Interview: Stuart Kauffman

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Stuart Kauffman is famous for arguing that biology must look beyond Darwin. From molecules to ecosystems, he sees self-organization as the twin to natural selection in giving order to living systems. He's joined the UVM faculty to continue making his case -- and he'll be in residence this fall, "eager for conversation across disciplines," he says. (Photo: Joshua Brown)

In the early 1980's, Stuart Kauffman was a tenured professor of biochemistry and biophysics at the University of Pennsylvania -- but he left his ivied job to go to the deserts of New Mexico. "I was lucky enough to be at the Santa Fe Institute near the beginning and fell in love with complex adaptive systems," he says, "but nobody knew exactly what that meant!"

A decade there, at the world-leading think-tank for complex systems -- including five years as a MacArthur "genius" fellow -- brought Kauffman closer to an answer than perhaps any scientist on the planet. "The combination of confusion and passion drove creativity," he says.

There, and later at the University of Calgary, he published research on a breathtaking range of topics from the origin of life, to gene regulatory networks, to molecular evolution, to so-called fitness landscapes in evolutionary biology. A medical doctor by training, his books span from the technical *Origins of Order: Self-Organization and Selection in Evolution* to his recent exploration of the links between religion and science, *Reinventing the Sacred*.

Kauffman will begin a three-year residency at UVM in the fall, with a joint appointment in the College of Medicine and the College of Engineering and Mathematical Sciences. He will be UVM's first Macmillian Scholar-in-Residence, working on campus each fall semester.

"There were about 30 of us at Santa Fe who grew the field -- hoping there would be others," he says. "And now there are, here in Vermont, twenty years later. UVM has a terrific complexity group -- and a terrific opportunity to lead."

UVM Today spoke with Kauffman at the annual Vermont EPSCoR meeting in downtown Burlington where he was giving the keynote address; we wanted to learn how he sees the world and his new post at the University of Vermont.

UVM Today: What do you hope to accomplish at UVM?

Stuart Kauffman: I'd like to play a friendly catalytic role. It's what, at 70, I really want to do.

Mostly, I'd like to foster the sciences of complexity on campus, but I think of complexity in a very broad sense. It reaches out and touches the humanities and the arts and engineering and biology and philosophy. I'll look forward to talking to the people in the religion department. I taught at Harvard Divinity School last spring. I talked to philosophers yesterday. I am studying philosophy of mind right now. I'm blogging on NPR now and look forward to carrying on this conversation at UVM.

I want to speak about the sciences of complexity and where the frontiers of complexity are today. I know complexity really well; I've been doing it since I was 24.

And what is complexity?

For the first time in my life I'm distinguishing "familiar complexity" and, well, something else! There is stranger stuff that we are barely glimpsing. That is the frontier.

First though, the reason why "normal" or "familiar" complexity has emerged in the last twenty-eight years is the computer. A computer allows us to look at a system with a large number of variables that interact with one another in highly heterogeneous ways -- and the unexpected properties that emerge. That's complexity. A lot of complexity is about seeing how the whole works and adapts. You couldn't do that with the differential equations or partial differential equations of the physics of the 19th and 20th centuries. You just couldn't, at all.

So the computer is a kind of macroscope -- the opposite of a microscope. We are in an era where there is a sea change in science from taking things apart to trying to put them back together again. Well, that's not exactly new: Newton knew how to do this! He integrated his equations for celestial mechanics -- but now we can do it for all kinds of things. Integrative science is here to stay and it's going to grow.

I've read some criticisms of complex systems science as failing to deliver on its promise of revolutionizing science.

What happened at the Santa Fe Institute is like the development of the British railroads: first there was a boom and then there was a bust. And most of the railroad track got laid after the bust. So the Santa Fe Institute represents the boom and the bust: in its first five years we became famous; everybody beat their way to our doors to find out: what's this new stuff you guys are doing? Then around six, seven years into it, people started to say, "yeah well, that's new, but is it good for anything? It's been hyped, and it's been oversold." I learned something important: that always happens! We're now in the stage after the bust where there is an enormous amount of track to be laid with complexity science -- and is it going to happen at UVM? You bet. With Maggie Eppstein as the director of the complexity group on campus -- she's terrific and there are a lot of smart people here.

