MEANING OUT OF CHAOS

Complexity: A New Science For A Postmodern World
Lecture notes for week #1, April 8, 1998
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"*The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living.*" -- Henri Poincare, first chaos pioneer.)

The Context of the Course

The heart of this course is about the establishment of a new relationship between humans and the natural world, the Earth. Chaos theory or complexity is a radically new way of perceiving the universe. Actually I should really say a radically old way of perceiving the universe. It is a shift from quantitative to qualitative, from determinism to general understanding, from order as the source of creativity to chaos as the source of creativity. The effect of this revolution is being felt in many areas: mathematics, chemistry, astronomy, biology, medicine, psychology, art, sociology, education, literary criticism, economics, earth sciences, etc.

The struggle between order and chaos goes back, at least, to ancient Babylonian mythology. Each year the god of Order had to reconquer the dragons of chaos, resetting the planets on their orderly (periodic) ways. Many of you will recognize the dragon as a symbol of the feminine creative energy. So this was an early manifestation of the patriarchy's subjection of the feminine. Chaos was in these myths the original creative energy. It is called the void in the Hebrew tradition. "And the earth was without form, and void." Chaos was defeated by Cosmos, order. This was part of the social transformation that elevated the gods over the goddesses.

Chaos emerged as a word around 800 B.C. in Hesiod's Theogony. It meant the gap between the sky and earth, where we and all life live. A few centuries later it had acquired its modern meaning, disorder. Joseph Campbell has identified the Cosmos/Chaos battle theme as the origin of the mythical concepts of heaven and hell.

This battle was completely won in the western culture by the 19th century. Classical science was totally dominant. Order was in control. Determinism was the only reputable position. Even with the advent of Quantum mechanics order was unchallenged.

Now Chaos is returning. She first reappeared about 100 years ago when the French mathematician, Henri Poincare, submitted the prize winning paper in a competition sponsored by King Oscar II of Sweden. The question was, "Is the solar system stable?" Poincare showed that the classical methods of Newtonian mechanics were not sufficient to answer the question, that is, the mathematics of order could not solve the problem. He invented new methods of geometric analysis. His work cast doubt on the orderliness of the solar system. Later he observed chaotic behavior in his model.

But it wasn't until the 1960's when computers were powerful enough to solve the nonlinear equations and display the results that chaos came into her own. And what a comeback!

It is most interesting to note that the most linear of technologies, computers, facilitated the return of the most non-linear of processes, chaos.

Today I will give a broad overview of that comeback. In the next weeks we will go into more details.

First, though, let's deal with the matter of definitions. Complexity is a new field and there is not agreement on the terminology. The people at the Santa Fe Institute would use the word "complexity" to represent the field and define it as: A collection of emerging paradigms of thought encompassing fractals, chaos, nonlinear science, dynamic systems, self-organization, artificial life, neural networks, and similar systems.

However, most of the researchers would use the word chaos theory to mean the above and would not use the word complexity. I will tend to use chaos for two reasons:

1. Chaos is a more powerful word. It has a meaning going back several thousand years. It relates to a primal issue in our culture, one that we must resolve positively. Complexity is a more technical word and conjures up a nice correct image of something complicated.
2. Ilya Prigogine uses the word chaos.

The Elements of Chaos?

1) Very simple deterministic mathematical equations can lead to chaotic behavior.

In other words chaos can come out of order. This was a great surprise to mathematicians and scientists. For example, take a simple equation like $x = kx(1-x)$. This is called the logistic equation. Biologists have used it for decades to model animal populations. It behaves very well for smaller values of k and then exhibits a strange order for larger values, and then becomes totally random for even larger values of k.

It was very hard for scientists to accept that such a simple deterministic equation could lead to order, then strange order, and then chaos. It did not make sense. In a later lecture we will go into the solutions to this equation enough to characterize the "strange order". But for now I will just note that this pattern of order, strange order, randomness is very typical for many systems. The complexity people call it order, complexity, and chaos. The chaos people call it order, edge of chaos, and chaos. Some like to use the metaphor of the phase transitions: ice, water, gas to refer to order, edge of chaos, chaos.

Let's define chaos in this limited sense. Chaotic behavior is apparently unpredictable behavior arising in a deterministic system because of great sensitivity to initial conditions. Chaos arises in a dynamical system if two arbitrarily close starting points diverge exponentially, so that their future behavior is eventually unpredictable.

Is this relevant for trying to understand nature? After all, this logistic equation is just that, an equation. Does it represent what happens in the real world? In animal populations? Well, populations biologists had been using this equation for a long time. It worked reasonably well. When the biologist used values of k for which the equation gave "strange order" or randomness, then the biologists thought that the model was failing. After all biologists are trying to understand very complicated systems, ecosystems in this case. So if the math falls apart, they are not bothered. After all most biologists are not very enamored of math in the first place. So if it fails them, they are not surprised and not interested in figuring out why. So that is how it stood. The logistic equation worked well over a certain range of k. Then it got funny and the biologists tried another tack.

Now the interesting thing is that the biologists were actually getting some strange empirical results. They actually saw the "strange order" in their animal populations; but they interpreted the results as caused by some unknown factor and just averaged the results out. Remember this was back in the 50's. There were no real computers, no hand calculators, only hand cranked adding machines. So it would have been an ordeal to check it out any further.

And then Robert May started working on the problem. May was a theoretical physicist, then a mathematician, and then became interested in biology, in particular, in population biology. During this time researchers were split along two lines. One thought that populations are regulated and steady, with some exceptions, and the regulation is by some deterministic mechanisms. The second thought that populations fluctuated widely, with some exceptions, not regulated by any deterministic mechanisms but bounced around by environmental factors. May cut right to the heart of the controversy by showing that a deterministic relationship leads to both regulated and wildly fluctuating behavior.

This was an important confirmation that the model did indeed represent the real world.

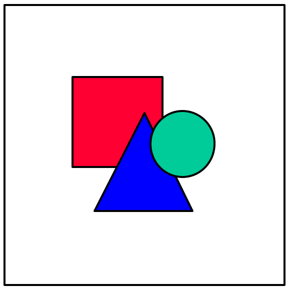
2. Natural systems usually have a sensitive dependence on the initial conditions.

While biologists may have been half-hearted believers in mathematical models. Other scientists were fully converted. The common belief was that the model and the reality are exactly the same, or, at least that any inconsistencies between the reality and the model is knowable and, in principle, determinable.

Ed Lorenz, a meteorologist at MIT around 1960, believed this. He was working on a model of the atmosphere to predict weather. Lorenz believed, as did all other meteorologists at the time, that if his model couldn't predict the weather correctly, then the problem was that the model wasn't good enough. It needed some more equations to model the atmosphere more accurately. Maybe an equation to model the difference in the temperature of the air rising from a mountain and rising from a forest or a desert.

One day, in what is now a famous story in the history of chaos, Lorenz was repeating a run on his computer. Halfway through he stopped the computations and went for some coffee. When he returned he decided that instead of starting over again and wasting a couple of hours, he would restart the program where it left off. So he typed in the last numbers of the truncated run and restarted the program. Then he went off again and came back a couple of hours later. Upon returning, he found that the two "runs" of the program were steadily diverging until they not longer bore any similarity. Lorenz discovered that a very slight rounding error in the numbers used as the starting values in the second run had caused this divergence. The modeling of non-linear systems like the weather are VERY sensitive to initial conditions.

Lorenz realized that weather prediction was doomed to failure. He made some interesting comments on just what the problem is. He compared predicting the weather to predicting the tides. Same complexity. Both fluids, etc. But in tides we are interested in the periodic aspect. The non-periodic aspect is not important. With weather we are interested in the non-periodic aspect. The periodic aspect, like it is warm in the summer and cold in the winter is not interesting. We want to know the slight variations: when will the storm hit? Will there be 3 or 4 inches of rain? Lorenz realized that any system that behaved non-periodically would be unpredictable.



Lorenz attractor (3D), a strange attractor. (See Turbulent Mirror, pg, 74)

What is the real issue here? If a system is very sensitive to the initial conditions, maybe that just means we have to make better measurements. Lorenz measured to 3 decimal places. Maybe we need 6, or 10, or 1,000 to ensure deterministic behavior. Isn't this just an experimental problem? Isn't the system really deterministic but we just can't make the measurements accurate enough?

Example of pool table, balls move at constant speeds, elastic. Same model for gas molecules. How accurate must we determine the velocity and position of each molecule so we can then predict the future? To ten places? Actually in the time it takes me to count out the number of decimal places, the system will have deviated.

Ok, you say. I can see that we cannot measure any real system accurately enough to ensure deterministic behavior. But is that inherent in nature or is that a human limitation? In other words, does God (Maxwell's demon or LaPlace's supreme intelligence) know exact position and velocity of every particle in a gas? And therefore the system really is deterministic? Or is there an indeterminism that exceeds even God's intelligence? In other words, did Cosmos or Chaos really win the great battle?

This is an important philosophical question. I will let you think about it for a few weeks and we will come back to it later in the course.

3. Contrary to the opinion of most scientists, nature is non-linear.

Until fairly recently, actually the advent of computers, scientists and mathematicians have not been able to solve non-linear equations. This is what Henri Poincare came up against 100 years ago. We can however solve linear equations. So when a student majors in science in college, like me, all the theory and problems involve linear problems and solutions. What has happened is that so many scientists, like me, were trained this way that it became the assumption, belief that the world was actually linear, for the most part, and the non-linear cases were odd, exceptions. Of course, what made this assumption easy to accept is the deeper assumption that Cosmos had defeated Chaos some time ago and the world was orderly.

The result of this is that when doing experiments, scientist had a linear model in mind and expected to find linear solutions. This influenced their acceptance of what constituted good data. Scientists have been insensitive to the non-linearities they observed.

Last week I talked with Ralph Abraham, one of the early pioneers in chaos theory. (Quoted in Capra, page 152) He is now retired from the math dept at UC Santa Cruz working on developing curricula on visible math. He made a comment which I think is very important in understanding the chaos revolution. He said that this represented a drastic change of paradigm in our understanding the world we live in. We now have the opportunity to increase our understanding of the cosmos from 10 to 11 percent.

As an example of this one percent increase he told me a story of his visiting a physiologist at UCLA. The physiologist had done some experiments some time ago and had lots of data but couldn't publish them because there were cycles in the data. Ralph asked a few questions, looked at the data and then told the physiologist that the data were supposed to have cycles. The data were chaotic. Ralph explained about chaos theory, gave the physiologist some references. The physiologist studied chaos theory to understand his data, ie, the system he was measuring and then published the data.

This is a very insightful (and true) story that can be taken symbolically. The physiologist represents our modern, western society. He (we) assumes that all important processes are linear. simple, deterministic. When he observes a "strange" behavior in a system, then he concludes that there is a mistake somewhere: the power isn't stable, some instrument is malfunctioning, the temperature isn't being held constant. Or there is some process going on which he doesn't understand, some process that he hasn't accounted for. So he can't publish the data because there is something wrong with them experimentally or, even worse, theoretically.

He can't publish the data because he would be wrong. He can't be wrong because that is very bad. Why is it bad to be wrong? Because there is a clear right in every situation and, of course, a clear wrong. Why does he assume that? Because he has grown up in a deterministic world. Each event has a clear cause. If the cause is not clear, then it is due to ignorance and can be remedied with some research.

Ralph Abraham represents the new paradigm, the new perceptual mode. He looks at the same data and says that they are just what is expected. That is, the system is not, after all, determinative.

Ralph Abraham also told me about the Club of Rome predictions back in the 70's. Their models behaved chaotically so they threw out the results and redid the calculations.

The science of complexity is often called non-linear dynamics. Some famous scientist quipped that calling it non-linear dynamics is like calling biology non-elephant biology.

Let's consider an example of a very simple system that is actually chaotic. Three body problem. You can write down the equations for this problem very simply. For three centuries scientists had looked at these equations and known that they cannot solve them; but assumed that the behavior of the system is simple because the equations are simple. Cosmos reigns. Chaos has been banished from the solar system. Well, Poincare saw a hint of trouble. But in the 60's it was painfully apparent. Example of dust in gravitational field of two planets. (Hill's reduced model.) This is even simplified from the simple three body problem. It is really three simple two body problems. Still it is chaotic.

