Stochastic dynamics for adaptation and evolution of microorganisms

Sylvie Méléard (Ecole polytechnique)

Understanding the adaptation and evolution of populations is a huge challenge, in particular for microorganisms since it plays a main role in the virulence evolution or in bacterial antibiotics resistances.

We propose a general eco-evolutionary stochastic model of population dynamics with clonal reproduction and mutations. Moreover the individuals compete for resources and exchange genes, as in the transfer of plasmids in bacteria. We study different asymptotics of this general birth and death process depending on the respective demographic, ecological and transfer time-scales and on the population size.

Firstly, we show how the dynamics of two types can be approximated by a nontrivial dynamical system when the population is large. The approximation is used to analyze the conditions for the invasion of a mutation under selection or its maintenance in a polymorphic state with the resident type. We also provide its probability of fixation and time to fixation. Next we consider a continuum of types. The population is described by a point measure-valued process and the dynamics includes births, mutations, deaths or exchange of genetic material. Under the biological assumptions of the adaptive dynamics (large population and rare mutations), we show that at the (long) mutation time scale, the stochastic measure-valued process converges to a jump process which describes the successive invasions of successful mutants. When restricted to the case without gene transfer, this process is the Trait Substitution Sequence first introduced in [1] and rigorously derived in [2], [3]. We explain how the gene transfer can drastically affect the evolutionary outcomes. Simulations show its effect on the elimination of pathogens strains but also the appearance of resistance patterns in very long times. It will be a great challenge to understand and quantify the rate of transfers one needs to avoid resistances.

This work is developed with S. Billiard, P. Collet, R. Ferrière and C.V. Tran.

References

[1] Metz J.A.J., Geritz S.A.H., Meszeena G., Jacobs F.A.J., van Heerwaarden J.S.: Adaptive Dynamics, a geometrical study of the consequences of nearly faithful reproduction. Stochastic and Spatial Structures of Dynamical Systems, 183–231 (S.J. van Strien, S.M. Verduyn Lunel, editors). North Holland, Amsterdam, (1996).

[2] Champagnat, N.: A microscopic interpretation for adaptive dynamics trait substitution sequence models. Stochastic Process. Appl. 116 (2006), no. 8, 1127–1160 .

[3] Champagnat, N.; Méléard, S.: Polymorphic evolution sequence and evolutionary branching, Probability Theory and Related Fields 151 (2011): 45–94.