FREQUENTLY ASKED QUESTIONS

PREPARED FOR
PARTICIPANTS IN SMITHSONIAN COURSE

STRATEGIC THINKING IN A COMPLEX WORLD
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Panel of Scientists

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Andrew Ilachinski, PhD, theoretical physicist and project director for the Center for Naval Analysis. Dr. Ilachinski's work focuses on the applications of complex systems theory and nonlinear dynamics to the understanding of land warfare. He pioneered the development of a sophisticated multiagent-based model of combat called EINSTein that is used by military operations research analysts throughout the world. He has published two books, and as a semi-professional photographer, he has been a featured artist in the *Life Imitates Art* journal. His photography website won rave reviews in the May 2002 issue of *Shutterbug* magazine. Several of his photographs are also on permanent exhibit at the *Washington National Cathedral.*

Michael C. Grant, PhD, Vice Chancellor for Undergraduate Education and Professor in the Department of Ecology and Evolutionary Biology, University of Colorado at Boulder. Dr. Grant is an active research scientist with three decades of consistent national funding and more than four-dozen refereed publications covering a wide-range of topics including acid rain research, ecological and population genetics, evolutionary theory, nonlinear dynamics and cellular automata modeling. Through the Faculty Teaching Excellence Program he is actively involved in improving the quality of classroom teaching and science education, and has won numerous awards for teaching excellence.

Peter Allen, PhD, theoretical physicist and Head of the Complex Systems Management Centre in the School of Management at Cranfield University (England). He is also coordinator of NEXSUS, an ESRC Priority Network in Complex and Dynamic Processes. His research is directed toward the applications of the new ideas concerning evolutionary complex systems to real world problems. As a Senior Research Fellow at the Université Libre de Bruxelles (1972-1987), Dr. Allen worked on the theory of complex systems with the Nobel Laureate, Ilya Prigogine. For 25 years he has worked on the mathematical modeling of change and innovation, and the development of integrated system models. He has written and edited several books, and published over 150 articles in a range of fields including ecology, social science, urban and regional science, economics, systems theory, and physics.

Question 1: What's new and/or different about complexity and complex systems science? Is it really new? Haven't scientists always studied systems and systems engineering?

Ilachinski: What is new is the realization that in order to better understand the world ("better" than has heretofore been possible, at least via the precepts of Western Science) one must appreciate that the world exists within, and depends upon, multiple simultaneous scales of resolution. Our traditional disciplines — physics, chemistry, biology psychology, geologists, etc.—are very good at examining individual layers of an expansive hierarchy or parts, behavior and function, but until systems theory—and now "complex systems" theory—came around, there was no overarching "science" devoted to studying the multiple scales simultaneously. While, on the simplest level, it is of course true that we're not studying anything that hasn't been studied before; but the deeper answer is that we are studying exactly the same world from a radically different, all encompassing holistic perspective.

Grant: I think it is very new to a large majority of practicing scientists; I am confident of this with respect to biologists. It is not new to a modestly sized group of founders, leaders and early devotees. As many have pointed out, there are some who think in terms of systems, but the dominant model of thinking for the last several decades has been the 'reductionist' mode; looking for 'underlying' mechanisms, principles, components; simplifying and isolating components to determine their experimental behavior.

Much of classical experimental design in science centers on attempts to 'hold constant' all possible influences except the one under study. Such an approach necessarily and inevitably minimizes the contextual influence, the interactions and many of the key system properties present in a fully functioning system. To illustrate: Much of microbiological research has been centered on organisms which can be cultured on artificial medium at a constant 37 degrees C. Clearly microbes operate in much more complex environments and recent research, for example, indicates that RNA molecules may well act as temperature sensors to activate the reproductive process when temperatures are 'right' and to slow them down when temperatures are 'wrong.' This may be a key feature of microbial biology which could not be recognized or appreciated in the classical experimental design mode of thinking.

Allen: Complexity and complex systems are about evolving and changing systems. What is new is that we are trying to understand systems that evolve and change over time, sometimes partly as a result of what we do. Instead of considering an organization or a firm as a set of processes that function by turning input into output—a mechanical system—we are interested in the way that organizations come into being and evolve and also how they design and modify their activities over time.

So, although a widget, car or aircraft is not itself a complex system, the design and the decision's about which "widget/car/aircraft" should actually be produced, and what this does to the organization, its suppliers, its customers, and the environment in which it all sits, IS a complex system. This recognition of the qualitatively changing, creative and structurally unstable evolution is NEW and very important—being a particularly explicit form of bounded rationality, since the outcomes often cannot really be predicted.

Question 2: Does it [complexity] really represent a new way of thinking? or is this just hype?

Ilachinski: Essentially the same response as my reply to # 1. The most important new idea (ironically) to emerge from complexity science is "emergence," or the realization that open complex dynamical systems create novelty; that an understanding of just the "'parts" of a system are insufficient to understand its high-level, emergent behavior. Complexity represents a shift from believing that "parts" alone describe a system (along with their associated sets of simple point-point interactions) to an understanding that one needs to explore parts, connections, communications, inter-relationship, and coevolutions to even 'hope' to describe the 'real' system.

The world is far messier than traditional methods and science has led us to believe. Indeed, much of the mathematics needed to forge a real understanding of complex systems has 'yet to be discovered' (or invented)! This is one reason that computers and agent simulations have recently become such a tremendous force in complexity research; not yet having the requisite arsenal of rigorous mathematical techniques (although it is being slowly developed), agent simulations allow us to test our ideas of how systems work by experimenting with surrogate/virtual worlds (that we typically let generate themselves, from the bottom up).

