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Handling Complexity: from the Unit Interactions to the Analysis of Emergent Behaviour

Abstract of Presentation

Complexity pertains to the structure of many real-world systems shaping their behaviour and dynamics. Hence, there has been an immense and increasing interest in studying the emergent complex dynamics of problems ranging from Fluid Mechanics and Materials Science to Internet and Social Networks and from Biological and Brain Activity to Epidemic and Ecological systems.

Due to the strongly heterogeneous character of such systems as well as the stochastic and nonlinear very-large scale unit interactions the emergent–macroscopic -behaviour is most of the times far from trivial to predict. Self-organization, sustained oscillations, travelling waves, multiplicity of stationary states and spatio-temporal chaos are paradigms of the rich nonlinear behavior at the coarse-grained systems level.

Hence the quest for developing new modelling, computational-assisted and control methodologies that have the potential to facilitate better understanding, predicting and designing of complex systems with important health, social and economical impact appears to be a major and timely challenge of our times.

Up to date what is usually done with detailed large-scale mathematical models lacking explicit macroscopic closures is simple simulation: set up many initial conditions, for each initial condition create a large enough number of ensemble state and network realizations, probably change some of the rules and then run the detailed dynamics for a long time to investigate for example how things like vaccination policies, malignancy/ mutation of a virus - and resource availability may for example influence the spread of an outbreak. However, this simple simulation is most of the times inadequate for the systematic analysis, control policies design for emerging phenomena.

I will show you how one can extract efficiently such "large-scale, system-level" information for the systematic analysis and the design of the emergent dynamical behavior of such large-scale simulators with important engineering, social and health implications. The key stones of the proposed framework lie on the "intersection" between numerical analysis, computational statistical mechanics, complex networks, bifurcation and dynamical systems identification and control theory.

For illustration purposes, I will present you problems from the fields of Social Dynamics (opinion formation), Computational Epidemiology and Computational Neuroscience.