4. Complex systems are correlated such that time symmetry is broken.

In both classical science and quantum mechanics equations are symmetric in time. That is, you can substitute negative time for positive time and it makes no difference in the equations. The system just runs backwards. Example of gas molecules. Example of two particle collision. Example of pool balls hitting colliding. However, in one area of classical science, thermodynamics, this is not true. Time goes only forward. So there is a schizophrenia in modern science. And, of course, in evolution time most certainly goes forward. Despite this, most physical scientists believe that time is reversible and that the problem in thermodynamics stems from our ignorance, our inability to solve the fundamental equations of physics in a complicated system. So we are forced to approximations. And it is in the approximations that we break the time symmetry. So the problem is our ignorance and lack of capability.

But we all have the experience of time going forward. That is what experience is. Have you ever seen a scrambled egg unscramble itself and rearrange itself back into an egg with shell? Have you ever seen two cars with injured people inside after a collision rerun the collision backwards and the people emerge unharmed? Nevertheless, that time is an illusion is very strong in modern science. Einstein made some famous quotes on this. In a letter to a good friend's widow he wrote that time is an illusion.

It is important to understand the implications of a time symmetric universe. Evolution doesn't happen. You and I are impossible. This issue has simply been ignored for decades by most scientists. It was filed away in the "too hard to figure out now, but we know what the answer will be" file. As Ilya Prigogine puts it, "Are we the product of our ignorance?" In other words, if we knew more about how to solve the fundamental equations for complicated systems and therefore time symmetry would be maintained, then there would be no evolution and we would not exist!

Indeed it awaited the genius of Ilya Prigogine for an elegant, simple resolution. The resolution is that time, the arrow of time points only forward. The symmetry of time is broken in all real systems. The only systems for which time is reversible are idealized, isolated, simple systems, usually with only two bodies.

Prigogine is very clear in the depth of the revision of science that is required. He state, for instance, "Quantum theory must be fundamentally revised." He is also very blunt in stating the inadequacies of other scientists' views. He says Einstein is wrong. Stephen Hawking is wrong. Murray Gell-Mann is wrong. We will return to Prigogine's work and crusade in a few weeks.

5. Ordered structures can be created and maintained far from equilibrium.

Again it was the work of Ilya Prigogine that demonstrated the order that can be attained in physical systems far from equilibrium. Prigogine developed the experimental and theoretical basis for understanding the behavior of what he called, "dissipative structures." A dissipative structure is a physical system that is:

1. organizationally closed, but structurally open. That is, the relationships among the components do not change; but there is a flow of energy and matter through the system.
2. far from equilibrium.
3. contains self-reinforcing feedback loops within its pattern of organization.

Prigogine studied the range of stability of these structures, their characteristics, and most importantly, their processes for maintaining their order.

It is easy to find examples of living systems that are dissipative structures. All living organisms are dissipative structures. The surprising finding is that there are non-living systems that organize themselves. This makes the distinction between living and non-living systems not quite as sharp as it used to be. The simplest example of a dissipative structure is a whirlpool. It is self-maintaining and satisfies the three criteria above. Another interesting system is the B-Z reaction. (see At Home In The Universe, pg. 53.) This is a chemical reaction

involving organic acids and heavy metal salts. High energy reactants must be added constantly to maintain the reaction. It is also called a clock reaction because the waves you see occur periodically. It is an incredible amount of long range order to behold in a strictly chemical system.
We shall return to this reaction in a future session.

6. The underlying dynamics of many natural processes, including human activities, are similar so that the insights gained from studying relatively simple systems, such as a double pendulum or a speck of dust in the gravitational field of two planets, can be applied to much more complex activities, such as literary criticism.

How can this be? Because the underlying dynamics are the same. The way that parts make a whole can be similar for very different parts and correspondingly very different wholes.

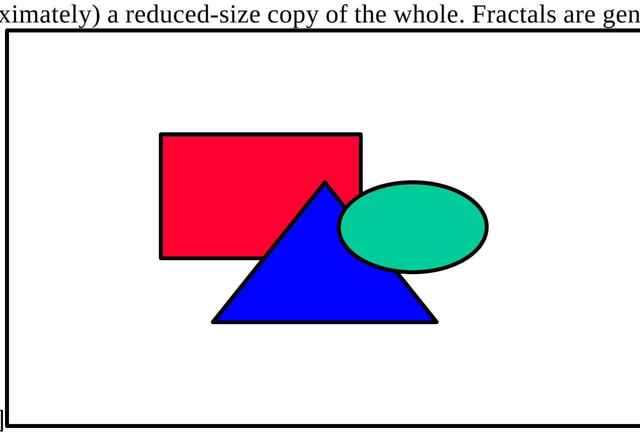
I did a search of titles containing the words, chaos and complexity, in the UCSC library. I found books on the following subjects: Of course, math, physics, astronomy. But also, Literature, Intoxication, sociology, Social change, Psychology of Learning , Children & Language, James Joyce, Crisis management in government, evolution of consciousness, Military science History, the postmodern agenda.

This was just the UC Santa Cruz library and just with the words chaos AND complexity in the title. It didn't include the new research on the heart and brain as chaotic systems.

7. A new expression involving mathematics and art, fractals, has emerged.

Fractals are mathematical objects which have a special property of being self-similar at all scales of magnification. So if you magnify or reduce a fractal see the same pattern. Now, actually, this is too tight a definition. Some fractals are somewhat self-similar. We also describe real objects as fractals, which are self-similar over a limited range of magnification, not all scales. Remember, this is a fairly new field. It is growing rapidly and being sorted out intellectually. Maybe you can contribute to this. Who knows?

[A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale.]



The most famous fractal is the Mandelbrot Set. Here is a picture of it. (see Turbulent Mirror, pgs, 98-101) There are also pictures on the display board. The Mandelbrot Set is somewhat self-similar at all levels of magnification. You can keep magnifying, the word is zooming, forever. I have it here on the computer. Each time you change the display, the computer must calculate the new display. At higher levels of magnification it takes more calculations. So if you want to zoom around fast, you need a very fast computer.

In these five overheads of the Mandelbrot set you can see what happens as you keep zooming each time by a factor of two or four.

The word fractal was coined by Benoit Mandelbrot in the early 60's. The root meaning is to break, to create irregular fragments. In a later session I will go through just how to create the Mandelbrot set.

There are many, many fractals. They are on the WWW, in books, in art stores. They are all around now.

Fractals have an interesting property: they are of non-integer dimension.

Mandelbrot discovered this when he asked the question, "How long is the coastline of Britain?" Seems like a simple question. Just look it up in a geography book. The problem is that you will find several answers. All of them are correct because it depends on how small your measuring stick is. But let's do the coastline of California. If you use a measuring stick that is 500 miles long, then you would say that the coastline is, say, 1000 miles long. 100 - 1200; 1 - 2500; 0.0001 - 4,000; etc. Now with a real world object you must run out somewhere around the atomic scale. But the point is that the coastline of CA is a fractal because we obtain a different size for it when we measure at different scales. There is a mathematical definition and formula for calculating the fractal dimension of an object. The fractal dimension of a coastline is typically between 1.15 and

1.25. The fractal dimension is a measure of the roughness of the object.
Here is another famous fractal, the Koch snowflake. (see The Web of Life, pg. 140)
Now this is a true fractal. It is easy to see how it has a fractal dimension greater than one.
Dimension = 1.26... Notice that the perimeter is 3 x 4/3 x 4/3... which is infinity. But it inside a circle with a perimeter of about 9.
There are also what is called Fractal forgeries, for example, fractal mountains, fractal clouds, fractal trees, fractal leaves (see The Web of Life, pg. 141). These are mathematical objects, fractals, that look like real objects. There are two reasons for doing this:
1. Video and film makers can create background objects in animated scenes easily. They don't have to draw them. They create them with a formula.
2. It's fun.
8. A new understanding of the evolution of the universe and of life on Earth is developing.
We will study one scientist, Stuart Kauffman, who has developed a understanding of evolution in which the complexity of the genome is part of the process of bringing forth new forms. His intuition was developed studying binary networks, networks of light bulbs that blink on and off according to certain rules involving relationships with their neighbors. Just imagine, by staring at simple networks of light bulbs and working on the effect of the rules on how they blink, he could come up with a very powerful insight into evolution, the first fundamental insight in evolution since the recognition of the role of genes.
He could do this because the common laws of complexity operate at many different levels of activities.
To appreciate Kauffman's contribution we must first review Darwinism. Darwin's insight was two fold: all living organisms have descended with modification from a common ancestor; and natural selection is the mechanism for culling the modified organisms. It was decades later that biologists determined that it was the organisms' genes that were being modified and selected against. Notice what that makes us. We are the result of a series of accidents, fortunate accidents to be sure, but accidents nonetheless. Had our ancestors' genes been modified differently long ago, everything would presumably been different. We probably wouldn't be here. We are accidents, as are all the other living organisms.
What Kauffman is suggesting is that natural selection is not the only "force" acting on modified genes. Maybe it is not even the most important one. Basically Kauffman's theory is that the interactions among genes to produce traits and therefore living forms is just between too ordered and too chaotic, so that order appears naturally, as it does in dissipative structures or in strange attractors. This emergent order operating at the level of the genome and is independent of natural selection. His theory is organized around the attractors in the organization of the genes. In this overhead (At Home In The Universe, pg. 109) you can see his prediction of the number of cell types in different organisms based on his calculation of the number of attractors. Kauffman is suggesting that the number of cell types in all living organisms is a function of the complexity of the organisms' genomes, perhaps totally independent of natural selection. This is a major break from current Darwinism. We will return to it in a future session.
9. A new understanding of the nature of life, mind, and matter.
Fritjof Capra has been developing a new synthesis of many old and current ideas. His basic theme is the synthesis of two very old dichotomies in science: pattern and structure or organization and matter. This is a very old discussion, going back at least to the classical Greeks. Since ancient times some scientists have emphasized either the pattern or the structure in the world. The structure proponents won out in later Greek times and that continued into our culture. It was certainly the mode of classical and most modern science. The debate corresponds to holism vs. reductionism. We will discuss more about that next week. The key to a comprehensive theory of life is the synthesis of these two approaches. Chaos theory is that synthesis.
The pattern of organization of any system is the configuration of relationships among the components that determines the system's essential characteristics. The structure of a system is the physical embodiment of its pattern of organization. For example, a bicycle has a pattern, a form, a set of relationships that constitutes bicycle. But that form can be embodied in many different structures. A bicycle can have many different actual physical structures: big wheels, small wheels, big and small wheels, even one wheel, two or one seats, etc.
For a living system we will add a third characteristic, process. The process of life is the continual embodiment of the system pattern of organization. So a bicycle does not make or remake its wheels; but a cell is constantly remaking every component.
Then Capra's new synthesis becomes the key criteria for life:
1. The pattern of life is autopoiesis, self-making. An autopoietic system makes its components and is, in turn, made from those components.
2. The structure of a living organism is dissipative. That is, it exists far from equilibrium, is open to the flow of

matter and energy, and contains positive feedback loops.
3. The process of life is cognition. All living organisms "know." This is the very interesting part of the new synthesis. Mind is the process of life. Mind is not a thing; it is a process. The brain is not necessary for mind to exist. A bacterium has no brain but has a mind; it exhibits a set of cognitive processes which constitute its perceptions and reactions to its environment. In vertebrates mind operates through the brain, and other modes as well. So the relationship between mind and brain is one between process and structure.
Since the brain is clearly matter, this establishes the relationship between mind and matter. So this synthesis heals the split between mind and matter that has been around since Descartes.

Conclusions

Complexity is about the emergent properties of the whole. It is the very opposite of reductionism. This new science presents both empirical and theoretical evidence of very fundamental incompleteness in the reductionistic approach to understanding the world. It opens our western mind to a new relationship with the complexity of life that has existed on Earth for 4 billion years as well as the complexity in which we live out our cultural and individual lives.

