Energy in the Context of Complex Adaptive Systems: Predator-Prey Dynamics

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I. Abstract

Complex Adaptive Systems (CAS) designers rarely look at the role of energy in the overall behavior of such systems. Energy both enables and constrains complex systems, thus critically defining their long-term performance. This project uses the domain of ecological systems to evaluate the changes introduced by the variations in available energy.

One of the foundations of our understanding of ecology dynamics is the Lotka-Volterra (LV) equations for predator-prey populations. These equations are both mathematically robust and widely accepted, but are also general in nature. Thus, they are limited by the assumptions imposed upon them: 1) unlimited food availability to the prey population; 2) the predator population depends entirely on the prey for food; 3) the natural growth rate for both populations are proportional to their sizes; and 4) the environment doesnt change to the benefit of either population. Idealized in this way, the LV equations present a baseline understanding of general predator-prey dynamics in the absence of real-world complications. By utilizing an Agent-based simulation Model (ABM), we can introduce stochastic elements into these interactions, allowing for a deeper understanding of LV by comparing the simulation results to the mathematical ideal. Furthermore, we show that these simulations can give insights that are not included within the scope of these classic equations.

Our investigation into a deeper understanding of the predator-prey dynamics began by changing assumption (1) above: we tailored the general simulation model so that the food (energy) available to the prey population is adjustable. There are three primary populations: food (generated by the simulation stochastically as a constant rate per grid cell); fish (the prey population); and predators (which reproduce as a function of the number of fish consumed). Additional experiments also utilize a fish-egg population, which are generated by the fish as a function of the food consumed.

Initially (as expected) an increase in the food supply to the fish directly results in an increased fish population. The predator population also increases as their food supply (the fish) becomes more abundant. Remarkably however, the gains in fish population are only temporary, and completely offset by the increased predation rates. Thus, the fish population returns to the same equilibrium level as that found with a lower supply of food: only the predator population remains elevated. This result indicates that all the gains resulting from the increased food supply are transferred to the high-trophic-level predators. The outputs have proven to be robust under various scenarios, but many questions remain. How will a changing environment affect these fundamental dynamics? What happens when each tropic level is representative of multiple species, instead of just one? How do the equilibrium states change if agent-level adaptation is introduced?