Evolution as Described by the Second Law of Thermodynamics

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By viewing evolution as the motion of energy flows toward a stationary state (entropy), evolution can be explained by the second law of thermodynamics, a law which conventionally describes physical systems. In this view, a cheetah serves as an energy transfer mechanism, and beneficial mutations allow the animal to transfer more energy within its environment, helping even out the energy. Image credit: Rob Qld.

(PhysOrg.com) -- Often, physics and biology appear as different worlds, from a scientist's point of view. Each discipline has its own language and concepts, and physicists and biologists tend to look at the world in different ways – not least being from inanimate and animate perspectives.

But at the core of these two sciences is the concept of motion. As a biological ecosystem evolves by the process of natural selection, it

disperses energy, increases entropy, and moves toward a stationary state with respect to its surroundings. Similarly, as energy flows in various physical phenomena, they too cause biological systems to move toward stationary states with respect to their surroundings, in accordance with the second law of thermodynamics. Whether an object is animate or inanimate, science does not seem to make a distinction. In both cases, energy flows toward a stationary state, or a state of equilibrium, in the absence of a high-energy external source.

In this way, explain Ville Kaila and Arto Annila of the University of Helsinki, the second law of thermodynamics can be written as an equation of motion to describe evolution, and, in doing so, connect biology with physics. Their study, "Natural selection for least action," is published in the *Proceedings of The Royal Society A*.

The second law of thermodynamics, which states that the energy of a system tends to even itself out with its surroundings ("a system's entropy always increases"), can be expressed in many different forms. Kaila and Annila focus on two of these forms. When written as a differential equation of motion, the second law can describe evolution as an energy transfer process: natural selection tends to favor the random mutations that lead to faster entropy increases in an ecosystem. When written in integral form, the second law describes the principle of least action: motion, in general, takes the path of least energy.

Then, the scientists showed how natural selection and the principle of least action can be connected by expressing natural selection in terms of chemical thermodynamics. As the scientists explain, nature explores many possible paths to level differences in energy densities, with one kind of energy transfer mechanism being different species within the larger system of the Earth.

Mechanisms of energy transduction, especially biological species, can be

intricate and complex. By randomly mutating individuals of a species, various paths are explored in the quest of increasing entropy most rapidly. These mutations sooner or later naturally converge on the most probable path. Although the energy landscape keeps changing, the most probable path is always that which is the shortest and follows the steepest energy descents. It leads toward a stationary state, such as an ecosystem evolving toward a state that will have just the right amount of plants, plant eaters, and other energy transfer mechanisms (both living and non-living) to maintain the highest rate of energy dispersal.

“In a biological context, when two rather similar species (i.e. energy transduction mechanisms) compete for the same source of energy (e.g. food), the one with even slightly more effective mechanisms (e.g. claws, teeth, feet, etc.) captures more than the other,” Annila explained to *PhysOrg.com*. “Gradually, the population of the more effective species will increase at the expense of the other. The overall process is pictured as flows of energy that gradually and naturally select the more effective, steeper paths. In biology, this physical consequence, which can be deduced from Lyapunov stability criterion, is known as the competitive exclusion principle.

“Let us assume that a mutation happens to improve the speed of a cheetah,” he added as an example. “Consequently, this cheetah will catch more food, i.e. more energy will channel through this individual – the path has become steeper. Likewise, a deleterious mutation will reduce the flow via the particular path that has turned less steep. In this case, the non-mutated paths are the healthy rivalries, and will enjoy correspondingly larger flows due to the diminished competition.”

The researchers note that this abstract description provides a holistic view of evolving nature, not a detailed explanation for how individual species emerge from the process. For example, plant-eating species distribute the solar energy acquired by photosynthesis, and the cheetah,

as a carnivore, disperses energy further down along the gradients of the food chain, which eventually terminates into cold space. And since these energy flows themselves yield and affect energy transfer mechanisms that, in turn, alter the flows, it's virtually impossible to predict evolution's next move.

"A system evolves to reach a stationary state with respect to its surroundings," Annila explained. "That is to say, when the surrounding environment is high in energy, then the system will evolve to a high-energy stationary state. Matter on Earth has evolved over eons in increasing its energy content to match that of the solar radiation density. During this process, mechanisms of energy transduction have improved, but presumably there are still ways to catch more of the sunlight to power activities that are presently fueled by non-renewables."

The idea of using the second law of thermodynamics to describe evolution is not new. As far back as 1899, physicist Ludwig Boltzmann, a great admirer of Darwin, was contemplating about connection. Also, Alfred J. Lotka, in his main work published in 1925, expressed full confidence that biotic systems follow the same universal imperative. Many scientists today have recognized the principle of increasing entropy as a way to understand life. The connection between increasing entropy and decreasing free energy, provided by Kaila and Annila via the principle of least action, has further strengthened the unified description of natural motions.

More information: Kaila, Ville R. I. and Annila, Arto. "Natural selection for least action." *Proceedings of The Royal Society A.* doi:10.1098/rspa.2008.0178.