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On the Transformation of Forms in Nature

We often picture evolution as a kind of arms race, but that is just one example of the types of interactions that can play out in nature.

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Evolutionary principles describe how traits in populations change across generations, assuming a common origin and linking organisms through kinship lines. These principles lay the foundation for models of species development, often represented in the form of "trees of life," bouquets, or garlands. Modern evolutionary theory reframes discussing transformation by focusing on the development of various traits within the context of their attractiveness or adaptability.

The concurrent development of theories in electromagnetism and thermodynamics paved the way for groundbreaking technological advances. Thermodynamics also provides a broader perspective on evolutionary processes, incorporating organisms' energy dynamics and how they transform energy in response to their environment. The paper "Natural Selection for Least Action" by Ville Kaila and Arto Annila of the University of Helsinki explains how selective processes follow paths where organisms evolve by minimizing differences in energy distribution. This view frames evolution as favoring adaptations that maximize energy dissipation and transfer. Kaila and Annila's study also shows that evolutionary trajectories are shaped by selective pressures, which set certain boundaries within which development unfolds.

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Natural selection and competition

The study of the principles of transformation has roots reaching back into ancient times. The emergence of evolutionary and thermodynamic frameworks fulfilled Aristotle's vision of examining both changing forms of matter and biological adaptations in the context of the laws of physics. Evolutionary theory emphasizes natural selection and competition as core factors that shape the distribution of traits within populations – an observation adapted from economic policy, where population growth often outpaces food supply, leading to resource scarcity and a "struggle for survival" that favors "advantageous variants."

Limited food resources drive intense competition for those resources – as is evident, for instance, in crises such as droughts. Overpopulation also amplifies competition for space, food, water, and other essentials, as seen, for example, in urban areas with dense pigeon populations. Rapid environmental changes, such as climate shifts or habitat loss, further reduce resource availability and intensify competition. For example, deforestation forces many species to compete for shrinking territories. The introduction of new species, especially those occupying similar ecological niches, can also exacerbate competition; invasive plants, for instance, compete with native flora for light, water, and nutrients. In competitive environments, populations often evolve traits that support specific survival strategies, including adjustments in reproductive style (such as the number of offspring, parental care, or mate selection), territorial behavior, or foraging strategies. Specialization within narrower niches can impact population dynamics and survival rates, creating new behaviors and interactions that drive complex, nonlinear changes in ecosystems. However, over time, competition can prove costly even for those that "win out."

Models examining competition's impact on populations show it often reduces genetic diversity, limiting adaptability. This pattern also appears in ecosystems and monocultures with low species diversity. Notably, evolutionary processes are reflective of interactions between goal-driven processes, chance events, and specific environmental pressures. Changing conditions can alter the balance between competition and cooperation, or between defensive and offensive adaptations, as well as other biological interactions. Each environmental shift opens new evolutionary pathways, fostering diverse life forms and survival strategies.

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Comprehension of evolutionary processes is aided by appreciating the adaptable mechanisms organisms use – including mechanisms that remain flexible enough to adjust within an individual's lifetime.

Correlations of evolutionary processes

Organisms maintain and adapt their structure and internal environment. Losing the ability to sustain and adjust their state ultimately brings the organism's life to an end. Sustaining life requires a continuous exchange of matter, energy, and information with the environment, encouraging actions, movement, substance secretion, and other biological processes. One organism's responses often serve as information for others. In thermodynamic terms, these informational signals can be described as system states tied to specific events. Interpreting these signals relies on frameworks that organize meaning, such as genetic code, hormonal and cellular signaling pathways, or cognitive processes.

I propose that this interpretive framework might itself be defined as intelligence. DNA is the primary medium for conveying information about an organism's structure and function, encoding specific instructions that cells adhere to. Traditionally viewed as a source code passed down generations, DNA can also be seen as a dynamic core around which complex, system-level processes occur, allowing organisms to adapt to shifting environmental conditions.

RNA also plays a key role in these adaptive processes, regulating gene expression and influencing DNA's function without altering the DNA itself. A revived interest in the early theory of inherited changes – known as *gemmule theory* – suggests a concept in which vesicles from different tissues accumulate in gametes throughout an organism's life, potentially passing information on acquired adaptations to future generations. The evolution of nervous systems has further expanded the potential for phenotypic plasticity, enabling compound learning, memory, and flexible behavioral adaptations – changes that occur more rapidly and with greater complexity than those involving DNA, RNA, or protein alone.

This behavioral plasticity, resulting from the nervous system's interaction with the environment, is not easily captured by traditional views of genetic inheritance. Building on a thermodynamic perspective, the Polish psychologist and philosopher Antoni Kępiński proposed a model of energy-information metabolism, in which organisms retain structure and identity. He identified biological, emotional, and sociocultural aspects of psychophysical processes and suggested that disruptions in processing these dimensions could underlie traits recognized as mental disorders. For example, a disruption in biological processing might lead to depression or psychosis, signaling altered functioning of the nervous and endocrine systems. While these changes may initially serve as short-term adaptive plasticity, they can become maladaptive over time. Fully understanding trait variability in organisms requires an integrative view that encompasses genetic, physiological, and environmental adaptation mechanisms. Future research may highlight further elaborate ways in which the diverse forms of life adapt to an ever-changing world. ■

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