Grant: To partially repeat my comments in #1, I believe it does represent a new way of thinking. It is an integrated, context-emphasizing, interaction-oriented frame of mind, which recognizes that many properties of systems cannot be recognized, understood or studied by examining the component parts in isolation.

Ecologists, for example, are just beginning to recognize that some long-puzzling phenomena such as population flushes and crashes in small mammals, may be well-modeled by non-linear dynamical equations and their 'deterministic' characteristics without the traditional recourse to explanations based on lower level phenomena such as variation in food supplies, density-dependent behavioral changes or climatic phenomena. This represents quite a revolutionary change in those scientists' way of thinking and framing questions which leads to very different designs for such studies.

Whether this turns out to be just hype or a fundamental scientific step-function forward can really only be determined at a later point in time. I think the odds are excellent it will comprise a major advance.

Allen: This is NOT HYPE. It is radical and important since it concerns the science of the limits to knowledge, and the key importance of accepting and dealing with irreducible uncertainty, and with change and unclear possible consequences of our actions.

Question 3: What is an agent? (as in agent-based modeling)
Note: Questions 3, 4 and 5 were presented only to A. Ilachinski for a response.

Ilachinski: Not easy to explain in a few words. The short answer is that an agent is any "entity that reacts to local sensory stimuli, processes and assimilates information, and communicates with other information processing entities."

The key is that all information processing takes place locally; agents typically have access only to finite, local bits of information (which may itself be incomplete and/or inaccurate) and talks to only a limited number of other agents. No agent is God-like, with a God-like knowledge of "everything" that defines the system. The question is ,"What does the system do a 'whole'?" as a consequence of the network of locally communicating agents.

Agents can be both simple (as in elementary cellular automata, in which they have just two states; on or off) or very complex (such as in my combat simulation EINSTein, in which agents have an extremely rich inner space and are able to sense and react to close to 100 primitive 'bits' of information). But in all such models, the fundamental 'agent' is nothing more than an abstract entity that processes "local" information in some well-defined manner.

Question 4: What's the difference between a Monte Carlo simulation and an agent-based model?

Ilachinski: Monte Carlo is simply a fancy-sounding term for estimating the probability distribution of likely outcomes of a model by repeatedly running the model. It is applicable to "any" model or simulation that includes some stochastic elements, and for which the researcher is interested in knowing how the model "typically" behaves; or what the "expected" values are of pertinent variables. An agent-based model represents a 'particular' kind of model, which—by the way—one may wish to run a Monte Carlo simulation of in order to better understand its output.

In my combat model EINSTein, for example, which contains some degree of randomization in both its spatial disposition of forces and within an individual agents' local optimization routines by which they adjudicate among possible movement and weapon targeting options, users typically first run the program interactively, and then, having settled on an "interesting" set of parameter values, run EINSTein in batch-mode (i.e. repeatedly over many random start configurations) to get an idea of a "typical" run; i.e. they perform a Monte Carlo experiment on EINSTein.

Question 5: What are the distinctions between agent-based modeling and systems dynamics modeling?

Ilachinksi: An inevitable difficulty that creeps in to any discussion regarding "complexity modeling" is that by virtue of its deep interdisciplinarity— *indeed, that is what gives the whole field its meaning, which results in multiple fields using the same terms but with sometimes subtly different innate meaning*— there is an unavoidable ambiguity and imprecision regarding basic terminology. What a physicist calls a "complex system" is not necessarily what a biologist understands or an economist or an engineer or business person. They are all talking about the "same thing" in the abstract, but each field has its own "model" of what that abstract looks like.

"Systems modeling" was introduced a long time ago, as you know, in a social dynamic setting; and thus developed a jargon all its own that was appropriate in that setting. Bartalanffy's classic (and still accessible and profound) *General Systems Theory*, for example, is an examination of "systems thinking" as a "model" of human organizational structure. And Koestler's opus *Janus* introduces the concept of a "holon" which is used as a basic "model" of abstract complex structures. But what these, and other early thinkers used as "models" is not what I as a researcher in complex systems regard as a "model."

For me, a model is a dynamic distillation of a mathematical surrogate or simulacrum of the "real" system; that is, a "model" is a dynamical representation of the physical system. In the middle ground between what I mean by model and what these early authors used as models are a slew of other "models as concepttualization" which are particularly prevalent in business/economic circles. Consider, for example, the conceptualizations in Gerald Weinberg's classic, *General Systems Thinking*. Here, a "model" can be something like a flow-diagram representing the important drivers of the system in question.

Agent-based modeling refers to a particular kind of dynamical model in which a system's global behavior is allowed to emerge from the collective interactions of (typically simple) agents that respond to local information and obey local rules. System models are more general and indeed include agent-based models as one kind of "system" model and, as a class, simply refer to any conceptualization and/or mathematical distillation of a complex system.

Ironically, many "systems models" actually represent the antithesis of what one intuitively understands as a system (as in whole greater than parts): many such models take a mean-field-theoretic view in which “ALL” the parts of an otherwise complicated system are assumed equal and the proceeds to "solve" a radically oversimplified differential equation (say) that is then regarded as a "systems model" of the real system. For example, the celebrated Lottka-Voltera equations of predator-prey interactions are a poor-person's "systems model" of the complex systems theoretic coevolution of competing species.