I would just add that mind is an emergent property of life. Life is an emergent property of matter. Matter is an emergent property of energy.

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THE CHANGING PARADIGM
Complexity: A New Science For A Postmodern World
Lecture notes for week #2, April 15, 1998
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"*If we grew up on the moon, our image of the divine would reflect the lunar landscape.*" --Thomas Berry
Capra does an excellent job in chronicling the change in the thinking of many scientists over the last century in understanding the limitations of the reductionist approach and the power and necessity of a holistic understanding of systems. There is no point in my repeating his history.

It is important to remember that Capra's main interest is a new understanding of life. His first paragraph reads. "This book is about a new scientific understanding of life at all levels of living systems--organisms, social systems, and ecosystems. It is based on a new perception of reality that has profound implications not only for science and philosophy, but also for business, politics, health care, education, and everyday life. It is therefore appropriate to begin with an outline of the broad social and cultural context of the new conception of life."

In a similar vein Prigogine in interested in time. Kauffman in evolution. And Briggs and Peat in how chaos manifests itself.

Capra starts with his understanding of the problem: a modern perception of reality inadequate for dealing with our overpopulated, globally interconnected world. Unfortunately, he doesn't include rampant consumerism. I always have a little trouble with someone's mentioning population as a world problem and not mentioning consumerism. Anyway the new paradigm that Capra suggests is Deep Ecology, a holistic worldview, an ecological worldview. Shallow ecology is anthropocentric; deep ecology is Gaiacentric. Deep ecology is deeply spiritual, religious (re-ligare; binding back).

But I want to point out a strategic difficulty: converting to Deep Ecology requires a conscious act. It requires a decision that goes against what we have assumed for thousands of years: the world was created for humans. There is another way which I consider strategically easier and spiritually more profound. (Overhead showing relationship among Story, worldview, and culture.) Use example of reading Microcosmos book as a way that education can change Story.

We, in the Western world, have grown up within a context, a set of assumptions about the world, our role in it, what is good/bad, etc. An example I used is that we have assumed that the world was made for humans because that is what our origin story says and that has been sustained by our culture for thousands of years. Associated with that is that humans are fundamentally different from non-human life, from animals and plants. There are other cultures which do not have this assumption so strong.

An example of how powerful Story is: he/she/it issue in English. We use he/she and him/her is very awkward ways in our writing and speaking. A very simple solution is to use it. But that is unacceptable because the word it is reserved for non-humans. Rather than be grouped grammatically with animals, plants, and non-living entities, we will use very awkward wordings. This is very odd, no?

Complexity is about emergent phenomena, the emergence of new forms and capabilities out of previous forms and capabilities. It is about development, evolution. It provides insight into what animates matter into life. It is concerned with the basic formulation of the Universe. Just how is the viewpoint of complexity different than our previous views?

One view that has come down to us from ancient times is the idea of spirit and matter: two different realms of reality, interacting but following different modes of behavior, different laws. These spirits have identified as divas, ghosts, Gods, Goddesses, aliens, and many others. These entities were/are of a different realm obeying different laws, ie, involved in different relationships within their own realm and with the phenomenal world. I am not saying that these spirits are not "real." I am trying to characterize a viewpoint in which there are two (or more) realms of reality, matter and spirit.

A few centuries ago a new view arose: scientific materialism, in which spirit was banished, or at least there was a concerted effort to banish any nonphysical manifestations of reality. Now, there never was complete agreement on the total banishing of spirit, but its presence was certainly greatly reduced in our everyday western life and the remaining manifestations were more peripheral.

In the clockworks universe of the era of classical science, there was no need for spirit. What was required, though, was mind, at least for humans. Remember that in our origin story humans were made different from the animals so it was quite reasonable that only humans would have mind. So, in a sense, spirit, spirits were banished and mind was put in as a limited replacement. The dualism was still intact.

But this was not a simple nor complete process, as Capra chronicles.

The Descartian view of the Universe as a clock or machine was powerful because the science of the day was powerful. It could explain the motions of the planets, the flow of blood in the human body, the tides, etc. Part of the power of the science was the ability to really focus on just what was important in the phenomena. This focus manifested in a recasting of language. Page 36 of the Universe Story explains very well the transition of scientists to mechanomorphic language. The gist of it is that by using very narrow, precise words, the essential aspects of phenomena were much easier to understand and formulate models for. For example, as Brian writes, the force of gravity between the Earth and Sun depends only on the masses and the distance between them. It doesn't matter if Earth is made of rock, or ice, or salt. It doesn't matter if there live on Earth beautiful antelopes or artists capable of rendering onto canvas their wonderful insights. It's only the mass that matters. Do you see how this is one more step down the road to scientific materialism?

We must remember that scientific materialism came not from science, but from scientists. Once Descartes, Bacon, and Newton, etc. started explaining the world physically and it worked so well, a subtle assumption crept in: this is all there is. Understand, this is totally unsubstantiated by empirical observations. It is a belief system. The reigning paradigm did such a good job explaining and predicting phenomena that scientists and all other intellectuals assumed that the rest is just a matter of time and better mathematics. Even with the interruption of quantum mechanics, this is still the dominant view. Anyway, back to our scientific materialism. Scientists and others assumed that all could be explained by forces on material objects. Everything was material, physical.

As Capra points out biologists, of course, had a lot of trouble with this approach. They dealt with living organisms, very complex entities. So they had trouble envisioning how such complex behavior could arise out of simple relationships such as Newton's and Maxwell's equations modeled. So it is easy to see how Vitalism would arise. Vitalism is, as Capra explains very well, the view that there is a spirit, a nonphysical entity that animates matter, makes it alive. Vitalism, at the time, could be considered a rethinking of the dropping of spirit for mind. Maybe it could be thought of as opting for a trinity of mater, mind, and spirit. Clearly the idea that spirits animate matter goes back long before 19th century biology. Vitalism was significant because it was proposed by scientists who were in the age of the machine universe paradigm.

Capra is very clear in his analysis of vitalism vs organicism. Important point that both were against materialism. Both agreed that the laws of physics & chemistry are insufficient to fully understand the phenomenon of life. Difference is what additional is required. Vitalists say that there is a nonenergy force, field, or entity. Organicists say that the extra required is human knowledge, human understanding of the organizing relations and capabilities inherent in any complex system. Note that the latter involves a human activity, understanding, knowledge; but no new ingredient in the system. In other words the assertion by the organicists is that this is the way systems behave. Self-organization is primordial. It is our job to understand and characterize it.

Is one view more spiritual than the other?

Capra mentions the famous experiments of Hans Driesch where he separated a two-celled sea urchin embryo into two separate cells. Each grew to a whole sea urchin. Now this is a startling result! How can you explain it? (Even today, when we can explain this particular aspect of embryonic development, the whole process is still a great mystery.) Again you can see why Driesch would assume that some extraphysical causal factor was working. He assumed the intelligence, the knowledge to carry out the embryonic process lay outside the embryo. Do you see how this devalues the embryo? How this assumption makes it an object of some intelligence residing elsewhere?

Driesch and others at the time had difficulty thinking that a capability could emerge as a property of a whole. He thought that the capability had to be totally within the individual cell. So he thought that the capability had to reside outside the cells so that they could be guided in their development.

As another way of thinking about it, let's think of an example. We can say that a Diva inhabits a tree and gives the tree its spirit, its life, or is the spirit of the tree. Or, alternatively, we say that the laws of complexity, of self-organization, that is the relationships among the components of the tree bring the tree to life, create and maintain the tree as tree and as the particular tree it is.

Does it make a difference how we say it? What are the differences? Which view is more "spiritual"?

So let's go out on the street or to a science department of nearest university and ask some scientists what they think of this spirit/mind vs. matter duality. The response by the scientists (not science) is likely to be primarily twofold:

1. It's not a problem. Angels, God, the resurrected Christ, heaven, hell, etc. are not subject to nor constrained by the physical universe. Therefore the laws that humans discover do not apply to these entities.

Remember there are lots of scientists who are believers, i.e., believing Christians, Jews, Moslems, etc. There are some famous ones. They do not see any conflict between the world of faith and the world of science.

2. It's not acceptable. The Universe is one. It is a uni-verse. One word. The universe developed as one

interconnected, interdependent entity. All aspects of the Universe are evolutionary developments of the primordial stuff of the universe, energy. Hence all aspects of the universe are connected in all fundamental ways. It has, so far, proven valid that it is possible for humans to discover and characterize the ways in which all aspects of the universe are connected. Therefore, such entities must be susceptible to normal systematic investigation, if they exist outside the human mind.

Is one view more spiritual than the other?

Now what I want to present is the sense of a self-organizing, self-emerging universe, an emerging Earth, emerging life, and complexity as the science of that emergence. First I will need some beautiful language because it is a beautiful process. So let's read the 12 principles of Thomas Berry. These principles concern the subjects of this course: time, development, the whole. They are in very different language than we will be using in this course; but they are the essence of what we will be concerned with.

Quote from Universe Story, page 34 "Beings with new powers create beings with new powers."

Now I will tell you a story. It is the real history of the birth of complexity, of the context out of which these scientists came. It is the context out of which we understood complexity. Start 15 B years ago for the history of complexity. Read from Cosmic Walk.

What does it mean to live in an emerging universe? It means that everything is new, constantly. It means that we have to reassess what constitutes meaning, that is, what something means, what it is.

Let me tell you another story as an example. Tell story of meaning of a glass. (Question is of eternal forms vs emergent forms.)

The water in this glass is water. Yes. But this water is not just some chemical substance, H2O, liquid, specific density = 1, etc. It possess incredible emergent properties. For example, it can, given the proper conditions, talk. Drink water. You see? It can express reflexive self-consciousness. That is an emergent property of water.

This challenges the usual answer to the question of "Who am I?" In the past our answer was that I am an entity that somehow resides in this body but is not really part of this body, and directs this body around. This is a form of vitalism. But in a developing universe, there can be no fixed answer. We are best identified with Story, the story of the Universe, the Earth, life, our human ancestors, our own personal experiences. We are best identified by the 15 billion year emergent process that we are. So when we study emergent phenomena, complexity, we study the very fabric of the universe, of ourselves.

Math:

For some of you this will be trivial. For some it will be interesting. For some it will be a bit mysterious. I have scheduled the conference room next door to continue this discussion. We can have lunch there and go until you have had enough.

1. functions and graphing

y = f(x) = x + 1 graph it.

y = f(x) = x2

2. differential equations

y = x + 1; slope is tangent. Same all along line. slope = 1

(45o)

y = x2; Slope varies along curve. Slope is tangent at point.

How get slope at a point?

delta y over delta x. Show. as deltas - smaller.

Show negative slope and positive slope.

If graph is of distance vs time, then show slope is constant speed. If slope changes, then being accelerated or decelerated (negative acceleration).

3. Iteration

f(x) = 3x; iterate. Graph solution. Two lines: slopes = 3 and 1.

x = kx(1-x) logistics mapping or equation. For k = 3, 0, .2, .4, .6, .8, 1. Try for k = 0.1.

Baker transformation. We will see in Prigogine another form of the Baker transformation where it is cut instead of folded.

Any two starting points, no matter how close, will end up arbitrarily far apart. This is the "Butterfly Effect."

4. Trajectories in phase space

x^2 + y^2 = 1; How to "solve" this equation? Graph it. Solutions are on circle of radius 1. Demo.

How about a pendulum? Draw picture. Angle and velocity vary. Describe motion. Hard to solve analytically. But easy to graph solution. Draw graph (ellipse) in phase space. Each point in phase space represents a possible state (configuration) of pendulum. Do some examples. But because of dynamics of system, i.e., Newton's laws of motion (conservation of energy), one point will naturally move into another nearby point. So there is another variable here, time. But time is not graphed explicitly here; it is implicit in the trajectory of the curve in phase space.

5. Attractors

The point 0,0 is an attractor for the pendulum with friction. The basin of attraction is the set of all points which will result in the attractor. In this case the basin of attraction is all values (not counting the propeller possibility).

