling and Analysis of complex biological systems

Ecosystems may respond gradually (and thus predictably) to external human and/or environmental disturbance or they may change their equilibrium state in a sudden and sharp manner. It is now well accepted that such sharp change (catastrophic transitions) may be explained with the existence in the ecosystems of two or more stable states.

Indeed, alternative states have been found in many ecosystems and many studies have explained mathematically catastrophic transitions in terms of possible regime shifts and/ or bifurcations.

For this reason, modelling of complex biological systems still continues to be a very important topic, due to its substantial impact on simulation, design, optimization and control of processes. Models have different degrees of complexity from the simple “black box” models to the “cybernetic” approach.

In this context, dynamic systems where vegetation-environment feedbacks are present are of particular challenge and the mathematical models are able to predict and reveal the mechanisms underlying emergent behaviour (e.g. phase transitions between stationary states, sustained oscillations, travelling waves and spatio-temporal chaos). Examples of real world biological systems that undergo such behaviour include but are not limited to ecology, cell plant dynamics, vegetation dynamics, agricultural and forestry systems and parasitology, tumor growth, brain dynamics and epidemiology.

Multidisciplinary collaborations

The PhD student will have a great opportunity to have different multidisciplinary collaborations. In particular, the will have the following different groups will help the PhD candidate to build his research project:

- Prof. Daniel M. Tartakovsky, Stanford University
- Prof. Christian Vincenot, Kyoto University, Biosphere Informatics Laboratory, Department of Social Informatics
- Prof. Max Rietkerk, Utrecht University, Copernicus Institute of Sustainable Development
- prof. Alexey Doroshkov, Novosibirsk State University (NSU), Novosibirsk, Russia

Innovation and originality of the project in relation to the state of the art

The scientific keystones of the proposed study are strongly interdisciplinary. In order to achieve the objectives described above the plan is to integrate recent advances from five different fields of research: (a) Modeling of biological systems, (b) Individual –based modelling (c) numerical analysis and bifurcation theory, (d) complex systems and networks and (e) machine learning/ manifold learning algorithms

We will develop, implement and validate a novel computational framework that will enhance the computational investigation of general complex biological systems. Moreover the PhD candidate will be applied this computation methods in some real case studies of the Department of Agricultural Science research activities.

In this contest, hybrid modelling is the integration of different modelling approaches. This proposal will focus particularly on the new paradigm emerging from the integration of differential equations (ODE and/or PDE) into individual-based models (IBM), two antithetical yet complementary views of systems.

In the last years, there have been an increasing number of examples of applications of this hybrid modelling approach in various scientific disciplines: biology, engineering, medicine, and also humanities science. Examples of real world biological systems that undergo such behaviour include but are not limited to ecology, vegetation dynamics, agricultural and forestry systems and parasitology, tumor growth, brain dynamics and epidemiology.

This line of research has the big advantage of simulating complex systems as sets of different modules, which can be implemented in different mathematical approaches most appropriate to render the subsystem under consideration. On the other hand, agent-based hybrid modelling also comes with a reduction in analytical capabilities to understand model behavior, for it relies on distinct, apparently incompatible formalizations (algorithmic vs mathematical, discrete vs continuous time, etc).

We aspire to develop and employ (beyond the) state-of-the-art methodologies to demonstrate through various applications the strength and weaknesses of hybrid modelling in biology. We also wants to review and discuss the challenges and relevant methods inherent to this discipline.

Keywords

- Hybrid model
- ODE, PDE
- Reaction diffusion
- Hybrid model
- Turing pattern
- Numerical methods
- Bifurcation analysis

Grant availability

- MOD_DEV_CELL "System dynamics modeling of microbial cell cultures: numerical methods, process optimization, and individual-based approach", Finanziamento della ricerca in Ateneo 2017, coordinator Francesco Giannino.

- PREVAIL: PREvention Action Increases Large fire response preparedness, H2020, responsabile scientifico di unità: Francesco Giannino
- Abcd - Astroni Bosco da Conoscere per Difendere, Fondazione per il Sud, , responsabile scientifico di unità: Francesco Giannino

Collaboration with foreign institutions

- Prof. Daniel M. Tartakovsky, Stanford University
- Prof. Christian Vincenot, Kyoto University, Biosphere Informatics Laboratory, Department of Social Informatics
- Prof. Max Rietkerk, Utrecht University, Copernicus Institute of Sustainable Development
- prof. Alexey Doroshkov, Novosibirsk State University (NSU), Novosibirsk, Russia