Give me an example of how an understanding of complexity advances a field of science.

Take systems biology. Now that we've done the genome project, how do all the parts interact with one another to give you an organism? That's an integrative task. There is a lot of work to be done.

And it's turning out that cells may be dynamically critical -- neither simple nor chaotic. This is amazing, but many biologists haven't caught up with this yet; they're just starting to come to terms with the idea that the cell is a dynamical system because molecular biology has been largely a local-function study: this protein binds to that piece of DNA and shuts off this gene or this protein touches that protein and gets phosphorylated, then this happens. It's reductionism and it's fine -- but it hasn't come to terms with complexity.

What you want to know is: how do genes regulate one another? And it's a dynamical system: what does it do and become? Well that's one of the big topics in systems biology; answers are going to emerge in complex systems science.

My passion is working on how cells get to be different from one another -- cell differentiation -- by genetic regulatory networks. I've now been working for five years on an idea that I started in 1971: that cancer may be unused cell types. I think we may be able to trick cancer cells into being normal. I call it differentiation therapy. And we're doing it up in Calgary and I'd love to bring it on campus here at UVM in collaboration with Calgary. I think it's a new way to try to treat cancer.

So all of this is complexity -- but meanwhile so is the economy. The economy isn't GDP; it's a bunch of interwoven businesses. I've been thinking about the economy as a web of goods and services and I've published on the economy being subcritical or supercritical -- like other energy systems.

Complexity is going to turn up in engineering in ways that I don't know, but people here in the complexity group here do. How do you make adaptive robots? That's complex.

I'm also interested in the origins of life; that's part of complexity theory. I would love to see a program here on making self-reproducing molecular systems; it's been done experimentally with proteins.

What holds complexity together theoretically? It seems to be this enormous polyglot beast! How is it different from the whole of human knowledge?

You are asking a totally relevant question to which there is not an adequate answer.

When coffee was discovered in the West, the Viennese asked: what are these green beans for? Because people thought it was brain food, they tried coffee on everything. Now we know it's good to drink at Starbucks in the airport.

We're going through this process right now with complexity and the macroscope of the computer, saying: what can we do with this?

I think it's legitimate that complexity is hard to pin down; we don't know yet! You're right that somehow it's the whole world. It's everything that is not simple. Well, that's a lot of things.

Do all these examples fit within the boundary of "normal" complexity?

Yes, mostly. Let's call it "almost-normal" complexity. We're getting to know the tools and the kinds of questions that can get asked and we know the kinds of answers that can be expected using these tools. We've drunk the coffee and begun to know what it's good for. Now let's get on with it, because there is an enormous amount of work to done within this normal or familiar complexity.

But what's beyond this?

Yes, let's look over the edge.

Consider the economy and the mess that we're in. How do we make a model that has agencies that make regulations, agents that play the game according to the regulations, and that reveals the emergent properties given those regulations? And then to the fun part: the agents will find ways to beat the regulations, right? How do you capture that? That's going beyond current complexity science and it's part of the frontier. That has to do with whether agents -- people -- can be captured by an algorithm. I think the answer is no. I don't think the human mind is algorithmic.

Do you know what Darwinian pre-adaptations are? These are unused features of an organism in its current selective environment, like swim bladders in fish or skin flaps on squirrels that allowed for the evolution of flying squirrels. They have no function originally but might turn out to be useful in some other environment.

The question is, can you say ahead of time: what are all possible Darwinian pre-adaptations? No, you can't. And that means that we cannot make probability statements about how the biosphere will evolve by pre-adaptations, nor can we have laws for how the biosphere will evolve by pre-adaptations -- even though it doesn't violate any physical laws.

The becoming of the universe -- because we're part of it -- is only partially describable by natural law. In its place is a huge creativity. I want to say that God is the natural creativity in the universe.

I think this means that not only do we not know what will happen; we often don't know what can happen -- like swim bladders or all sorts of technological evolution. There are limits to knowledge -- and we have to live anyway.