Without friction there are an infinite number of attractors. Each starting point lies on a closed ellipse loop which is a periodic attractor. The basin of attraction, in this case, is only the particular loop. (If go to high velocity then propeller.)

The third type of attractor is a strange or chaotic attractor. The simple pendulum has no strange attractor. But a somewhat more complicated pendulum does: a driven pendulum. Such a system has a strange attractor. The basin of attraction is again the entire plane (but not for high velocities). What this means is that no matter where (in phase space) the complicated pendulum starts, it will end up in the same vicinity. But that vicinity is not a single curve; it is a very complicated trajectory which never repeats itself.

Now here is the vocabulary problem. Chaotic, as used here, does not mean random. It refers to a system that is determinative and patterned but not periodic, seemingly random until the solution is plotted and then the order is apparent.

6. Complex numbers

Set up real and imaginary axes and explain. Go through addition, subtraction, and multiplication.

Do examples of iteration $z = z^2 + c$.

7. Julia sets.

Given a c, do the above iteration for all z. If stays bounded, then a member of the set. Show overhead. Some are connected; some are disconnected. Amazing variety. Show computer program.

8. Mandelbrot set.

Is the collection of all values of c from which the corresponding Julia set is connected. Get it by iterating $z = 0$ for all values of c. If bounded, then member of Mandelbrot set and corresponding Julia set is connected.

- end -

ORDER FOR FREE
Complexity: A New Science For A Postmodern World
Lecture notes for week #3, April 22, 1998
by Larry Edwards, ledwards@sasq.net
Reading: Kauffman ch. 1-6
I will go over some math, not all of what I didn't cover last time, but enough for today's session.
MATH
Iteration
f(x) - 3x; iterate. Graph solution. Two lines: slopes = 3 and 1.
x - kx(1-x) logistics mapping or equation. For k = 3, 0, .2, .4, .6, .8, 1.
Try for k = 0.1.
Baker transformation. We will see in Prigogine another form of the Baker transformation where it is cut instead of folded.
Any two starting points, no matter how close, will end up arbitrarily far apart. This is the "Butterfly Effect."
Trajectories in phase or state space
Consider the equation, x2 + y2 = 1; how to "solve" this equation? Graph it. Solutions are on circle of radius 1. Demo.
How about a pendulum? Draw picture. Angle and velocity vary. Describe motion. Hard to solve analytically. But easy to graph solution. Draw graph (ellipse) in phase space. Each point in phase space represents a possible state (configuration) of pendulum. Do some examples. But because of dynamics of system, i.e., Newton's laws of motion (conservation of energy), one point will naturally move into another nearby point. So there is another variable here, time. But time is not graphed explicitly here; it is implicit in the trajectory of the curve in phase space.
Attractors
The point 0,0 is an attractor for the pendulum with friction. The basin of attraction is the set of all points which will result in the attractor. In this case the basin of attraction is all values (not counting the propeller possibility).
Without friction there are an infinite number of attractors. Each starting point lies on a closed ellipse loop which is a periodic attractor. The basin of attraction, in this case, is only the particular loop. (If go to high velocity then propeller.)
The third type of attractor is a strange or chaotic attractor. The simple pendulum has no strange attractor. But a somewhat more complicated pendulum does: a driven pendulum. Such a system has a strange attractor. The basin of attraction is again the entire plane (but not for high velocities). What this means is that no matter where (in phase space) the complicated pendulum starts, it will end up in the same vicinity. But that vicinity is not a single curve; it is a very complicated trajectory which never repeats itself.
Now here is the vocabulary problem. Chaotic, as used here, does not mean random. It refers to a system that is determinative and patterned but not periodic, seemingly random until the solution is plotted and then the order is apparent.
ORDER FOR FREE
Today we will go over the first half of the book, At Home in the Universe, by Stuart Kauffman. In this book and in much more detail in his previous book, The Origin of Order, Kauffman explains his theory of evolution in which the complexity of the genomic regulatory network, that is the genome, RNA and protein products, is part of the process of bringing forth new forms. What Kauffman is suggesting is that natural selection is not the only "force" acting on modified genes. Maybe it is not even the most important one. Basically Kauffman's theory is that the interactions among genes to produce traits and therefore living forms is just between too ordered and too chaotic, so that order appears naturally, as it does in dissipative structures or in strange attractors. This emergent order operates at the level of the genome and is independent of natural selection.
His intuition was developed studying binary networks, networks of light bulbs that blink on and off according to certain rules involving relationships with their neighbors. Just imagine, by staring at simple networks of light bulbs and working on the effect of the rules on how they blink, he could come up with a very powerful insight into evolution, the first fundamental insight in evolution since the recognition of the role of genes.
He could do this because the common laws of complexity operate at many different levels of activities. Kauffman's main goal is the setting up of a model of the genomic regulatory network that is a complex system, whose complexity manifests itself in characteristics that correspond to the empirical observations of the evolution of living organisms. As a prologue he sets up a theory for the origin of life.

Kauffman's key point is on page 8. The "Laws of complexity spontaneously generate much of the order of the natural world. It is only then that selection comes into play, further molding and refining... I believe that this emergent order underlies not only the origin of life itself, but much of the order seen in organisms today."

To appreciate Kauffman's contribution we must first review Darwinism. Darwin's insight was two fold: all living organisms have descended with modification from a common ancestor; and natural selection is the mechanism for culling the modified organisms. It was decades later that biologists determined that it was the organisms' genes that were being modified and selected against. Randomly mutations occur which change the genome inherited by the progeny. Usually this results in the debilitation of the progeny and therefore death. But sometimes the mutation is beneficial and results in the offspring having more progeny. Then that modified trait is preserved and spread throughout the species. Notice what that makes us. We are the result of a series of accidents, fortunate accidents to be sure, but accidents nonetheless. Had our ancestors' genes been modified differently long ago, everything would presumably been different. We probably wouldn't be here. We are accidents, as are all the other living organisms.

To be viable Kauffman's model must explain at least three fundamental characteristics of the evolution of life on Earth:

1. The relatively small number of stable cell types, around 250 in humans.
2. The ability of cells to maintain themselves in a great variety of adverse conditions, ie, homeostasis.
3. A graceful stability in changing from one cell type to another during embryonic development.

Before developing his model of the genomic regulatory network, let's follow his theory of the origins of life. This is closely related to his genomic model.

Life springs whole. Life is a phase transition.

Key is to understand catalysis. "At its heart, a living organism is a system of chemicals that has the capacity to catalyze its own reproduction." The chemicals are non-living; the system is living.

Let's review what a catalyst is. A + B to C + D has a certain rate. But a catalysis makes it go faster, sometimes much, much faster. Makes reverse reaction go faster also.

See illustration in Kauffman, page 65. When get a complete loop, then self-sustaining. Ratio of reactions to chemicals becomes higher as get more chemicals in net. So probability of auto-catalysis goes up. Life emerges as a phase transition.

It is as simple as that. Life emerges as a phase transition.

Now let's jump to Kauffman's model for the genomic regulatory network

Boolean networks. Light bulbs, each wired to its neighbors. There is a certain relation between state of each and next state of neighbor. Like an iteration. Simplest relationships are AND and OR. If have N light bulbs and each light bulb can be on or off, then have 2N configurations or states. K connections per bulb to nearest neighbors. Overhead page 76. State cycle, attractors. All cyclic.

Kauffman and friends have looked at hundreds, maybe thousands of such networks and have found certain characteristics. Generally the length of the state cycles is the square root of number of states. Very large for even small networks. So cycles are so long cannot see them as cycles. Look like randomness. K = N, K =1, K = 5,

Take N = 100,000 (the number of genes in the human genome) and K = 2. This is a sparsely connected network. It exhibits order. What does that mean? Only square root of N = 317 attractors! The 2^100,000 = 10^30,000 states are all drawn to only about 317 attractors. And, in addition, the state cycles are about 317 states long. This is incredible order! Kauffman states both of these without proof. I have not had a chance to check them out. Number of attractors true for certain kind of Boolean relationship (canalyzing).

Overhead showing relationship between cell types and attractors. You can see his prediction of the number of cell types in different organisms based on his calculation of the number of attractors. Note that his prediction of 317 cell types for humans is amazingly close to the empirical number of 256. Kauffman is suggesting that the number of cell types in all living organisms is a function of the complexity of the organisms' genomes, perhaps totally independent of natural selection. This is a major break from current Darwinism.

So Kauffman's model of the Boolean network represents the genome pretty well:

1. Cell type = attractor; so around 300 cell types.
2. Within the basin of attraction of an attractor is homostasis.
3. State can jump from one attractor to another; but not easy. This models the switch from one cell type to another. This last point is very important for ontogeny, or development of the individual.

- end -

CHOAS OUT OF ORDER

Complexity: A New Science For A Postmodern World

Lecture notes for week #4, April 29, 1998

by Larry Edwards, ledwards@sasq.net

Readings:

Briggs & Peat Chapters 1-4; Prigogine Chapters 1-3

Briggs & Peat

I must warn you about Briggs & Peat. They don't explain themselves well. I presume it was deliberately to keep the difficulty down. Many diagrams are not documented well. For example, they don't say what the axes are in many of their diagrams.

We return once again to the logistics equation. B&P go into this equation in some detail. It is important because: it is relatively simple to do; it was one of the first equations to be so deeply investigated; and, most important of all, it corresponded with what actually happens in the world, i.e., it is a good model.

Note B&P's graphs on page 38. The overall behaviors of the trout and pike are very ordered, that is they follow a pattern which is easily recognizable by us. For this to hold some trout and some pike must die during certain years. The numbers of trout and pike which die are not arbitrary or random. The numbers are, in fact, determined in a sense. How is this possible? What, who is determining the number of deaths? Remember death is not an isolated activity. It has to do with the fish's genetics, the temperature of the water, the fish's consciousness, etc. But overall it seems very simple. How can that be? Note that the relationship, law, whatever "determines" the order in the populations is "outside" the populations. It is not a property of an individual trout or pike. It is not even a property of the trout or pike population alone. It is a property of the two populations + the water + ??. It is not even specifically a property of these because it also holds if for foxes and rabbits. What is producing the order? The trout, the pike? God?

Do the 1-D explorer on the computer. Especially around p=3.85. Overheads from pages 59 and 61. Explain difference between plotting f(x) and k (p).

Iterations are real in that the present state of a dynamical system is related to the past state by its dynamics.

It is important to understand bifurcation and extreme dependence on initial conditions. Prigogine says that a system at a bifurcation point can "see", can sense the surroundings and respond. This is a manifestation of the system's sensitive dependence on initial conditions. The tiniest fluctuation at the bifurcation point can send the system in a certain direction.

Prigogine

The reading in Prigogine's book is about the development and philosophy of science. It is very well written by someone who is truly knowledgeable. I believe that you will all be very interested in these chapters, especially if your interest is in some aspect of the relationship between science and some other aspect of human knowledge.

Prigogine documents the rise of science to the high level of esteem it enjoyed in the 17th and 18th centuries and then its decline in the eyes of some intellectuals. Prigogine's major point is that the science that has been criticized is classical science. Even today the science that most people are upset about is really the science of the last century. But more on that in a moment.

Prigogine reviews classical science, that is, forces and acceleration in non-frictional systems. He makes several important points.

First classical systems are:

-- lawful. They obey laws of motion.

-- deterministic. If positions and velocities and forces are known, then system is known forever.

-- reversible. There is no Arrow of Time to distinguish the future from the past. So known forever backwards in time.

In addition he points out that classical systems are very hypothetical & simplified. For example, solid spheres. No deformation. Infinite forces; zero time of collision. Elastic: what does that mean at atomic levels?

Hubris is the word I would use to characterize the classical scientists. They thought that all was solved. Well, they learned their lesson with the revelation of quantum mechanics. But many scientists have now come back to the same hubris. Well, all things cycle (or do they?).

I want to take this opportunity to lay out what I think is important to know about how scientists actually operate in doing science. I do this because there is a great range of opinions in the literature and among people about role of science in our culture and many of you have expressed an interest in this.

