Appendix B

Redesigning Health Care with Insights from the Science of Complex Adaptive Systems

Paul Plsek

The task of building the 21st-century health care system is large and complex. In this appendix, we will lay a theoretical framework for approaching the design of complex systems and discuss the practical implications.

SYSTEMS THINKING

A “system” can be defined by the coming together of parts, interconnections, and purpose (see, for example, definitions proposed by von Bertalanffy [1968] and Capra [1996]). While systems can be broken down into parts which are interesting in and of themselves, the real power lies in the way the parts come together and are interconnected to fulfill some purpose.

The health care system of the United States consists of various parts (e.g., clinics, hospitals, pharmacies, laboratories) that are interconnected (via flows of patients and information) to fulfill a purpose (e.g., maintaining and improving health). Similarly, a thermostat and fan are a “system.” Both parts can be understood independently, but when they are interconnected, they fulfill the purpose of maintaining a comfortable temperature in a given space.

The intuitive notion of various system “levels,” such as the microsystem and macrosystem, has to do with the number and strength of interconnections between the elements of the systems. For example, a doctor’s office or clinic can be described as a microsystem. It is small and self-contained, with relatively few interconnections. Patients, physicians, nurses, and office staff interact to produce

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diagnoses, treatments, and information. In contrast, the health care system in a community is a macrosystem. It consists of numerous microsystems (doctor's offices, hospitals, long-term care facilities, pharmacies, Internet websites, and so on) that are linked to provide continuity and comprehensiveness of care. Similarly, a thermostat and fan comprise a relatively simple microsystem. Combine many of these, along with various boiler, refrigerant, and computer-control microsystems, and one has a macrosystem that can maintain an office building environment.

A distinction can also be made between systems that are largely mechanical in nature and those that are naturally adaptive (see Table B-1). The distinctions between mechanical and naturally adaptive systems are fundamental and key to the task of system design. In mechanical systems, we can know and predict in great detail what each of the parts will do in response to a given stimulus. Thus, it is possible to study and predict in great detail what the system will do in a variety of circumstances. Complex mechanical systems rarely exhibit surprising, emergent behavior. When they do—for example, an airplane explosion or computer network crash—experts study the phenomenon in detail to design surprise out of future systems.

In complex adaptive systems, on the other hand, the "parts" (in the case of the U.S. health care system, this includes human beings) have the freedom and ability to respond to stimuli in many different and fundamentally unpredictable ways. For this reason, emergent, surprising, creative behavior is a real possibility. Such behavior can be for better or for worse; that is, it can manifest itself as either innovation or error. Further, such emergent behavior can occur at both the microsystem and macrosystem levels. The evolving relationship of trust between a patient and clinician is an example of emergence at the microsystem level. The AIDS epidemic is an example of emergence that affects the macrosystem of care.

TABLE B-1 Mechanical Versus Naturally Adaptive Systems

Type of System	Mechanical	Naturally Adaptable
Simple	Thermostat and fan	Patient giving history information to a physician
Complex	Office building heating, ventilation and air conditioning	U.S. health care

The distinction between mechanical and naturally adaptive systems is obvious when given some thought. However, many system designers do not seem to take this distinction into account. Rather, they design complex human systems as if the parts and interconnections were predictable in their behavior, although fundamentally, they are not. When the human parts do not act as expected or hoped for, we say that people are being "unreasonable" or "resistant to change," their behavior is "wrong" or "inappropriate." The system designer's reaction typically is to specify behavior in even more detail via laws, regulations, structures, rules, guidelines, and so on. The unstated goal seems to be to make the human parts act more mechanical.

RECONCILING MECHANICAL AND ADAPTIVE SYSTEMS THINKING

This apparently misguided thinking arises from traditional science. In the Renaissance, Galileo, Newton, and others gave us the image of the clockwork universe (Capra, 1996). The paradigm of science for the last several hundred years has been one of reductionism; that is, further study of the parts of systems will lead to deeper understanding and predictability. Indeed, this tradition has led to great advances in knowledge.

Reductionist thinking has also been applied to organizations. Taylor (1911) introduced "scientific management" a century ago and changed our view of systems of work. Taylorism resulted in huge gains in productivity through the introduction of scientific study of time and motion in work. Taylor believed that if workers would do their work in the "one best way," everyone would benefit (Kanigel, 1997). These ideas form a continuing and deeply held paradigm today (Morgan, 1997; Zimmerman et al., 1998; Brown and Eisenhardt, 1998).

Mechanical systems thinking does work in many situations when applied to human systems, and it has led to great progress in the past century. It is precisely because mechanical systems thinking works in many situations that it has become such a strongly held paradigm.

