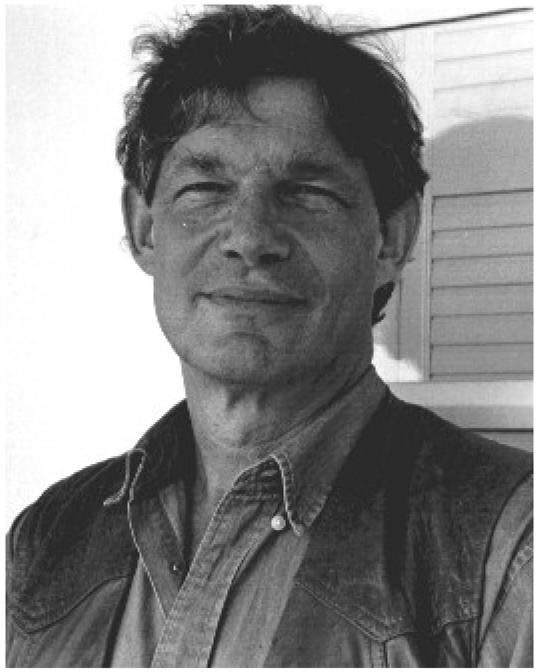
February 2002 Meeting: Stuart Kauffman on Investigations

by Dave Thomas

New Mexicans for Science & Reason (NMSR) heard Stuart Kauffman of the Santa Fe Institute and BiosGroup speaking on "Investigations" on February 13th, 2002.



Kauffman is a biologist and former professor of biochemistry at the University of Pennsylvania and a professor at the Santa Fe Institute; author of Origins of Order: Self Organization and Selection in Evolution (1993), and coauthor with George Johnson of At Home in the Universe (1995). He talked to NMSR about his third book, Investigations.

Kauffman began by introducing the concept of "autonomous agent." Is a bacterium, which could be said to act on its own behalf as it gleans food from its environment, an autonomous agent? Stuart then gave his definition of such an agent: "A self-reproducing system that can do one thermodynamic work cycle." He raised and lowered a pen, illustrating a work cycle, and thus demonstrated his own status as an autonomous agent. The bacterium is also such an agent, of course. But something that reproduces without work, such as a crystal, isn't an autonomous agent. Even DNA is not an autonomous agent; it specifies order, but does not perform work cycles. Kauffman mentioned that Schrödinger predicted that life would require aperiodic crystals bearing a code nine years before the elucidation of the structure of DNA by Watson and Crick. Stuart said the question of what makes a cell alive is still open.

One of the perplexing problems of the origin of life (not to be confused with the subsequent evolution of diverse life forms over billions of years) is that DNA codes for proteins (strings of amino acids), but proteins are required to help copy the DNA. As yet, we haven't been able to make a molecule that makes copies of itself without the assistance of other molecules like proteins. It's hard to get RNA (ribonucleic acid) to duplicate itself, because too many G's and C's (guanine and cytosine nucleotides) make it fold up in knots. But it's probably not impossible, Kauffman said. He mentioned Gunter's research on a "cousin" of RNA, in which hexamers made copies of themselves without other proteins to assist. Stuart also mentioned work on a 32-amino-acid protein that breaks into smaller subunits (of 15 and 17 amino acids each), and how the subunits catalyzed the production of more copies of the 32-amino-acid sequence. He said this self-reproducing protein "blew the field wide open."

He went on to discuss systems in which components catalyze each other, but not themselves. If two molecules A and B can catalyze each other's formation, as has been demonstrated, why can't three? Or four? Or hundreds or thousands? Kauffman called such assemblages "autocatalytic systems." He talked about a button-and-thread model for self-organization, in which buttons and threads are strewn on a floor. Pairs of buttons are connected with the threads randomly. At first, most of the buttons are free; there are a few pairs, and even some triplets. But as more threads are added to given pairs, the number of interconnections rises steeply. Larger clusters are joined into still larger clusters, until BAM! - giant clusters are formed.

Kauffman then introduced the concept of "adjacent possible." If you have a bunch of molecules and reactions, what collection of molecules will exist after one reaction step? There are many possibilities, which constitute the immediate "adjacent possible." For example, once there were just a few organic molecules; but now, there are trillions. "The biosphere has expanded into its adjacent possible," Kauffman said. Additionally, the number of ways to make a living has exploded.

Stuart then discussed work cycles and energy. Work cycles are a way to link spontaneous and non-spontaneous reactions. For example, the hexamer (6-acid molecule) which catalyzes pairs of trimers (3-acid molecules) to form more hexamers performs work cycles. It "eats" energy (supplied as photons of light) and trimers, and produces more hexamers like itself. The process can oscillate back and forth, respond to feedback, and so on. Kauffman criticized the standard definition of work as force times distance, and says he prefers to define work as "the constrained release of energy." But where do the constraints come from? Who makes the pistons in Carnot engines? It takes work to make the constraints, and it takes the constraints to produce work. Work can be non-propagating, like shooting a cannonball into a field; while a hole and hot dirt are created, no useful work is performed. But arrange the cannonball to turn a paddle wheel as it zooms away, and that can be harnessed to, say, pump water and irrigate the fields. This is "propagating" work, he said.

In cells, the cells make lipids of different types that combine in layers, producing vital cell membranes; these are the "constraints" of the cell. And the cell makes copies of itself, providing closure. Kauffman said it's not just a question of matter, energy, or Shannon information: it is an organized system that propagates itself, a "living" state of matter and energy.

Unlike physics, in which the "adjacent possible" states of, say, atoms in a sealed vessel can be easily described, the biosphere is not finitely pre-describable. As an example, Kauffman discussed Darwinian pre-adaptations. We all have hearts, needed for pumping blood. But what if the heart could have another as-yet-unanticipated function? What if some one person's heart happened to be sensitive to vibrations typical of impending earthquakes, and that this ability caused the person to run to safety outside just before massive earthquales can strike? That person might have more descendants than others without sensitive hearts, and if there were many earthquakes, that ability might spread to many descendants. We can't possibly anticipate all the possible pre-adaptations, and so we can't even define the "adjacent possible." Stuart suggested that a possible "4th Law of Thermodynamics" for the biosphere is that it will expand into the adjacent possible as fast as it can get away with it. But Kauffman hasn't figured out how to mathematize it, because he can't even list all the possibilities.

A lively question and answer period followed the donut break. In response to one question, Kauffman cautioned that we don't really know for sure what will happen because of genetically modified foods, because we don't know for sure how those genes will interact with others in the field. Paul Gammill asked about teaching "Intelligent Design" in schools. Kauffman replied that design theorists have not made their case to biologists, and don't deserve equal time in schools, because the fact of evolution appears to be incontrovertible. Gammill proceeded with a laundry list of questions regarding chirality, complexity, and so forth. Kauffman said these questions included some very good ones, and he provided some good answers and areas for exploration. He said the Design Theorists need to identify their Designer if they expect to develop their theory as a science.

Stuart Kauffman concluded with a brief discussion of Maxwell's Demon, a hypothetical construct that could appear to violate the laws of thermodynamics by, say, allowing only atoms of a certain speed to go though a hole connecting separate containers, thus changing the state into one of disequilibrium. While no Demon can exist in the domain of atoms alone, it's different in the biosphere. There, Darwinian pre-adaptations can be "measured" by the biosphere (much as the Demon would measure an atom's speed), and adaptations that are favored in the environment can be "catalyzed." He concluded that "The biosphere keeps finding new ways to measure displacements from equilibrium, and how to get work from them."

NMSR thanks Stuart Kauffman for a mind-expanding talk!