First I want to define science and scientists and characterize them both. Overhead and handout. Read and ask

for additions. Note that technology proceeds science by some four billion years. Examples: photosynthesis, respiration, metabolism, wheel.
Some say that science is a human construct. That is certainly true, but very, very misleading. Let's go through such a statement.
Methodology
The methodology is certainly a human construct. But it is a very old mode. It is simply systematic curiosity. Example of fish as fertilizer. I don't know if it is older than humans. I don't know what process chimpanzees go thru when they investigate something new. Maybe it is the same, maybe not. I don't know.
Facts
The facts or observations are to some extent human constructs in that humans set up the experiments, the conditions under which the phenomena is observed and the observing instruments. But what is observed is not a human choice. Quite often it is a total surprise and decidedly not what the observer either had in mind or wanted as results. Read page 43 of Prigogine. "The experimental method is central to the dialogue with nature established by modern science. Nature questioned in this way is, of course, simplified and occasionally mutilated. This does not deprive it of its capacity to refute most of the hypotheses we can imagine. Einstein used to say that nature says 'no" to most of the questions it is asked, and occasionally 'perhaps.' The scientist does not do as he pleases, and he cannot force nature to say only what he wants to hear. He cannot, at least in the long run, project upon it his most cherished desires and expectations...."
Hypotheses, models, theories
Certainly these are human constructs; but they are very tightly constrained not only by the observations in the particular experiments in questions, as Einstein says above, but more importantly by all the other theories. A model inconsistent with the observations is not even considered. A model inconsistent with other established models will not be accepted (by scientists) unless it is very, very compelling. And then the other incompatible models will have to be questioned. Tell example of meteorites having an age of 4.57 B years. This is a severe constraint on any model/theory of how the solar system was born.
I experience a deep yearning in some people for science and scientists to be wrong. Note that science as a whole cannot be wrong. The facts cannot be wrong. The models can be wrong and, indeed, most all certainly are. Wrong here means that there exists or will exist in someone mind a better model. Better means that it will fit the observations better, be more consistent with other models, and/or involve more accurate predictions.
But that is not what people really mean. I believe what is of concern is the loss of the sacred. I claim that that is not due primarily to the rise of science. It is mostly due to the inability of our Story to make meaning out of our new, scientific experiences, that is, to provide a context in which life, all life, can function in a meaningful manner. For example, when Galileo had the experiences which convinced him, and eventually everyone else, that the heavens were not perfect, that the Earth was not the center of the solar system, the Story tellers, the Church, could not make meaning out of those experiences. So the experiences were left out in the space of meaninglessness. That was a very dangerous position to take and it eventuated in our current loss of the sacred. Our Story, our sacred Story must make meaning of all our experiences or we suffer the consequences.
Here is my hypothesis: spirituality lies in complexity, in what we are calling the laws of complexity, the relationships of emergence, of wholeness. These are the relationships, experiences we have, in the past, called spirituality. Spirituality is a property of the whole.
Following is an overhead used in the lecture.
Science and Scientists
Science
Methodology -- Knowledge
1. observations - facts
2. hypotheses - models (theories)
3. (predictions)
4. testing - new and/or modified models (theories)
Requirements/agreements:
1. Observations must be consensual, ie repeatable by others.
2. Models must be consistent with each other.
3. The simpler the model the better it is.
Characteristics:
1. Science involves models of reality, not reality itself. Scientists believe that better models are closer to reality. Reality is not describable directly.
2. Models are valid only within the range of observations.

3. Science doesn’t say or do anything. Scientists do.
4. Science makes possible technology and industry, but is not them.
Scientists:
Characteristics:
1. Are people.
2. Have a Story, i.e., set of assumptions about the world. In particular most western scientists share that aspect of the western Story that the Earth was made for humans to use, that the human drama is the central issue of Earth life, and that the non-human world has value insofar as it is useful to humans. (Note that this has nothing to do with science but everything to do with technology and especially industry.)
3. Do not necessarily connect their Story with their scientific knowledge.
4. Are no more or less spiritual or religious than lawyers, bankers, politicians, entrepreneurs, school teachers, postal workers, etc.
5. Because scientists are people, science progresses and digresses in very human ways, i.e., lots of arguments, power struggles, fears, hates, loves, inspirations, lies, and surprises.
6. Scientists started our 400 years ago with strong reductionism. Now have brought forth models of wholeness, e.g., development of the universe, and now, complexity, the science of wholeness. Quote from Prigogine, page 55. "Classical science, the mythical science of a simple, passive world, belongs to the past, killed not by philosophical criticism or empiricist resignation but by the internal development of science itself."
- end -

ORDER OUT OF CHAOS
Complexity: A New Science For A Postmodern World
Lecture notes for week #5, May 6, 1998
by Larry Edwards, ledwards@sasq.net
Readings: Prigogine Chapters 4-6 (100)
"You believe in a God who plays dice, and I in complete law and order."
Albert Einstein, in a letter to Max Born
A brief follow up to last week:
I experience a deep yearning in some people for science and scientists to be wrong. It always catches me by surprise when I experience this; but having experienced it many times, I now recover very quickly.
Now science as a whole cannot be wrong. The facts cannot be wrong. The models can be wrong and, indeed, most all certainly are. Wrong here means that there exists or will exist in someone mind a better model. Better means that it will fit the observations better, be more consistent with other models, and/or involve more accurate predictions.
But that is not what people really mean. I believe what is of concern is the loss of the sacred, of the beautiful, of the mysterious, of the sensitive. Science has become associated with a materialistic, non-spiritual, "hard nosed", factual approach to life.
Last week I tried to differentiate between science and scientists. Here again I make that distinction It is scientists who have become over the centuries materialistic, non-spiritual, factual. And, of course, so have other people in our western culture. The interesting question is why? I believe that that is not due to the rise of science, although it is certainly associated with it. It is primarily due to the inability of our Story to make meaning out of our new, scientific experiences, that is, to provide a context in which life, all life, can function in a meaningful manner. For example, when Galileo had the experiences which convinced him, and eventually everyone else, that the heavens were not perfect, that the Earth was not the center of the solar system, the Story tellers, the Church, could not make meaning out of those experiences of his. The option to change our Story so as to incorporate the new experiences was not taken, or, if it was, it was unsuccessful. So the experiences were left out in the space of meaninglessness. That was a very dangerous position to take and it eventuated in our current loss of the sacred. Our Story, our sacred Story must make meaning of all our experiences or we suffer the consequences.
Here is my hypothesis: spirituality is a manifestation of the "laws" of complexity, the relationships of emergence, of wholeness. These are the relationships, experiences we have, in the past, called spirituality. Spirituality is a property of the whole.
Prigogine: The Science of Complexity
Thermodynamics developed in the early 1800's. It was, and still is a direct challenge to classical (and quantum) science. Thermodynamics incorporates irreversibility, a break in the symmetry of time. So in thermodynamics there is an arrow of time. In real world processes time cannot be symmetric, that is, it cannot go backwards. It can only increase. This is not the case in classical and quantum science. This discrepancy was noted early on and various unsatisfactory solutions have been proposed. We will return to this important issue in the next sessions.
Thermodynamics is expressed in three laws:
First law: Conservation of Energy.
Second law: Production of Entropy.
Third law: Entropy = 0 at absolute zero temperature and a perfect crystal.
The third law is not used much. It gives a reference point for the value of entropy. But usually we are interested in changes in entropy in some process so that its absolute value is not very interesting.
First law: Conservation of Energy.
You can't win. That is, no matter what you do you cannot create energy. You can only convert energy from one form to another.
Energy is the ability to do work. It was to understand this ability to do work that was the focus of the research into energy in the 19th century. Prigogine recounts the story of the recognition of this law. During this time the various forms of energy (gravitational, electrical, heat, kinetic, etc.) were discovered and their interconversions verified. So the first law says that while one type of energy can be converted into another, the total amount of energy is conserved.
The word energy is used in this context in a very restrictive sense. These energies are associated with mass through Einstein's equation E=mc2. We use the word energy in many ways in normal conversation. For

example, people speak of energy work or energy emanating from a particular place on Earth. These are not, normally, first law energies. These are not, as far as I know, interconvertable with, say, potential energy. So these energies are not necessarily conserved. As I have mentioned before, we are free to use words however we wish to facilitate communication. We just have to be careful to understand what we refer to.

Another facet worth noting is that energy itself is not well characterized. Its various manifestations or forms are well characterized but energy itself is not. Perhaps there is no such "thing" as "pure" energy only various forms of energy. Perhaps there is pure energy but it is not empirically observable.

Second law: Production of Entropy.

You can't even break even. The second law was formulated in the attempt to characterize how energy is transformed in real world processes. In particular in any process some energy may be transformed into work, but some is dissipated as heat. That is, some of it is lost in that it cannot be used to perform work. This "wastage" is irreversible. That is, you cannot combine the wasted energy with the product energy and convert them back into the initial energy. You cannot run time backwards. There would be no violation of the first law in doing this; it just cannot be done. So the second law states this restriction. Let's follow Prigogine in setting up a formulation of this law. Consider a system and its surroundings. Overhead. The system undergoes some process. In this process it can change internally in its entropy, energy, and matter composition. It can also interact with its surroundings in the exchange of entropy, energy, and matter. Let's write equations for very small such interactions.

$dS = dSe + dSi$ where dS is a small change in entropy of the system, and
$dE = dEe + dEi$ dSe is the entropy exchanged with the surroundings, and
$dh = dhe + dhi$ dSi is the entropy produced internally by the system.

Same notation for E, the internal energy, and h, the number of hydrogen molecules, as an example of some chemical constituent. The equations say that the change in something in the system is the sum of the change caused internally by the process and the change caused by transport across the boundary of the system from the surroundings.

There are no restrictions on the exchanged components. Entropy, energy, and matter can all be exchanged with the surroundings. So these terms could be zero, positive, or negative. Now consider the internal terms. The matter term, can be positive or negative. That is, hydrogen molecules, for instance, can be created or consumed in some chemical process within the system. The energy term can be only zero. Energy is conserved; it cannot be produced. If it is produced in some part of the system, an equal amount must be consumed elsewhere in the system. Finally, consider the entropy term. It can be only positive for any real world process. That is a statement of the second law: entropy in produced in any system undergoing any (real) process.

Note that there is no conservation of entropy as there is for energy. Entropy always increases. And the direction of the increase in entropy is the direction of increase of time, that is, the future. Thus the second law forbids time's going backwards.

Note also that the entropy of an isolated system always increases until it becomes a maximum. At that point the system is at equilibrium. So equilibrium is a point attractor for isolated systems.

In 1865 the first two laws of thermo were stated as: The energy of the universe is constant. The entropy of the universe is increasing.

Prigogine makes a very interesting point here. He quotes Max Planck's, one of the great physicists of the late 19th and early 20th centuries, use of very anthropomorphic words in describing aspects of a system's thermodynamic behavior. He speaks of Nature's favoring certain states, equilibrium states. Non-equilibrium states are attracted to the equilibrium state. In so doing the system forgets its initial conditions. The system will not move from its equilibrium state of its own free will. Nature doesn't allow movement to less attractive states. Compare this kind of language to the mecanomorphic language of classical science.

In contrast in dynamics a system remembers its initial state, actually all states, forever.

So you see the challenge that thermodynamics presented to classical science. One who took up the challenge most seriously was Ludwig Boltzmann. It was Boltzmann who made the connection between entropy and disorder. Most scientists today think of entropy as an increase in disorder. While there is a great insight in this viewpoint, it is incomplete because, as we shall see, an increase in entropy can also lead to order. But the dominance of the view that entropy was disorder held back the understanding of complexity for many decades.

A very popular and powerful result of these investigations into thermodynamics of systems was the concept of free energy. In particular, in every process some energy is not freely available; it is wasted, dissipated into heat and not available to do work. Thus a heat engine must waste energy. A steam locomotive must give off heat.

In thermodynamics the free energy is the energy available to do work. The free energy is always less than the total energy. The difference is the dissipated energy.

All processes on Earth run on free energy. The Sun supplies energy. All Earth processes dissipate some of that energy. The free energy is what we live on. Life is about utilizing the free energy.

