Holistic Systems

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This note is yet another opportunity to consider why it is so difficult to develop systems and networks with predictable behavior — and especially those that must satisfy stringent requirements for trustworthiness. We contrast these difficulties with somewhat similar situations in several other fields. In particular, we seek to discover some useful insights from consideration of analogous problems in energy, agriculture, and health care. In each of these areas, we contrast holistic approaches with nonholistic approaches. Holistic approaches are those that consider systems in their entirety rather than just focusing on specific properties or specific components. In each case, enormous culture shifts are required in education, training, business, government, and economic models.

There is much to be learned about how to effectively develop trustworthy computer systems and networks. For example, alternative energy and alternative agriculture both seek to maintain economic and ecological balance, in each case with people and the environment considered as part of a single system. Holistic health care seeks to treat the mind and body as a whole in the context of the environments in which the individual lives. What we here identify as *holistic system development* seeks to consider application systems in the large, in the total environment of their use, with whatever people, inputs, outputs, sensors, actuators, and so on may be involved. It also seeks to anticipate and prevent or otherwise mitigate against risks to the people and the environment that may result.

Table 1 hints at a few of the issues that contrast holistic approaches with nonholistic approaches. The table is of course a gross oversimplification of a highly multidimensional space, but nevertheless leads to some provocative contrasts. Let's consider a few of the specific analogies alluded to therein.

Particularly poignant is the common choice between (1) trying to cure or eliminate the underlying causes versus (2) trying merely to treat the symptoms by attempting to alleviate them or suppress them, or in some cases even to deny the significance of their existence, sometimes failing to realize that much better solutions can result by considering a broader context. This dichotomy is certainly relevant in health care, energy, and agriculture, and has long been a topic of discussion in environmental concerns — as for example in Rachel Carson's *Silent Spring*. However, it is also symptomatic in information system development.

Various contrasts relate to the nonholistic side of the table.

• With regard to energy, there is a historical tendency toward inertia — continuing to pursue fossil fuels such as coal, oil, and gas, with minimal attention to long-term alternatives. Economic factors have starkly reduced the availability of spare electrical power generation, relying instead on the questionable assumption that power can always be transferred from somewhere else. Short-sightedness has clearly been a problem for the U.S. automobile industry. Similar short-sightedness is found in the commercial computer system industry, where inertial factors have resulted in hardware optimization as a potential hindrance to security, backward compatibility as a hindrance to innovation, and a prevalence of buggy systems that leave the detection of bugs to users.

• Biological pest controls have some similarities with antivirus software. They both provide partial solutions to a problem, but mask other more long-lasting ones. Toxic chemicals tend to result in pest mutations and serious consequences in wildlife and people. Antivirus software defends against known attacks, but masks the reality that the systems they purport to protect are riddled with security flaws that could have been avoided with constructive system development. Proactively principled approaches to system architecture and software engineering could largely eliminate the vulnerabilities that viruses and malware exploit — for example, through sensible security, confined execution, and nonexecutables.

• Overdependence on antiobiotics in health care also has similarities with antivirus software. Bacteria tend to adaptively mutate, developing resistance to the drugs. Because virus writers can test their incremental wares against existing antivirus software, it is typically not necessary to resort to stealthy, polymorphic, and self-modifying malware.

Contrasts also are noted on the holistic side of the table.

• Seemingly holistic energy has various problems. Wind power creates environmental changes and risks to migrating birds. Hydrogen fuels require significantly more energy to generate than they yield (which holistically are not really effective). Corn-based ethanol produces only slightly more energy than that required to produce it (and is heavily subsidized in the U.S.). (Sugar-based ethanol is almost an order of magnitude more efficient in that regard.)

• Organic farming has many potential benefits to health and well-being. However, to be profitable, it relies heavily on inexpensive unskilled labor. Its labor-intensive nature can be contrasted with formal methods for system development with respect to representations and analyses of requirements and both source and object code, as well as assurably composable system architectures. However, formal methods usually depend on rather expensive highly experienced skilled labor. The labor pool is also quite different, where there are nontrivial training requirements and relatively few formal methodists. Furthermore, although organic farming was the norm before industrial farming, formal methods have unfortunately never been in the mainstream.

• Holistic health care has had difficulties gaining market share, in part due to established medical interests, pharmaceutical lobbies, and spotty insurance coverage. To succeed, it must overcome doubts regarding its effectiveness. Similarly, free and open-source software have an up-hill battle in the mass marketplace, in part due to customer preferences for the common denominator, and in part due to a lack of competitive application suites.

