Chapter 4

Complexity and Emergence

1. THE HISTORY OF COMPLEXITY SCIENCE

The mind, we've seen, is a self-organizing system of patterns, relations and wholes, constantly rebuilding itself and re-relating itself, leading to the creation of new wholes and newer ones and newer ones. Philosophy gives us various perspectives on the mind process; but when one looks at the level of conceptual precision required to engineer an intelligent Internet, the vagueness of philosophical notions becomes apparent. One step toward concreteness is to seek scientific formulations of one's philosophical notions. Science then becomes a middle ground between philosophy and engineering, both in its language and in its concrete conclusions.

In terms of the study of digital mind, the branch of science that is most valuable in bridging the philosophy-engineering gap is the one called "complexity science" or "general systems theory." This is the area of science that focuses precisely on understanding systems as wholes rather than combinations of parts – i.e., on synergy, emergence, Fourth. In a certain sense, I view the work done by complexity scientists and systems theorists over the last 50 years as a continuation of the philosophical work reviewed in the last chapter.

What I mean is this. The philosophers I've championed above represent an ambitious, all-encompassing style of philosophy that is not terribly popular these days. It's tempting to say that science has taken over from philosophy as the grand integrative discipline. But one must remember that, 100 or 200 years ago, the boundary between science and philosophy was not as strict as it is today – theoretical science was "natural philosophy." So a more accurate statement would be: Natural philosophy lives on!

In fact, one can trace this kind of integrative thinking much further back than the philosophers discussed in the previous chapter. Buddhism, as discussed in the previous chapter, is a systems theory, as are even earlier shamanic theories of the world. Understanding the world as a collection of systems with holistic properties is not a new idea – in fact this is the original way of understanding the world, far predating modern scientific reductionism and having a firmer foundation in everyday intuition.

Carrying out holistic, systemic understanding in a scientific and mathematical way, however, is a somewhat more recent endeavor. The first major landmark in the development of systems theory, thus conceived, was probably Norbert Wiener's book *Cybernetics*, which came out in the 1930's (Wiener, 1972) and was the first systematic attempt to use mathematics to explain computational, biological and cognitive systems in one fell swoop. Looking back at that book today, one is amazed both at the synthetic power of Wiener's intuition, and at the amazing amount of conceptual ground we've covered since he wrote that book. One indication of the difference between science and philosophy is that it's still interesting to read Peirce and Nietzsche and Buddhism, whereas Wiener's groundbreaking ideas have essentially been superseded in their details, so that at this point his work is of primarily historical interest rather than being a treasure-trove of useful ideas.

Following up on Wiener's early ideas, in the 1940's and 50's, a fairly large amount of work was done under the name of "general systems theory." This body of work dealt with engineering, biological and psychological systems, and involved many of the same people who laid the foundations for what we now call computer science. Among the various successes of this research programme were Gregory Bateson's (1980) psychological theories, Ashby's work in cybernetics, McCulloch's groundbreaking work on neural networks, and a variety of ideas in the field of operations research. As molecular biology reduced more and more of human life to mechanism, Bertallanfly and others were tirelessly demonstrating what many modern biochemists and geneticists still forget: that the essence of life lies in emergent properties of whole systems, not in individual mechanisms.

The general systems theorists understood that the whole is more than the sum of the parts – that in a complex system, behaviors and structures emerge via cooperative processes that you can't easily predict from looking at the parts in isolation. Furthermore, they realized that many of these cooperative phenomena didn't depend on the details of the parts, that the same essential phenomena occurred for many different systems. They thought about brains, robots, bodies, ecosystems, and so on and so on. But they failed to articulate a general systems theory that was really useful at solving problems in particular domains, and because of this, as the 1960's progress, General Systems Theory faded. The brilliant work of the early systems theorists was absorbed into various disciplines: neural network theory, nonlinear physics, computer science, neurobiology, operations research, etc. Today, bolstered by advances in computing power, complexity scientists have picked up where the general systems theorists left off.

1.1 Chaos and Pattern

One key notion of the complexity/systems-theory renaissance is "chaos": apparent unpredictability in a system that nevertheless is known to follow predictable rules. This concept was introduced by Poincare' toward the end of the last century but not really explored in detail until the 1970's. Simple systems, if you let them run a while without disturbing them, either converge to a steady state or cycle back and forth between states in a repetitive way. Complex systems fall into subtler behavior patterns called "strange attractors" which are neither steady nor repetitive; the movement of a system within a strange attractor cannot be predicted in detail, even though the shape of the attractor as a whole is known. Often attractors are emergent, in that their shape can only be explained by reference to the whole system giving rise to them.

In real systems, of course, detachment from the environment rarely happens, so that it's hard to isolate attractors at all, whether they're strange or not – what one has in reality is even stranger than a strange attractor; it's a shifting network of patterns, almost converging to a strange attractor and then getting diverted by some environmental interaction into the basin of a new attractor, which it doesn't quite converge to either, and so forth. For this reason, the explicit detection of attractors has not proved very useful in the analysis of real-world data from complex systems. Instead, it's more interesting to look for patterns in the data, and simply track the fluctuations of the patterns, not trying to suss out which patterns come from internal attractor dynamics and which come from environmental interactions. My own introduction to the realities of analyzing highly complex real-world data came in the context of financial prediction (Pressing and Goertzel, 1999).