Back to the dissipation of energy. The conclusion was that the universe is running down. As natural processes take place, some of the energy is converted into heat which cannot be used further. So the universe is suffering a slow heat death. Eventually the universe will be a big homogeneous, low temperature dead "thing."

This is a pretty heavy view: the universe is dying. But there were the laws of thermodynamics. I will add that this is the view of many scientists today, but it is held lightly. Most scientists today know that we know very little about the universe as a whole. Extrapolating from experiments on Earth to the whole universe is fraught with dangerous assumptions. So a healthy attitude is, "OK, that is what thermodynamics says today. Let's wait a few hundred million years and see how it plays out."

Even without Darwin's theory in the late 1800's, it was quite obvious that the Earth was not running down. In fact, there was no evidence that anything was running down except human machines. But theories are powerful. Many concluded that life was contrary to the laws of physics. Imagine that! We are contrary to the laws of physics! What could that mean? This is similar to Kauffman's point that our current view of evolution is that we are accidents. This sense of alienation was very strong. Note that this is fundamentally a failing of our Story. That we consider ourselves as outside the "normal" process of Earth life could happen only if our Story allows it, i.e., does not prevent it by having built-in a complete unitary view including us.

The answer to this paradox, of course, is that there is order far from equilibrium. This may be obvious now, but scientists were not able to perceive it because they had decided that order exists only at equilibrium, that increasing entropy leads to increasing disorder. It took decades to change the view.

Consider a reaction, A + X -- B + Y. Put on board. A good assumption is that the rate of the reaction is proportional to the concentrations of the reactants. So, the rate of the reaction is: kAY.

But the rate of the reaction is the rate of consumption of A, so $dA/dt = kAY$. This holds for all the reactants as well as the products (the reactants in reverse). Then at equilibrium the forward and backward reactions are equal.

Suppose I mix 10 molecules of A and 10 molecules of X. Then the system comes to equilibrium with some fewer molecules of A and X and some B and Y. Let's just say that the equilibrium state is 6 molecules of A and X and 4 molecules of B and Y.

Now let's repeat the experiment this time starting with 8 molecules of A and X and 2 molecules of B and Y. Will come to the same final equilibrium state. This is what Prigogine means when he says that a system going to equilibrium forgets its initial state. The equilibrium state depends (primarily) on the temperature, pressure, and the nature and number of molecules of the reactants and products.

Far from equilibrium it is another story entirely. Let's start with a simple well-known example, turbulent flow. Imagine movement of water behind a boat propeller or in a swollen stream. Some image of violent, turbulent flow. Now that looks really chaotic. Water going back and forth with no apparent overall direction or plan. But this is very misleading. Compare the turbulent flow with placid water. Quiet water looks very ordered. There is not movement. It is still. But this is on the macroscopic level. On the microscopic level water molecules are dashing about at hundreds of miles an hour, banging into each other and bouncing off for some new collision. There is no long range correlation among the molecules. That is, they operate independent of each other except during collisions. But in the chaotic, turbulent flow great numbers of molecules move coherently. That is why we can see their movement. So, in fact, there is more order in turbulent flow; but there is not enough order for a stable structure.

Show overhead of Benard cell. Thin layer of liquid being heated from below. Temperature is increased. This is a highly ordered turbulent flow. Highly enough ordered to be a structure, a dissipative structure. Remember the definition:

1. Open to matter and energy from the surroundings.
2. Far from equilibrium.
3. Contains a positive feedback, a self-reinforcing loop or reaction.

Think of the sizes of the correlations in the Benard cell. Instead of distances of 10-8 cm, molecules are correlated over distances of cms.

Here is a set of chemical reactions that constitutes a dissipative structure. Show overhead. Note periodicity. This is a chemical clock reaction. It has a periodic attractor.

A - X
B + X - Y + D
2X + Y - 3X
X - E

If X were blue and Y were red, the system would change from blue to red and back again, indefinitely. But this happen only if the concentrations were constant across the container. Instead it is normal that the concentrations vary so we would see these kinds of patterns. Overhead. Note the great degree of order.

Bifurcations

Consider some set of chemical reactions like the previous one, that is, a set capable of becoming a dissipative structure. Overhead of two figures. Lambda is the control parameter, for example, could be chemical B in the reactions. We increase the concentration of B until the system is pushed so far from equilibrium that it changes it basic structure. This is a bifurcation point. It is like the start of the rolls in the Benard cell. Now the system "chooses" one of the two possibilities. What are the factors in this choice? Near, very near the bifurcation point the system is extremely sensitive to deviations. One such deviation shown in the second figure is the effect of gravity. Even though the effect is tiny, gravity does make a difference. So the second figure shows the bifurcation point magnified many times. The two paths are not symmetric. So the system will take the upper path. But if any other deviation, such as a fluctuation in concentration or temperature or whatever can, at the time of the crossing of the bifurcation point, make a difference comparable to the deviation caused by gravity, then the system can "choose" the lower path. As Prigogine says on page 165, "Matter...perceives differences that would be insignificant at equilibrium." These differences are not only slight but fleeting.

Free will vs. Determinism

In bifurcation there is free will, randomness. Away from the bifurcation point there is determinism or homeostasis. The point here is not to try to assign free will to a chemical reaction but to see free will, consciousness as an emergent phenomena. Thus, even a non-living chemical reaction can "choose" to some limited extent. In general, the more complex the chemical reactions, the more choice there is. Once the phase transition is passed into life, then choices become much greater. But a bacterium can choose which way to move. Still, in simple organisms homeostasis is much more powerful than choice. That is, a bacterium is more involved in maintaining itself than in seeking new vistas. For example, a bacterium cannot choose to die. It took a couple of billion years and the development of the nucleated cell before that became a choice for living organisms.

My point is that as we contemplate the human, ourselves, it is important to understand our many astonishing capabilities as part of a continuum of life’s emergence. While we are sure to be amazed by our talents, we must also be amazed by the long process that eventuated in these talents.

- end -

CHAOS TO ORDER
Complexity: A New Science For A Postmodern World
Lecture notes for week #6, May 13, 1998
by Larry Edwards, ledwards@sasq.net

Readings: Briggs & Peat 0, 4-1, Prologue (140);

Time is a river which sweeps me along; but I am the river.
It is a tiger which destroys me; but I am the tiger.
It is a fire which consumes me; but I am the fire.
--Jorge Luis Borges

Your reading for today was a mix of applications of the principles of complexity. I will be happy to go over any of them with you. But I have planned to really comment on only a couple. I'll do that at the end of today's session.

For most of this session I would like to share some ideas and generalities about the laws of complexity. However, before starting this larger subject I would like to pick up some thoughts that occurred to me as a result of the last session.

Last week we talked about a Benard cell which upon heating formed a dissipative structure. It is important to realize that the cell was about 4 inches in diameter and one-fifth of an inch in height. If the cell were, say 2 inches high the dissipative structure would not form. The point is that the formation of a dissipative structure in a system driven far from equilibrium is not automatic. Its formation depends on the boundary conditions. Its existence and development are both very sensitive to the environment. The same is true for whirlpools in the bathtub. Sometimes they form, sometimes not. After one forms you can sometimes make it change direction by swishing the water around. The important point is that the formation of a dissipative structure depends critically on the conditions extant.

All these characteristics are very different from equilibrium systems. Equilibrium systems are very fixed, very reliable, very repeatable, very static in the overall sense.

Last week Prasad complained about the use of the term "free will" to characterize a bifurcation that was deterministic. What I was trying to get at was the distinction between a dissipative structure and a system at equilibrium. Also I was making the point that if we look at "free will" along an axis, we would put equilibrium systems at one end and, presumably, humans at the other end. Dissipative structures would be close to equilibrium systems but still a distance away.

equilibrium systems | dissipative structures | bacteria | animals | mammals | humans
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At what point along this axis would we take the quotes off "free will"? Well, we would draw the line where we believe that the entity makes decisions on its own, not determined by the environmental stimulus. Of course, it is related to the stimulus, but not determined by it. This is exactly the issue that Maturana and Varela deal with. Capra mentions this briefly in his chapter 5. In chapter 7, the reading for June 17 Capra goes into more detail. In summary it is the issue of cognition as defined by Maturana and Varela. So they would put the dividing line at bacteria. Prigogine wants to put it down towards dissipative structures because he is suggesting that since we don't really know what caused the "decision", it is as though the system made the decision by itself, independent of the stimulus. Now you can say that you could figure out just what was the cause. Maybe you could and maybe you couldn't because it is liable to be quite variable. You may be able to determine a variety of possible causes but you could seldom be certain that a certain possible cause was the actual cause in a particular instance.

The rest of the session we will be discussing, in general, the laws of complexity, the laws that govern the behavior of a whole. As before we must be careful to have a very light understanding of the words, law and govern, and other such control words we will have to use in our conversation.

First, let's go over what a "law of nature" is.

Overhead on Laws
I include "things" because ultimately, things are relationships. That is, if I measure the mass of an electron by bending its trajectory in a magnetic field, I actually measure the relationship among mass, force, distance, acceleration, and magnetic field strength. Then I calculate the mass based on another relationship, another law.

So laws are our characterization of how the universe acts, the way it happens. We are, of course, delighted that it often happens in a way we can understand, that it even happens in a way we can characterize mathematically. A great surprise!

We seek the laws of complexity. Where are they to be found on our overhead?

Let's consider Capra's answer. He sets it in the context of the dispute between vitalists and organismic biologists. [Capra qote on page 25.] " Vitalists and organismic biologists differ sharply in their answers to the question 'In what sense exactly is the whole more than the sum of its parts?' Vitalists assert that some nonphysical entity, force, or field must be added to the laws of physics and chemistry to understand life. Organismic biologists maintain that the additional ingredient is the understanding of 'organization' or 'organizing relations.'"

In other words Capra asserts that no new forces or fields need to be invoked, only a new understanding, a change in the human mind, is required. So we need new dynamics.

The biologist Rupert Sheldrake would disagree with Capra. Capra refers to Sheldrake's theory of a morphogenetic field on page 26. Capra considers it a sophisticated form of vitalism because the field is non-physical, i.e., has no mass or energy associated with it.

So would the physicist David Bohm. In chapter one (the last chapter in the book) of your reading for today Briggs and Peat explain Bohm's quantum theory. It involves a quantum potential, a non-physical field. I believe this is a major reason that Bohm's theory is not accepted by both Capra and mainstream physicists today.

But Prigogine agrees with Capra. Prigogine says that those dynamics in the overhead are true only for idealized systems. They are not valid in general. He recasts classical and quantum dynamics at the fundamental level to break the symmetry of time. He has not finished his work. It will take decades more. But his intention is a recasting of modern science within the context of complexity. This will be the subject of the next two sessions.

First let me state my purpose for today. I want you to think carefully about just what complexity actually is. What the laws of complexity are. What the nature of a law is if there is no determinism.

To start out let's write down some words that we and others before us have used to describe the idea of a whole, a whole that has characteristics not found in its parts. For example, some that come to my mind are: whole, dissipative structure, catalytic net, holon, autopoietic network...

These words do not all have the same meaning. Let's use the word holon which was coined by Arthur Koestler to mean an entity which is simultaneously a whole and part of a larger whole.

Now I will set up a hierarchy of holons in terms of the forces that hold them together. Simple holons are held together by one or more of the four fundamental forces: gravity, electromagnetism, strong nuclear, and the weak nuclear force. For example, a hydrogen atom is held together by the electromagnetic force. So is a molecule like cellulose. Larger holons are held together by the "forces" of complexity.

To make the discussion interesting I want to exclude some things from being holons. It is perfectly okay to say that everything is a holon because everything is composed of stuff and everything is part of the universe. But this lessens the usefulness of the word. So I will exclude some things like a grain of sand or a piece of wood or a room. It is arbitrary but I want to focus on holistic properties. A grain of sand has essentially the same properties that a molecule of sand has. (That is not really true. Any conglomerate of molecules will have bulk properties, e.g., melting, temperature, etc. that a single molecule doesn't have.) A room may be made of parts like chairs and people but those parts aren't really integral to the room.