Organizational theorist Ralph Stacey (1996) provides a way to think about this seeming paradox (Figure B-1). Zimmerman et al. (1998) further describe this concept and provides several examples of its application in health care. In the lower left portion of the diagram are issues in which there is a high degree of certainty (as to outcomes from actions) and a high degree of agreement (among the people involved in taking the actions). Here, mechanical systems thinking with detailed plans and controls is appropriate. An example in health care is a surgical team doing routine gall bladder surgery. Through experience and the accumulation of knowledge, there is a high degree of certainty about the surgical procedures that lead to successful outcomes. The members of the surgical team agree on the way they will operate. In a good surgical team, everyone's actions need to be relatively predictable and somewhat mechanical. Someone who behaved unpredictably would be expelled from the team. In this area it is important to fully specify behavior and reduce variation, and there are many such issues at both the micro- and macrosystem level in health care.

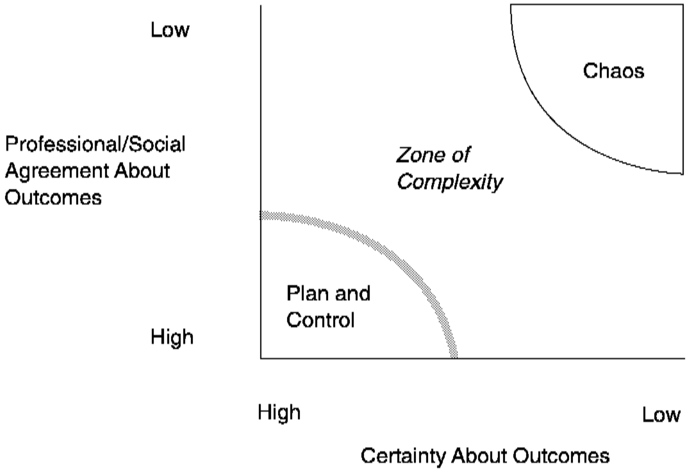

FIGURE B-1 Stacey Diagram: Zone of complexity. SOURCE: Stacey, 1996.

For other issues in human systems for which there is very little certainty and very little agreement (the area in the upper right of Figure B-1), chaos reigns and is to be avoided. A riot in the streets is an example.

Mechanical systems thinking (as intuitively applied by people designing and managing organizational systems) seems to allow only these two possibilities; it is necessary to plan and control, or there will be chaos. This seems so obvious to our mechanical-thinking mental model that it may not always be consciously acknowledged. Complex adaptive systems thinking allows for a third possibility.

There are many issues in human systems that lie in a "zone of complexity" (Langton, 1989; Zimmerman et al., 1998). These are issues for which there are only modest levels of certainty and agreement. Examples of such issues in health care might include: How should health care be financed? What is the best way to deliver primary care? For such issues there are many different models that have been successful in some situations and less successful in others; that is, only a modest level of "certainty" exists regarding what actions lead to what outcomes. Further, well-meaning, rational, intelligent people might not always agree as to the approach or outcome, meaning that there are only modest levels of agreement. For the most part the issues associated with designing the 21st-century health care system are in the zone of complexity where it would be more appropriate to use the paradigm of a complex adaptive system.

THE SCIENCE OF COMPLEX ADAPTIVE SYSTEMS

A complex adaptive system (CAS) is a collection of individual agents that have the freedom to act in ways that are not always predictable and whose actions are interconnected such that one agent's actions changes the context for other agents. Such systems have been the focus of intense study across a variety of scientific fields over the past 40 years (see Waldrop, 1992; Lewin, 1992; Wheatley, 1992; Kelly, 1994; Gell-Mann, 1995; Zimmerman et al., 1998; Brown and Eisenhardt, 1998). A major center of such research is the Santa Fe Institute, which includes several Nobel Prize winners among its faculty and associates (see Gell-Mann, 1995, p. xiv). Examples of systems that have been studied as a CAS include the human body's immune system (Varela and Coutinho, 1991); the mind (Morowitz and Singer, 1995); a colony of social insects such as termites or ants (Wilson, 1971); the stock market (Mandelbrot, 1999); and almost any collection of human beings (Brown and Eisenhardt 1998; Stacey, 1996; Zimmerman, et al. 1998).

The study of such systems reveals a number of properties. Although the list below is not a comprehensive description of the field, it illustrates some key elements of a way of thinking about complex organizational systems such as health care.

