MAR14-2013-000766

Abstract for an Invited Paper
for the MAR14 Meeting of
the American Physical Society

Exploring the Dynamics of Evolution and Ecology of Biological Systems

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We established the potential and flux landscape theory for evolution. We found explicitly the conventional Wright's gradient adaptive landscape based on the mean fitness is inadequate to describe the general evolutionary dynamics. We show the intrinsic potential as being Lyapunov function (monotonically decreasing in time) does exist and can define the adaptive landscape for general evolution dynamics for studying global stability. The driving force determining the dynamics can be decomposed into gradient of potential landscape and curl probability flux. Non-zero flux causes detailed balance breaking and measures how far the evolution from equilibrium state. The gradient of intrinsic potential and curl flux are perpendicular to each other in zero fluctuation limit resembling electric and magnetic forces on electrons. We quantified intrinsic energy, entropy and free energy of evolution and constructed non-equilibrium thermodynamics. The intrinsic non-equilibrium free energy is a Lyapunov function. Both intrinsic potential and free energy can be used to quantify the global stability and robustness of evolution. We investigated an example of three allele evolutionary dynamics with frequency dependent selection (detailed balance broken). We uncovered the underlying single, triple, and limit cycle attractor landscapes. We found quantitative criterions for stability through landscape topography. We also quantified evolution pathways and found paths do not follow potential gradient and are irreversible due to non-zero flux. We generalized the original Fisher's fundamental theorem to the general (i.e., frequency dependent selection) regime of evolution by linking the adaptive rate with not only genetic variance related to the potential but also the flux. We show there is an optimum potential where curl flux resulting from biotic interactions of individuals within a species or between species can sustain an endless evolution even if the physical environment is unchanged. We offer a theoretical basis for explaining the corresponding Red Queen hypothesis proposed by Van Valen. Our work provides a theoretical foundation for evolutionary dynamics.