Complex Maladaptive Systems


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Here is a provocative fact: Searching Web of Science for articles with the words *complex adaptive system* in the title yields 1006 results as of this writing; searching for articles with the words *complex maladaptive system* in the title yields zero results.

Why such an imbalance? Granted, complex systems that count as adaptive might warrant more attention, but 1006 to *zero*? Furthermore, when complex systems go wrong, such as an economic collapse, a disease pandemic, an invasive species, an immune system disorder, or the breakdown of democratic governance, it is hard to pay attention to anything else.

Understanding Complex Adaptive Systems

We attribute the imbalance to widespread confusion about what the phrase *complex adaptive system* means and the stringent conditions that are required for a complex biological, human, or technological system to function well *as a whole system*. Clarifying these issues and appropriately directing engineering efforts can go a long way toward transforming complex maladaptive systems into complex adaptive systems in myriad aspects of daily life.

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Digging deeper into the phrase *complex adaptive system* yields diverse examples such as cities, firms, markets, governments, industries, ecosystems, social networks, power grids, animal swarms, traffic flows, social insect colonies, the brain, the immune system, a cell, and a developing embryo. This list comes from Wikipedia, which can itself be regarded as a complex adaptive system.

Some of these—social insect colonies, the brain, the immune system, a cell, and a developing embryo—are complex systems that clearly function well *as systems*. They are also clearly products of natural selection, whereby better-functioning systems replaced worse-functioning systems over a large number of generations.

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The others are complex systems composed of agents that follow their own adaptive strategies, such as a driver negotiating traffic in a city, a politician trying to stay in office in a government, a species maximizing its fitness in an ecosystem, or a company trying to maximize its profits in an economic system. But these systems do not necessarily function well *as systems*. Indeed, we know that in many cases they do not, resulting in traffic jams, political gridlock, ecological and economic collapse. Wikipedia functions remarkably well as an encyclopedia but still suffers from imperfections, such as misinformation that serves the interests of the authors.

An Evolutionary View

We distinguish between two meanings of the phrase *complex adaptive system*: a system that functions adaptively *as a system* (CAS1) and a system composed of agents that *separately pursue their own adaptive strategies* (CAS2). The fact that these two meanings are usually not distinguished is a major source of confusion.

From an engineering and public policy standpoint, systems should function well as systems (CAS1), such as smooth traffic flow, efficient governance, and ecosystems that maintain diversity and provide various services. There are two major possibilities for how this can be accomplished: (1) *CAS2 can self-organize into CAS1* or (2) CAS1 systems can arise only from a certain process—namely, *selection at the level of the whole system*.

The first possibility is suggested by the metaphor of the invisible hand in economics and the concept of a balance of nature in ecology. In both cases, the presumption is that the system, left to itself, results in some kind of harmonious balance. Both of these concepts can be historically traced to pre-Darwinian notions of nature as harmoniously organized from top to bottom by a benign and all-powerful creator. Darwin's theory of evolution challenged this notion and provided a stark alternative: that nature can be harmoniously organized at lower levels, as evidenced in the exquisite design of a single organism, but discordant at higher levels, as seen in a war among members of a single species or of species in ecological communities. In one of Darwin's most unsettling metaphors, he described nature as a multitude of inwardly pointed wedges being driven against each other.

Modern evolutionary ecologists have largely abandoned the balance of nature as an antiquated concept. Left to itself, nature is frequently out of equilibrium or settles into one of many local stable equilibria. The term *ecological regime* is often used, which aptly invokes what we already know about human political regimes. A human political regime has a degree of stability, but that doesn't necessarily mean that it functions well as a system for the good of all its citizens. There are despotic and corrupt regimes in addition to enlightened regimes. Single-species societies and multispecies communities are no different.

CAS1 systems do exist above the level of individual organisms in nature, but only when they have been units of natural selection, such as colony-level selection in the eusocial insects and ecosystem-level selection in the case of microbiomes. Human social and economic systems are no different. The metaphor of the invisible hand, which makes it seem as if the pursuit of individual- and corporate-level self-interest robustly benefits the common good, is profoundly misleading except in the narrowest of contexts seldom realized in real-world economic systems. Just as for all other species, lower-level entities that compete against each other are far more likely to lead to complex maladaptive systems than complex adaptive systems of the CAS1 variety, unless a process of system-level selection organizes the interactions among the lower-level agents.

Yet system-level selection cannot take the form of centralized planning because most systems are too complex to be comprehended by any group of experts. Instead, system-level selection must be cautious and experimental, weighting alternatives and selecting those with the best whole-system consequences. It must truly be an evolutionary process in which the target of selection, variation oriented around the target, and the selection of best practices are managed with the welfare of the whole system in mind.

Engineering Systemic Selection

Where does the engineering profession stand with respect to all of this? In some respects, it is old news. The simplest engineering projects can be straightforwardly designed, but a tipping point of complexity is quickly reached where a more experimental variation-and-selection approach is required. And it goes without saying that the whole system cannot be optimized by separately optimizing its parts. The engineering profession is in accord with modern evolutionary theory on these points.

But what most people regard as engineering—both inside and outside the profession—is a very small subset of the complex systemic problems that need to be thought through and addressed, ultimately at the global scale. Hence, there is an urgent need for complex systems thinking in engineering to be integrated with modern evolutionary thinking in guiding responses to complex systemic problems.

In short, CAS1 systems require a process of system-level selection. Otherwise, complex maladaptive systems will be the inevitable result.