Why Do things become More complex?

By W. Brian Arthur

Fifty years ago our technologies, our organizations and our lives were less complicated than today. Things were simpler. Most of us prize this plainness, this simplicity. Yet we are fascinated by complexity. Lately I've been wondering why the simple becomes complex. Is there a general principle causing things to get more complicated as time passes? Is complexity useful?

One good place to look for answers to these questions is the history of technology. The original turbojet engine, designed by Frank Whittle in the early 1930s, was beautifully simple. The idea was to propel aircraft by a jet of high-speed air. To do this, the engine took in air, pumped up its pressure by a compressor and ignited fuel in it. It passed the exploding mixture through a turbine to drive the compressor, releasing it through an exhaust nozzle at high speed to provide thrust. The original prototype worked well with just one moving part the compressor-turbine combination.

Yet over the years, jet engines steadily became more complicated. Why? Commercial and military interests exert constant pressure to overcome limits imposed by extreme stresses and temperatures and to handle exceptional situations. Sometimes these improvements are achieved by using better materials more often by adding a subsystem. And so, over time, jet designers achieve higher air pressures by using not one but an assembly of many compressors. They increase efficiency by a guide-vane control system that admits more air at higher altitudes and velocities and prevents engine stalling. They increase combustion temperatures, then cool the white-hot turbine blades by a system that circulates air inside them. They add bleed valve systems, afterburner assemblies fire-detection systems, fuel-control systems, deicing assemblies.

But all these additions require subsystems to monitor and control them and to enhance their performance when they run into limitations. These subsystems in turn require subsubsystems to enhance their performance. All this indeed improves performance--today's jet engine is 30 to 50 times more powerful than Whittle's. But it ends up encrusting the original simple system with subsystem upon subsystem and subassembly upon subassembly in a vastly complicated array of interconnected modules and parts. Modern engines have upwards of 22,000 parts.

There's nothing wrong with this increase in complexity. We can admire it. On the outside, jet engines are sleek and lean; on the inside, complex and sophisticated. In nature, higher organisms are this way, too. On the outside, a cheetah is powerful and fast; on the inside, even more complicated than a jet engine. A cheetah, too, has temperature-regulating systems, sensing systems, control functions, maintenance functions-all embodied in a complex s assembly of organs, cells and organelles, modulated not by machinery and electronics but by interconnected networks of chemical and neurological pathways. The steady pressure of competition causes evolution to "discover" new functions occasionally that push out performance limits. There's something wonderful about this--about how, over eons, a cheetah forms from its simple multicellular ancestors.

But sometimes the results of growing complexity are not so streamlined. For example, 60 years ago in most universities, bringing in and managing research grants might have occupied only a few people. These functions now require a development department, legal department, sponsored projects office, dean-of-research office, grants accounting department, budget control office, naval research office, technology licensing office. In part, such growth is necessary because the research-grant world itself is more complicated (and so complexity engenders further complexity). But often, new bureaucratic offices and departments become entrenched because the career interests they create overpower any external competitive forces that might pare them away. In 1896 my own university, Stanford, had only 12 administrators. It is still leaner than most, yet now it has " more administrators than the British had " running India in the 1830s.

It's that way with our lives, too. As we become better off, we gain more ways to squeeze more performance from our '` limited time. We acquire a car, profession, house, computers, fitness programs, pets, a pool, a second car. Fine. But all these bring with them maintenance, repairs, appointments, obligations- a thousand sub activities to keep them going. In this case again, the overall result is increased complexity of debatable effectiveness.

So in answer to the original question, I believe there is a general law: complexity tends to increase as functions and modifications are added to a system to break through limitations, handle exceptional circumstances or adapt to a world itself more complex. This applies, if you think about it, not just to technologies and biological organisms but also to legal systems, tax codes, scientific theories, even successive releases of software programs. Where forces exist to weed out useless functions, increasing a complexity delivers a smooth, efficient machine. Where they do not, it merely encumbers.

But, interestingly, even when a system gets lumbered down with complications, there is hope. Sooner or later a new simplifying conception is discovered that cuts at the root idea behind the old system and replaces it. Copernicus's dazzlingly simple astronomical system, based on a heliocentric universe, rejected the hopelessly complicated Ptolemaic system. Whittle's jet engine, ironically, replaced the incurably complicated piston engine of the1930s before it also became complex. And so growing complexity is often followed by renewed simplicity in a slow back-and-forth dance, with complication usually gaining a net edge over time.

The writer Peter Matthisssen once said, "The secret of well-being is simplicity".   True. Yet the secret of evolution is the continual emergence of complexity.   Simplicity brings sparseness, a grit; it cuts the fat. Yet complexity makes organisms like us possible in the first place. Complexity is indeed a marvel when it evolves naturally and delivers powerful performance. But when we seek it as an end or allow it to go unchecked, it merely hampers. It is than that we need to discover the new modes, the bold strokes, that bring fresh simplicity to our organizations, our technology, our government, our lives.

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