What I want to get at is holons that have surprising properties, properties that are unexpected (by humans) from an understanding of the parts. These are emergent properties. So I want to restrict the word holon to mean a whole that expresses emergent properties. Back to our examples. No human would ever have predicted the properties of the hydrogen atom based on knowledge of the electron and proton. Similarly, no one would conceive of the properties of cellulose based on knowledge of carbon, hydrogen, and oxygen.

Larger, more complex holons are held together by the "forces of complexity" as well as one or more of the fundamental forces. Such holons are dissipative structures. Not all dissipative structures are holons. For example a Benard cell is not a holon. While it is certainly a whole, it is not part of some larger whole. Of course, it is part of the room we are working in or the universe. But I want to keep meaning in the use of the word holon. The room doesn't change its characteristics as a whole depending on the Benard cell existence. So the Benard cell is not a functioning part of the room as a whole.

A bacterium is the simplest example of this more complex holon. Bacteria have been parts of a whole ever since Gaia was born. But even before her birth, they came out of a simpler catalytic network of some kind. An interesting question is whether or not the "forces of complexity" which hold together a bacterium can be understood in terms of the four fundamental forces, in particular the electromagnetic and gravitational forces.

The answer is no. That is the whole point of Prigogine's argument about time and irreversibility. The four forces are time symmetric. No living organism is possible in a time symmetric cosmos. But it is a very interesting and enlightening adventure to understand as much as possible the workings of such a holon within the framework of the four forces, i.e., within the reductionistic viewpoint. Such an understanding just cannot be complete.

More complex holons would be ecosystems, societies, groups, maybe families, as well as complex living organisms. They are held together solely by the forces of complexity.

So what are these laws, these forces of complexity? Are they forces in the same sense as the fundamental four forces? Or laws in the same sense as Newton's laws or Einstein's laws of relativity or the laws of thermodynamics? Are there just a few of them or different ones for different situations?

Well, those are just the questions that many scientists today would like to answer. No one has the answers to those questions although there has been much knowledge gained in the last several decades. So we can't answer the questions definitely or, perhaps, even correctly. But we can discuss them and set them in the context of the last few centuries or longer of human contemplation.

Overhead. What is complexity?
What are the laws of complexity? Just the way it happens? Is that acceptable to think that way? Is it an abdication of our reason? What is entropy? Just the way it happens? (Definition = that which increases in every real world process.) What is order? disorder?

Ultimately all things dissolve into relationships, the way the universe works, the way it happens. Things are not fundamental; relationships, processes are.

As way of thinking about this consider the dispute between the vitalists and the organismic biologists Capra recounts. Capra quote on page 25. "Vitalists and organismic biologists differ sharply in their answers to the question 'In what sense exactly is the whole more than the sum of its parts?' Vitalists assert that some nonphysical entity, force, or field must be added to the laws of physics and chemistry to understand life. Organismic biologists maintain that the additional ingredient is the understanding of 'organization' or 'organizing relations.'"

In other words Capra asserts that no new forces or fields need to be invoked, only a new understanding, a change in the human mind, is required. So here we can follow Capra and distinguish between laws and forces. Laws are statements of how the universe acts. Physical laws are fundamental. For example, gravity is fundamental. You cannot explain gravity in terms of some more primal action of the universe. You can set up models to reflect how gravity works. These are fields and forces. But they are not fundamental. Gravity is fundamental. So Capra is stating that we must not seek the forces of complexity but the laws of complexity. He is asserting that all the forces and fields needed to express the laws of complexity are already in place.

The biologist Rupert Sheldrake would, of course, disagree with Capra. Capra refers to Sheldrake's theory of a morphogenetic field on page 26. Capra considers it a sophisticated form of vitalism because the field in non-physical, ie, has no mass or energy associated with it.

So would the late physicist David Bohm. In chapter one of your reading for today Briggs and Peat explain the Bohm's quantum theory. It involves a quantum potential, a non-physical field. I believe this is a major reason that Bohm's theory are not accepted by mainstream physicists today.

So we have a problem. If we can't evoke some new force to explain the laws of complexity, then we have make do with the four fundamental forces. But we know that they are time symmetric and cannot explain an evolving universe. What to do?

Prigogine faces that one straight up. He recasts classical and quantum dynamics at the fundamental level to break the symmetry of time. He has not finished his work. It will take decades more. But his intention is a recasting of modern science within the context of complexity. This will be the subject of the next two sessions.
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FROM BEING TO BECOMING

Complexity: A New Science For A Postmodern World
Lecture notes for week #7, May 20, 1998
by Larry Edwards, ledwards@sasq.net
Reading: Prigogine 7-9 (70)

"In any attempt to bridge the domains of experience belonging to the spiritual and physical sides of our nature, time occupies the key position." --A. S. Eddington

Here is one way to think about what Prigogine is trying to do. Our primary mission is to have a deep relationship, to enter into communion with the real. To fulfill our humanity we must establish a meaningful relationship with the cosmos. Then, out of that can come our spirituality or religion. We live in a culture of ideas, or abstractions. These are very powerful, to be sure. But we live disconnected from the great powers of the Earth, from the storms, from the temperature, from the waters, from the night, from danger. Our culture and our cultural myths are of transcendence, of being outside of. These myths tend to obscure the temporality of our existence. You may not believe these myths consciously; but you live in them. And so do the scientists. Over the last 400 years scientists constructed a paradigm, a world view, an abiding mythology in which time is not real. Time is an illusion. Prigogine is saying "Look around you. What is your own experience? Time is real. Time is not only real; it is dominant." If we are to base our spirituality on what is real, then we must live in time. We must live and think in the real.

The three assigned chapters of Prigogine for this and next weeks will be a challenge for some of you. But it is very important for a clear understanding of the present state of our culture as well as the scientific establishment. In these chapters Prigogine suggests a fundamental reformulation of both classical and quantum science. While we don't need to go into all the details, we can go over his analysis enough so that you can understand the fundamental issue. It is an opportunity for you to understand the very foundation of science today. But it will take a little focus to set up.

The basic question is how to reconcile the world of dynamics and the world of thermodynamics, the worlds of being and becoming.

Classical science sought a complete timeless description of reality, an objective view in that it contains no reference to the observer. The universe was out there. You, I, and God observe it. It functions independent of the observer. Its development depends only on the Newtonian dynamical laws and the initial conditions. It is a beautiful, calm, dependable, stable model of reality. It fit in nicely with the reigning world view of an all powerful, all knowing transcendent God. God was all powerful; the laws of dynamics were all powerful. One would expect clear and all powerful laws from an all powerful God. The dynamical laws were timeless; time was an illusion. One would expect that from a God that transcends time. If ultimate reality transcends time, then time must be an illusion. It all fit together quite nicely. It did have a nice advantage in that humans graduated to a more God-like, more transcendent position in the sense of perceiving the world, at least conceptually, from a timeless, external frame.

But Einstein taught us that we live in an evolving, expanding universe. Now we observe very strange, very complicated processes in the heavens and on Earth. We now find that stability and simplicity are the exceptions, not the rule. The systems that classical science were based on, the pendulum, falling bodies, planetary motion, are exceptions in a complicated world. Simplicity is not the hallmark of the fundamental. These observations present a challenge for the scientific model of the universe and, perhaps more importantly, for the cultural model of reality. I might just interject that the scientific models have changed drastically while the cultural models have been much slower to evolve.

Now we might think that dynamics appear not simple, i.e., predictable, because we don't have enough knowledge of the initial conditions. The laws are deterministic. So accurate prediction requires complete knowledge. This is true. We talked about this during the first session. This is the situation of sensitive dependence on initial conditions. We saw in the video how initial starting points grouped very close together eventually diverge. This was using the Lorenz equations and the graph was the Lorenz attractor. This sensitive dependence on initial is true and important, but not fundamental. One could insist that we could approach complete knowledge as an ideal. We do this in Calculus when we go to ever smaller increments of some variable and then say that in the limit of ever smaller increments, such and such is true. Such an approach does not shed any new light on reality, on any limitations on the laws of dynamics.

Thermodynamics, relativity, and quantum mechanics are all rooted in the discovery of impossibilities, of limits to classical physics. Cannot create energy. Entropy increases in every process. Information and mass cannot travel faster than the speed of light. Momentum and position cannot be measured arbitrarily precisely simultaneously. All these are limitations on the transcendence and disconnectedness of the observer, and the timelessness of the dynamical laws. So we will follow Prigogine's development of a new limit which leads to the breaking of the symmetry of time, i.e., leads to irreversibility. That is, he will develop a new limitation on classical dynamics, a new impossibility. It is the impossibility of going backwards in time.

One of the fundamental requirements of relatively theory is that a scientific description must be consistent with the resources available to an observer who belongs to the world it describes and cannot refer to some being who contemplates the physical world "from the outside." This requirement does not follow from anything. It is a guess, a guess as to how the universe works. A guess as to what are the characteristics of the universe. Similarly when Einstein "required" the limit of the speed of light on the propagation of signals, this was again a guess, a hypothesis, to be confirmed or disproven by experiments. These guesses, these requirements have stood the test of thousands of experiments for over 90 years. You must understand that these experiments were set up, essentially, to refute or at least allow the refutation of these requirements and the measurements were very accurate.

There is no universal constant in classical physics. This is the reason for its claim to universality, why it can be applied at all scales. Like Einstein's speed of light c, Planck's constant, h, sets up a natural scale according to an object's mass. So the universality of classical physics is lost. We observe different behavior at high speeds than at low speeds. Also different behavior of large and small masses. The result is a different formulations of the dynamics in the different regions. The good news is that Einstein formulated his dynamics so that in the limit of low speeds, they become the same as classical Newtonian dynamics. The bad news is that the dynamics of small (quantum) systems look very unlike and do not become like the dynamics of large systems. This has been the situation for a half of a century. Prigogine does not accept this situation.

Relativity was formulated from the point of view of a real human observer in a given reference frame. As Prigogine says this gives it a "human" quality. However it is not subjective, the result of our preferences and convictions. It remains subject to intrinsic constraints that identify the human observer as part of the physical world it is describing. Quantum physics takes a somewhat different approach.

Planck black body = exchange of energy between matter and radiation occurs in quanta. Einstein photoelectric effect. Wave-particle duality $E=hv$, $p=hk$

Bohr model of H atom.

Remember how Einstein "guessed" that the speed of light was a limitation. In quantum physics another "guess" was made. Again this guess has been verified by thousands, even hundreds of thousands of experiments. The guess was that we can represent a classical quantity like energy by a quantum mechanical operator. This was, and is a very strange notion.

Explain operators. $f(x) = \exp x$, $f(x) = 2\exp(2x) + 3\exp(3x)$.

Explain eigenfunction, eigenvalue.

The basic concept of quantum mechanics are: to every physical quantity, like energy, momentum, position, angular momentum there corresponds in quantum mechanics an operator, and the numerical values that may be taken by this physical quantity are the eigenvalues of this operator. Note the distinction between the physical quantity (an operator) and the values the physical quantity can take (eigenvalues).

Heisenberg's Uncertainty Relation

The operator which correspond to position x and momentum p are x and d/dx. A very interesting and important property of these two is that they do not commute. That is, x d/dx does not give the same result as d/dx x. Show example operating on exp x. Since x and p do not commute, they cannot have common eigenfunctions. Therefore there is no quantum state in which they both have well defined values. This is the Heisenbery uncertainty principle.

The result is that the concepts that form the basis of classical mechanics are profoundly altered.

There have been many that have interpreted this as a result of a perturbation in the measurement process. It is easy to understand why scientists and others would want this to be so. This would preserve classical physics. It would preserve their intuitive understandings of position and momentum. It would mean that really there are well defined positions and momenta. We just can't measure them because we are experimental klutzes. But that cannot be fundamental. We could always do a better job tomorrow in making our measurements. No, it is not the measurement process. It is the wave-like nature of matter, first enunciated by Einstein, that is the culprit.