The balance between chaos and pattern is crucial to intelligence and is observable in the Internet today, as well as in the Webmind system, in the brain, and so forth. There is no way to predict how much traffic a given Internet router is going to get; but it is not hard to make some predictions about what general patterns will emerge among routers under various load conditions. There's no way to predict what an individual Webmind node is going to do, but one can predict some things about the overall structure and dynamics of a Webmind, because there are structures and behavior that are very common among complex, intelligent systems.

In the end, though chaos is fascinating, the really interesting point is that complex, self-organizing systems, while unpredictable on the level of detail, are interestingly predictable on the level of structure. The structure of the strange attractor of a complex system contains a vast amount of information regarding the transitions from one patterned system state to another. The essence of mind and life is in how this strange attractor structure interacts and co-creates with the strange attractor structures of the other complex systems with which the system interacts. And this brings us back to more of aa "process perspective" in which a system is viewed as a complex network of interacting, inter-creating processes. As we have seen, this has a long and rich philosophical history, tracing back to Peirce and Nietszche and the early Buddhist philosophers (and others, such as Whitehead and Leibniz, whom I did not mention above for lack of space).

1.2 The Complexity Renaissance

Chaos theory was very hot in the 1980's, but in the 90's, we saw a shift from the language of chaos to the language of complexity. It was recognized that chaos is only one among many interesting phenomena related to complex systems, and that while the early systems theorists may have erred in believing they could formulate truly general laws of complex systems, they were right to focus on emergent properties of systems, properties that come from the interactions of the system components as much as from the particular nature of the components themselves. The work done in this area is diverse and defies a simple summary, but I will mention a few relevant items here.

The Santa Fe Institute, in the early 1990's, was a focus of media attention and a center of complex systems research. Their website (http://www.santafe.edu) has a nice archive of research papers. They have pursued a particular approach to complex systems science which is strongly physics-inspired, and which is perhaps not as universal as they like to think, but is nonetheless very interesting, covering a broad variety of domains including economics, biology, computer science, and so forth.

For the past few years the Santa Fe Institute has sponsored an annual workshop on "Artificial Life" – computer programs that simulate whole living environments. These programs provide valuable information as to the necessary and sufficient conditions for generating and maintaining complex, stable structures. The proceedings of this conference were published by Addison-Wesley. My personal favorite is "Artificial Life II" (Langton, 1991). See http://www.alife.com for online references and relevant alife code to download. I will return to the topic of Artificial Life a little later on.

A whole discipline of complex systems research that we won't touch on hardly at all here, because it's not directly relevant to Webmind, is "cellular automata" – 1 or 2 dimensional space and time discrete dynamical systems in which the state of each cell depends on the state of the other cells around it. A lot of fantastic work has been done in this area, both in pure mathematics and in modeling of phenomena from immunodynamics to fluid dynamics. The classic book here is Stephan Wolfram's *Cellular Automata: Theory and Applications*,. After he got tired of doing CA research, Wolfram wrote a little software program called Mathematica, which has occupied most of his time since.

Neural network theory has also advanced tremendously, synergizing with chaos theory, cellular automata, and just about everything else. Simulated neural networks, originally introduced by McCullough and Pitts (and related to even earlier work by Rashevsky) for purely theoretical purposes, are now embedded in automobiles and computer electronics. A huge amount is understood about their dynamics, and their relationship to the brain – although many important questions still remain.

The notion of evolution has played a large role in the resurgence of complex systems thinking. Inspired by Jerne's "clonal selection" theory of immune function, which envisions the immune system as a complex, self-organizing, evolving learning system and which has been extensively empirically validatated, Gerald Edelman (1988) has re-thought brain dynamics as a form of evolution. And John Holland's "genetic algorithms," a simplified computer simulation of the evolutionary process have become very trendy in computer science. Genetic algorithms are used extensively in Webmind although, as we have found, a more thorough understanding of the role in evolution in mind leads one somewhat away from Holland's simple abstractions.

Finally, in parallel with these developments, Vilmos Csanyi, George Kampis, and Robert Rosen, among others, have kept alive the grand European tradition of General Systems Theory, using sophisticated ideas from mathematics and physical science to demonstrate that complex self-organizing systems must be understood to be **creating themselves**. I have reviewed these ideas in great detail in *Chaotic Logic*. And then there is Valentin Turchin's work on Metasystem transitions, and the work of his colleagues such as Francis Heylighen and Cliff Joslyn in the Principia Cybernetica Project.

My own work on digital mind has drawn on all these developments in spirit and often in detail. But, since there is no well-organized "complex systems science" with general laws of complexity, one cannot say that my

http://www.springer.com/978-0-306-46735-6

Creating Internet Intelligence
Wild Computing, Distributed Digital Consciousness, and the Emerging Global Brain
Goertzel, B.
2002, XVI, 330 p., Hardcover
ISBN: 978-0-306-46735-6