Although short-term benefits (profits, marketplace dominance, and so on) are generally cited to justify nonholistic approaches, the long-term benefits potentially can favor holistic approaches. However, much greater effort is needed to make an economically and socially convincing case that could seriously inspire some fundamental cultural shifts on a global scale with respect to each of the four categories.

Table 1: Contrasting Approaches

Holistic Approaches	**Nonholistic Approaches**
Alternative energy: Renewable resources such as solar, wind, biomass, hydrogen, hybrid vehicles with inertially recharged batteries could improve ecological balance and promote long-term sustainability.	**Conventional energy:** Fossil fuels tend to exacerbate global warming and result in long-term resource depletion. Nuclear power creates difficult long-term waste disposal problems and raises surrounding water temperatures.
Sustainable agriculture: Natural fertilizers, biological pest controls, and crop rotations can improve health, well-being, and long-term agricultural sustainability.	**Industrial farming:** Synthetic chemical fertilizers, pesticides, single-crop farming, soil contamination, toxic runoffs, create worker health problems, and long-term soil nutrient depletion.
Alternative health care (Cure the causes): Whole-person approaches such as proactive prevention, homeopathy, acupuncture, diet, exercise, and orthomolecular rebalancing can lead to long-term sustainability, less drug use, lower overall costs.	**Allopathic medicine (Treat the symptoms):** Suppressing symptoms (with pharmaceuticals, radiation, chemotherapy, corticosteroids, ...) causes iatrogenic effects. Antibiotic overuse induces mutations of resistant bacteria. Long-term effects may offset short-term benefits.
Principled system development: Pervasive use of requirements, specifications, composable system architectures, sound software engineering practice, design for trustworthiness, evolvability, maintainability and use can enhance long-term sustainability and yield overall cost savings.	**Unprincipled system development:** Seat-of-the-pants ad-hoc constructions lead to rampant vulnerabilities, low assurance, patch-and-pray system administration, continual remediation, iatrogenic upgrades, cost overruns, development delays, system failures, project cancelations, wasted human resources.
Multidisciplinary Commonalities: Foresight, global optimization can pay off. Governmental and commercial forces could be beneficial. Sound incentivizing economic models are needed to provide convincing cases for holistic approaches. Diversity of approaches can be very valuable. Demonstrable large-scale successes are needed (efficient energy, organic farming, cancer prevention, carefully documented successful system developments). Conclusion: Holistic approaches can significantly reduce long-term costs when optimized in totality.	**Multidisciplinary Commonalities:** Myopia, local optimization are commonplace. Political and commercial forces tend to dominate. Short-term optimization generally drives out long-term issues, which are generally disregarded. Monolithic, centralized, or homogeneous solutions prevail. Cures (oil independence, cancer remediation, large-system development successes) are slow to emerge. Conclusion: Nonholistic solutions may generate larger problems elsewhere and are generally more expensive when all peripheral issues are considered.

Furthermore, holistic approaches that appear ideal need themselves to be evaluated holistically, for example, considering the environmental effects of wind power and the labor-intensive nature of organic farming. Perhaps the insights gained therefrom would provide some inspiration for the development of systems that must be trustworthy.

Reflecting on the past issues of *SEN* (now 30 years old), it would seem that progress toward long-term solutions is very slow, and that an enormous culture shift is needed to achieve the effective holistic development of trustworthy systems. Cost-benefit-risk analyses must begin to systematically factor in global considerations of all would-be uses and downstream costs of maintenance, patching, evolutionary change, and environmental effects. (See PGN, Optimistic Optimization, *Comm. ACM 47,* 6, June 2004 for a further reminder of the importance of optimizing in the large, as well as PGN, The Big Picture, *Comm. ACM, 47,* 9, September 2004.)

This may sound like a very old story to long-time readers of *SEN* and RISKS, who have for many years heard cries from me for more far-sighted alternatives. However, realization of the similarities with other disciplines such as energy, agriculture, and health care suggests that the culture shift required is not just limited to computer system development, and that a successful culture shift would also require pervasive changes that result in holistically motivated education.

In addition, a major commitment is required to achieve enlightened system architectures and principled composable system developments, along with up-front attention to reducing the long-term costs throughout the entire cycles of development, redevelopment, and use. The alternative of not seeking such holistic approaches is to continue on paths that do not converge and certainly do not scale to extensively interconnected highly distributed large-scale networked information system environments such as the Department of Defense's Secure Global Information Grid. However, in principle, we should have an easier challenge than in the other disciplines because there are fewer variables beyond our control.

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