- *Adaptable elements.* The elements of the system can change themselves. Examples include antibiotic-resistant organisms and anyone who learns. In machines, change must be imposed, whereas under the right conditions in CAS, change can happen from within.
- *Simple rules.* Complex outcomes can emerge from a few simple rules that are locally applied.
- *Nonlinearity.* Small changes can have large effects; for example, a large program in an organization might have little actual impact, yet a rumor could touch off a union organizing effort.
- *Emergent behavior, novelty.* Continual creativity is a natural state of the system. Examples are ideas that spring up in the mind and the behavior of the stock market. In machines, new behavior is relatively rare, but in CAS it is an inherent property of the system.
- *Not predictable in detail.* Forecasting is inherently an inexact, yet bounded, art. For example, in weather forecasting, the fundamental laws governing pressure and temperature in gases are nonlinear. For this reason, despite reams of data and very powerful supercomputers, detailed, accurate long-range weather forecasting is fundamentally not possible. However, weather forecasting (and forecasting in general in any CAS) is bounded in the sense that we can make generally true statements about things like the average temperatures in a given season and place. The behavior of a machine is predictable in detail; it is just a matter of more study (reductionism). In a CAS, because the elements are changeable, the relations nonlinear, and the behavior creative and emergent, the only way to know what a CAS will do is to observe it.
- *Inherent order.* Systems can be orderly even without central control. Self-organization is the key idea in complexity science (Kaufmann, 1995; Holland,

1998; Prigogine, 1967, 1980). For example, termites build the largest structures on earth when compared with the height of the builders, yet there is no CEO termite. Similarly, there is no central controller for the stock market, the Internet, or the food supply of New York City.

- *Context and embeddedness.* Systems exist within systems, and this matters. For example, global stock markets are linked such that if the currency of Thailand falls, the U.S. stock market reacts. In a machine, one can extract the parts and characterize the response of a part to a stimulus. Although one can study the parts of a CAS independently, its context matters in fundamental ways.
- *Co-evolution.* A CAS moves forward through constant tension and balance. Fires, though destructive, are essential to a healthy, mature forest. Competition is good for industries. Tension, paradox, uncertainty, and anxiety are healthy things in a CAS. In machine thinking, they are to be avoided.

COMPLEXITY THINKING APPLIED TO THE DESIGN OF THE 21ST-CENTURY HEALTH CARE SYSTEM

With challenges that naturally fall in the zone of complexity, such as the design of the 21st-century health care system, it is not surprising if the system does not act like a machine. CAS science and the Stacey diagram suggest additional metaphors to assist our thinking. Box-B-1 highlights some key ideas that emerge from the application of CAS science to the challenges of designing the 21st-century health care system.

Biological Approach and Evolutionary Design

It is more helpful to think like a farmer than an engineer or architect in designing a health care system. Engineers and architects need to design every detail of a system. This approach is possible because the responses of the component parts are mechanical and, therefore, predictable. In contrast, the farmer knows that he or she can do only so much. The farmer uses knowledge and

BOX B-1 Key Elements in an Approach to Complex Adaptive System Design

- Use biological metaphors to guide thinking.
- Create conditions in which the system can evolve naturally over time.
- Provide simple rules and minimum specifications.
- Set forth a good enough vision and create a wide space for natural creativity to emerge from local actions within the system.

evidence from past experience, and desires an optimum crop. However, in the end, the farmer simply creates the conditions under which a good crop is possible. The outcome is an emergent property of the natural system and cannot be predicted in detail.

CAS science suggests that we cannot hope to understand a priori what a CAS will do or how to optimize it. A design cannot be completed on paper. Past attempts to do this in health care have not succeeded in part because they may not have been satisfactory designs, but mainly because a new understanding of "design" is needed.

Complex biological species (for example, human beings) get to be the way they are through evolutionary processes such as genetic mutation, and random variation. Changes that are useful to survival tend to persist. In a parallel manner, Holland (1995) points out that CAS need two processes in order to evolve: (1) processes that generate variation and (2) processes that "prune" the resulting evolutionary tree. Translating this insight to the task of designing the 21st-century health care system means combining the many ways to generate and test ideas with ways to enhance the spread of "good" ideas and impede the spread of "not so good" ideas. (Just as in biological evolution, seemingly harmful genetic variations do not die out completely in a generation; a not-so-fit characteristic might prove highly fit when combined with some other characteristic that evolves in a later generation.) These notions of evolutionary design are intuitively behind rapid-cycle plan-do-study-act (PDSA) improvement methods, which have been widely used in health care (Berwick, 1998).

