Modelling Biodiversity and Pattern Formation with Evolutionary Games

(Dr Mauro Mobilia, 2018)

Understanding the maintenance of biodiversity and the emergence of cooperation are important topics in the Life and Behavioural Sciences. Evolutionary game theory, where the success of one species depends on what the others are doing, provides a promising mathematical framework to study the dynamics of interacting populations. As paradigmatic examples, the prisoners dilemma and the rock-paper-scissors games have emerged as a fruitful metaphor for cooperative and co-evolutionary dynamics, with applications in microbiology and ecology. While mathematical biology classically deals with deterministic, often spatially homogeneous, models; the joint effects of noise and spatial degrees of freedom are important for realistic description of population dynamics. In our research, we use stochastic processes, differential equations and computer simulations to study the dynamics of interacting populations. Possible lines of investigation are:

(i) It has recently been demonstrated that populations movement can have important evolutionary implications. Here, we shall consider evolutionary models with realistic forms of mobility (e.g,. inspired by chemotaxis) and different types of interactions between the species (e.g., to account for long-range interactions between bacteria, or mutations), and study the joint influence of movement and randomness on population's self-organisation and co-evolution.

(ii) Mathematical models of population dynamics are classically formulated in terms of rate equations whose predictions are known to be altered by stochastic effects. The extinction of sub-populations and the fixation of mutants are striking examples of the influence of stochastic noise. To analyse these phenomena we will notably use suitable size expansion methods (e.g. diffusion approximation, WBK theory) that respectively allow to account for random fluctuations of various intensity. It will be interesting to carry out this line of research for ecologically and biologically motivated models, first on complete graphs and then on complex networks.

(iii) In nature, organisms often interact with a finite number of individuals in their neighbourhood. The population is thus heterogeneously structured and cannot be described by well-mixed models. This often results in patterns observed in ecosystems and whose origin is an intense subject of research. According to Turing's deterministic theory, diffusion can yield pattern-forming instabilities in systems if some specific conditions are satisfied. However, these conditions are often too stringent, and pattern formation has been observed in many ecosystems where they would not be expected according to Turing's theory. In this context, it has recently been proposed that noise together with movement can be a mechanism responsible for the emergence of patterns. We would like to test this scenario by investigating the origin of pattern formation in paradigmatic examples like the "rock-paper-scissor" model and its variants. Our approach will be to adopt an "individual-based" metapopulation model formulation in which interacting sub-populations are subdivided in connected islands and can migrate from one patch to another.

Keywords: population dynamics, ecosystem modelling, complex systems, individual-based modelling, patterns, stochastic processes and simulations, evolutionary games, networks.