Learning from Nature

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We are destabilizing the biosphere on which we depend. One reason is that our culture makes heavy use of processes that create wasteful byproducts and exploit resources in an unsustainable way. Natural systems have evolved a remarkable ability to thrive without doing these things. This took hundreds of millennia of trial and error. We are transforming the biosphere far more rapidly—but we have the ability to adapt much faster as well. One way is to *learn from nature*: study how flourishing natural ecosystems function, and take them as role models.

Most simply, we can develop "biomimetic technologies", which are technologies based on natural systems. For example, termites maintain nearly constant internal temperatures in their mounds through a system of channels. They don't need fans that require power. In 1996, a large office and retail building was built based on this idea: the Eastgate Centre in Harare, Zimbabwe [TS]. It has chimneys and ventilation channels that draw cool night air through the building. It uses roughly 90% less energy for climate control than a conventional building of comparable size. That translates directly into far lower carbon emissions.

This success inspired emulation, but the technology hasn't really caught on. Why not? First, it is climate-specific. It works well only in sites with warm days, cool nights, and low humidity year-round. Second, termite mounds integrate structure and ventilation into a single system. This goes against standard architectural and engineering practices.

Both these problems are quite general. Our current civilization favors simple technologies that work uniformly in many environments, while biological systems have had time to adapt in intricate ways to local situations. And while existing human technologies are often made of modular parts designed in isolation, biological systems always evolve as a whole. To learn the most we can from nature, we need to absorb *these* lessons, not just air-drop individual biomimetic technologies into our existing systems.

"Ecological engineering" goes deeper. Here the idea is to design systems that don't just copy nature, but actually work with it. The central insight is that given the right conditions, nature assembles and maintains its own systems, running on solar energy rather than fossil fuels. The ecological engineer's job is thus not to build and control a system from scratch, but to act as a facilitator between human needs and natural processes.

In the 1950s, Käthe Seidel of the Max Planck Institute initiated what would later be considered one of the prime examples of ecological engineering [Se]. She began using wetland plants like bulrushes to treat wastewater, improving on the poor performance of rural septic tanks and pond systems. By the early 1980s this technology had been introduced to Denmark, and by 1987 nearly 100 systems were in operation there. The UK, France, Netherlands, and Austria followed. By now, constructed wetlands are recognized as a reliable treatment technology suitable for many types of wastewater.

However, engineering is not unique: every discipline can profit from taking nature as a teacher. Consider my own field, mathematics. This has been spectacularly successful at describing simple systems—particles, crystals, planets—yet the living world runs on something else: complex networks of interacting subsystems, redundant and diverse, assembling and repairing themselves. If mathematics is to help us develop more sophisticated technologies and social systems that work with nature instead of despite it, we need new ideas. This is the dream of "green mathematics": a future style of mathematics that is as well suited to biology and ecology as traditional mathematics is to physics.

Some first steps are already underway. To take just one example: biologists, chemists, ecologists, and engineers have long ago independently invented diagrams of networks to depict systems of interacting parts: reaction networks, food webs, stock and flow diagrams, and so on. These are often treated as informal sketches on the way to "real" mathematics. But the branch of mathematics called category theory [C] lets us treat these diagrams as rigorous mathematical objects, with a precise grammar all their own [L]. Once diagrams become a mathematical entities, we can prove theorems about them, and mathematically study what happens when we create bigger diagrams by gluing small pieces together.

For example: in epidemiology, a model is traditionally built as a single monolithic block of code, hard to reuse and hard to modify. New modeling software built using category theory works differently: a model is a diagram assembled from reusable parts [B]. Nonspecialists on an interdisciplinary team can build and critique models using these diagrams, without ever seeing the mathematics beneath. A team can take a model of one disease and compose it with a model of contact tracing simply by fitting modular pieces together, with the underlying category theory guaranteeing that everything stays consistent. The whole is built from parts, yet behaves as an integrated system.

The last point hints at why this matters beyond epidemiology. Natural systems integrate structure and function, and achieve robustness through redundancy and diversity. New mathematics might help us understand how they do this, and use that understanding to develop new technologies, supply chains, energy grids, and institutions. The aim would be not merely to imitate nature or cooperate with it, but to absorb its organizing principles into the very tools we use to design our world.

So far we are just getting started. Green mathematics may end up looking stranger than anything sketched here, demanding a shift of viewpoint we can barely imagine. But we are already seeing that even mathematics can learn from the living world.

References

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