Simple Rules, Good Enough Vision, and Wide Space for Innovation

A somewhat surprising finding from research on CAS is that relatively simple rules can lead to complex, emergent, innovative system behavior. For example, astrophysicists point out that all of the beauty and complexity we see in the universe emerges from two simple rules: (1) gravitational attraction and (2) the nonhomogeneity of matter in the early universe. In mathematics, the complexity and beauty of the Mandelbrot set (fractal mathematics) come from a very simple equation that is executed recursively. Reynolds (1987) showed that complex flocking, herding, and schooling behavior in animals could emerge from having each animal, such as a single fish in a school, apply three simple rules: (1) avoid collisions, (2) match speeds with your neighbors, and (3) move toward the center of mass of your neighbors. No central controller or director is needed; each animal can simply apply the rules locally. The behavior of the system emerges from the interactions, and this behavior is successful in avoiding predators. Holland (1998) shows how simple rules lead to emergent complexity in game theory, which models many situations in human interactions.

This idea of simple rules is counterintuitive to mechanical-systems thinking, in which if one needs a complex outcome, one needs a complex machine. There have been several past attempts to set out a complex set of rules to govern health care. When these have not yielded desired results, our instincts have been to create even more rules. CAS science asserts that these instincts take us in exactly the wrong direction.

The concept of complex system design using simple rules has also been demonstrated in organizations. The credit card company VISA built a trillion dollar business with very little central control. The banks that issue credit cards agree to only a few simple rules regarding card numbering, card appearance, electronic interface standards, and so forth. They are free to innovate and compete in all other aspects. There is no central control on new service development, and banks can go after each other's customers (Waldrop, 1996). In their study of high-tech firms, Brown and Eisenhardt (1998) found that the most successful firms had fewer rules, structures, and policies than their less successful competitors. Finally, the Internet is another example of a CAS. The few simple rules have to do with Hyper Text Markup Language (HTML), site naming conventions, and so on. Innovation is occurring daily in this arena. Zimmerman et al. (1998) provide several examples from early work applying these principles in the VHA, Inc. health care systems.

Again, the concept of simple rules clearly links to notions based on evolutionary genetics, game theory, innovation theory, and other sciences that are embracing new ideas about complexity. The concept provides wide boundaries for beginning the work of self-organization.

It is liberating to realize that the task of complex system design does not itself need to be complex. Although it has been suspected intuitively that it may not be possible to design in detail something as complex as the U.S. health care system, there is no need to fall victim to chaos. The answer is to create the conditions for self-organization through simple rules under which massive and diverse experimentation can happen.

Simple rules for human CAS tend to be of three types: (1) general direction pointing, (2) prohibitions, and (3) resource or permission providing. A good set of simple rules might include all three types. These three types of rules tend to match the predispositions of many systems designers. Those who would focus on leadership and aim setting are drawn to the simple rules of the first type.

Those who are drawn to regulation and boundary setting are comfortable with the second type. Those who would focus on incentives and resources are drawn to the third type. The theory honors all three points of view and suggests that it is best to have only a few such rules, so that no one point of view dominates.

Self-organizing innovation occurring in the health care system suggests that there is an implicit set of simple rules already in place. Experience in the fields of creativity and innovation suggests that changing these underlying rules might result in great innovation (Plsek, 1999).

Because the parts of a CAS are adaptable and embedded within a unique context, every change within a CAS can stimulate other changes that we could not expect. This approach to system design can never provide the assurance that is possible in a mechanical system. This is the nature of CAS. Therefore, rather than agonizing over plans, the goal is to generate a "good enough plan" and begin to observe what happens. Then, modifications can occur in an evolutionary fashion.

CONCLUSION

Complexity science provides a new paradigm to guide system design. Some key questions raised by a CAS-inspired approach to redesigning health care for the 21st century include:

- How can conditions in the health care system be established to allow many new ideas to emerge and mix into the existing system, while maintaining discipline to do just a little bit of nurturing, see what happens, then decide what to do next?
- How can diverse people be brought together, information shared, and forums convened among those to stimulate creative connections who do not normally come together to do so (similar to genetic cross-over and mutation)?
- How can desirable variation (innovation) be separated from the variation that ought to be reduced (error and waste)?
- What are the few simple rules that might guide the local development of the 21st-century health care system?
- What is the implicit, existing set of simple rules from which current innovations in health care emerge?
- How can these existing, implicit rules and underlying assumptions be modified?
- How can communication infrastructures be set up to disseminate the new simple rules?
- How can infrastructures be established in public policy to encourage experimentation and innovation under the new simple rules?
- How can experimentation be made highly visible so that the "fitness" of each evolution can be judged to quickly spread the best ideas?
- What is a "good enough plan" to begin the change?
- Who should take on the role of continuing to evolve the plan as the CAS plays itself out?

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