Now here is the interesting part. When I make a measurement, I must choose what to measure. But therefore, by the uncertainty principle, I must choose what not to measure. So I make my measurement and therefore know something about the system. But I have chosen what to know and what not to know. I can't know everything simultaneously about the system. Do you see how different this is from the classical perspective? In classical physics I can measure everything simultaneously. In fact I really don't have to make any measurements. I just start with the initial conditions and calculate everything. But in quantum mechanics I must make a measurement even to get the initial conditions! And I cannot get all the initial conditions simultaneously! But the important point philosophically is that even though I pick what I want to measure I cannot pick what numerical value I will measure. That is not subject to my wishes.

The dynamical equation of quantum mechanics is called the Schroedinger equation. It is an equation involving the energy in its operator form and a function, the wave function, which contains all the information of the system. The wave function, Y, changes in time according to the Schroedinger equation. The equation is reversible and deterministic, just like in classical mechanics. Generally the wave function, Y, can be expressed as a sum of eigenfunctions of the energy operator, H. If we measure the energy, we get some eigenvalue of H. Beforehand we do not know what energy we will measure; but we can know the probability of measuring a particular value if we know the form of Y. That is, if we know in what way Y is composed of a sum of eigenfunctions of H. So the measuring process is probabilistic, not deterministic. Let's review. The time development of the wave function is time reversible and deterministic. The measurement process is irreversible and probabilistic. A very strange combination.

How is the measurement process irreversible? Once we measure the energy and get some eigenvalue of H, we know the system is now described by the eigenfunction of H that is associated with the eigenvalue we measured. So the system used to be in some state Y which was a sum of eigenfunctions and now is in a particular eigenfunction. We say the wave function has been collapsed by the measurement. Notice that now the system is completely deterministic because any subsequent measurement of energy will give the same eigenvalue. So our measurement caused an irreversible change from the initial wave function to the particular eigenfunction whose eigenvalue we obtained in our measurement.

Now Einstein and others did not like this probability part. In a letter to Max Born he made this famous statement "You believe in a God that plays dice and I in complete law and order." But as Prigogine points out in several places, there is no empirical evidence for Einstein's view.

In any case we have a strange combination of reversibility and irreversibility. The measurement process cannot be formulated in terms of any equation or formula. In particular it cannot be represented in the formulas or equations of quantum mechanics. Quantum mechanics is not complete in the sense of being able to be represented entirely mathematically. This has been and still is a major problem in quantum mechanics.

So classical mechanics and relativity are time symmetric, reversible. Quantum mechanics contains both reversible and irreversible aspects. Thermodynamics is very irreversible. There have been many attempts in the last 100 years to deduce a theory of irreversible processes from the laws of classical physics. The most famous is the attempt by Boltzmann because this led to a very common understanding of the relationship between entropy and probability. We will go over that. But overall the attempts failed. Prigogine's summarizing remarks are, "we will never be able to deduce a theory of irreversible processes that will be valid for every system that satisfies the laws of classical (or quantum) dynamics. There isn't even a way to speak of a transition from order to disorder!" Later he says, "Irreversibility, as has been repeatedly stated, is not a universal property. Therefore, no general derivation of irreversibility from dynamics is to be expected." And again, "We should therefore not be astonished at our failure. We have not yet formulated the specific features that a dynamic system has to possess to lead to irreversible processes." In the last chapter he will clarify those specific features. We will cover that next week.

What Prigogine clearly says is that irreversibility is not due to ignorance.

-end-

THE END OF CERTAINTY

Complexity: A New Science For A Postmodern World

Lecture notes for week #8, May 27, 1998

by Larry Edwards, ledwards@sasq.net

Reading: Prigogine 7-9 (70), Postlude

The title of today's session is The End of Certainty. Our view of certainty is intricately tied to our view of time. You have undoubtedly heard of C. P. Snow's two cultures. Many have spoken and written about these two divisions of the western world. They have been characterized primarily as a deterministic, reductionistic science and an intuitive, holistic humanities. Overhead. This is, of course, the Cartesian split between spirit and matter phrased in a slightly different way. Prigogine has something to say about these two cultures, something profound, I believe. So today before I go over the last two chapters I will mention an implicit implication of his work, that is, that the normal division between the two cultures is not as useful for understanding our modern dilemma as a simpler characterization, a division between two views of time, reversible and irreversible. Although not directly, Prigogine implies that the more powerful split is over the concept of time.

On the one hand are the time reversibles. They believe that time is reversible. Within the scientific community that includes classical science, to a large extent quantum mechanics, and relativity. Within the non-scientific community this would include most, if not all classical religions; philosophies involving unchanging, eternal forms or modes; and many belief systems and people who set themselves in an unchanging cosmos.

If time is reversible, then the cosmos is an abiding, reliable, constant place wherein processes seem to unfold. But these processes are an illusion because really, deep within the order of things there is no change. "There is nothing new under the Sun." Any process that seems to go forward in time could go backward in time. The future is known or could be if we had enough information about the present. This is the cosmos of certainty. There is an abiding order, abiding laws, abiding gods and goddesses, abiding forms, abiding human character, abiding certainty. The Sun rises and the Sun sets. The moon goes through her phases. The planets ride their eternal paths around the Sun. All is known or can be known. Amen.

Understand that this is an ancient belief system, a paradigm that goes back certainly to the beginnings of the patriarchy and perhaps before. Also note that determinism long precedes modern science. What scientists, and subsequently technologists and industrialists, introduced was the idea and realization of control, of controlling the non-human world for the enormous benefit of humans. That desire has been phenomenally successful and has literally changed the face of the planet. With the knowledge and theories developed in this crusade against the Earth the western world has taken control of the biological, chemical, and to some extent the geological processes of the Earth. Many believe that it is just a matter of time before we humans attain Godhood and control not only this planet but the entire galaxy.

On the other hand are the time irreversibles. Thermodynamics, evolution, process philosophy are the main proponents that I know of. Time goes only forward, at least in real world processes. The future is not known. It is not knowable, not even theoretically. The process of the cosmos is unidirectional, and it is happening now and only now. In fact the definition of now might be when the universe process is happening. The Sun rises, but it is a different Sun every morning. It is a different morning every morning. Each moment the universe recreates itself. Each "thing" is a process. Each process is the recent manifestation of an infinite number of previous processes as well as the birth of an infinite number of unknown future processes. This is the universe of uncertainty.

Recognize this dichotomy? It is our old friends Cosmos and Chaos again. Overhead. It is Certainty and Uncertainty. It is also the Old Story and the Universe Story. Yes, it is, once again, a matter of story, a matter of what assumptions we impose on the universe.

Prigogine is saying that many of the current assumptions that most scientists make about the nature of dynamical systems are not as universal as commonly held. As a result it is the End of Certainty.

Too bad. I rather enjoy certainty.

The first point in chapter 8 is the famous Boltzmann development of the relation between entropy and probability. Prigogine does this using the Ehrenfest urn model. I will first follow his text on page 123. Then I will extend it to an equivalent physical model: a dilute gas in two boxes. It is a bit less abstract. [Overhead.]

Two boxes. N particles total, say 8 particles. Only one way of 8 particles in one box. 8 ways to put one particle in one box and 7 particles in the second box. Each way is called a complexion. So we say that there are 8 complexions to the one distribution consisting of one particle in one box and 7 particles in the other box. There are 70 complexions (8!/4!4!) in the distribution of 4 particles in each box. If you had your eyes closed while someone distributed the 8 particles randomly in the two boxes, you would bet that the distribution would be even, i.e., 4 in each box. You would bet that because that is the most probable distribution because it has the highest number of complexions.

Now consider a few grams of a gas in two connected containers. A few grams of a gas contains some 1023 molecules, a very large number. If the initial condition is that there is an asymmetry in the distribution of the gas molecules in the two boxes, then the system will go toward evenness, equilibrium because that is the configuration with the greatest number of complexions, the greatest probability. For example, suppose there were 1023 + 1 particles in one box and 1023 - 1 particles in the other. The probability for this configuration relative to the symmetric configuration is 1023 / 1023 +1. This is a little less than one, but not much. What about the probability for a millionth of a percent change? The probability for this is ten to the minus 107 . This is a very small number. In other words it is extremely unlikely that there were be a spontaneous millionth of a percent change in the symmetric, i.e. equilibrium configuration. In this and other such derivations Boltzmann derived the famous equation, $S = k \log P$, entropy is equal to a constant (Boltzmann's constant) times the logarithm of the probability. This is probably the most widely held understanding of entropy among scientists. As Prigogine repeatedly says, this view makes the second law important practically, but unimportant conceptually.

Chapter 9 is entitled "Irreversibility - The Entropy Barrier". In it Prigogine explains his new interpretation of entropy. His development is as follows.

In the macroscopic world we experience reversible and irreversible processes. Therefore neither reversibility nor irreversibility can be universal. But since we know that large systems, especially gases for example, consist of microscopic interacting parts, something in the microscopic world must manifests as irreversibility. The question is what is the microscopic property that manifests as entropy, as irreversibility?

Entropy is often called the Arrow of Time. But, as Prigogine points out, there are many process which manifest an Arrow of Time but cannot be easily associated with entropy. Popper gives a simple example of such a unidirectional process. Consider a disturbance in the middle of a pond. The circular ripples expand outward. We would find it very strange to see circular ripples contracting inward. It would be impossible experimentally to arrange such an event. Another example is the expansion of the universe. This is a unidirectional process but is not associated with entropy.

The key is to realize that while the equations of motion are symmetric in time, the solutions need not be. The requirement is that any such symmetry breaking solutions must occur in pairs. That is, if there is a solution that goes to equilibrium in the future, there must also be a solution that goes to equilibrium in the past. Now only certain kinds of systems will have such pairs of solutions. When there is such a pair of symmetry breaking solutions, then the second law can be stated as a selection principle stating that only one of the two solutions is permissible, that is, can be realized or observed in nature. Notice that this selection principle is just stated. A similar type of principle is Einstein's statement that no signal can propagate faster than the speed of light. It was just a statement by Einstein, to be substantiated or disproven by experiments. So is this selection principle of Prigogine's.

Well, the first thing to figure out is what kind of classical systems exhibit these time symmetry breaking solutions. Obviously, a pendulum does not have such paired solutions. It is chaotic systems, systems that have a sensitive dependence on initial conditions that exhibit these paired time symmetry breaking solutions.

Let's consider the example of the Lorenz equations. Overhead. You remember how in the video they showed how four initial points in the phase space gave rise eventually to four very different trajectories. Let's consider one of those trajectories. We watch it run for a while and then stop the process at some time. We note the point at which the system stops. The paired time backward solution would be one that has as its initial point the final point of the forward solution. Now this is easy to say but hard to do. We have to know the final point of the forward solution exactly, with infinite accuracy. Any discrepancy will lead to missing the initial point of the forward solution. That would not be the paired solution. You see the difficulty. Going forward we just pick some initial starting point. It doesn't matter how accurate it is; we just pick it for whatever reason. But for the backward solution we must pick our starting condition infinitely accurately. This second solution is excluded by the second law. Technically what is excluded is the initial condition because it would take an infinite amount of information to realize it. Its information content would be infinite.

Contrast this to the $t = -t$ for the pendulum. If we start the backward solution at a point that is slightly off from the end of the forward solution, it makes no difference. The trajectory will still go through the initial point of the forward solution. The second law cannot be applied as a selection principle.

But wait you say, "Maybe we cannot prepare an initial state with infinite information content; but maybe we can get arbitrarily close as we get technologically more proficient in the future. Thus the second law would get less important in the future." I asked this question during the first lecture in the form, "Could God(dess) know enough to prepare a state with such precision that it would be totally predictable forever?" The second law will not get less important until we reach infinite accuracy and then it becomes irrelevant. Here we jump between what is practical and some hypothetical "supreme mathematician" as Poincare called it. Notice that the assumption of the existence of such a supreme mathematician, a god(dess) who transcends time and space puts us right in the camp of the reversibles. But no matter, let's see if it is possible. The Heisenberg uncertainty principle, that is, the wave nature of matter, places a limit on the accuracy of positions. Also space itself is quantized at around 10-35 cm. Either way there is a theoretical limit on the accuracy of knowledge of position. Now 10-35 cm may seem small to you but it is very far from infinite knowledge of position.

For a chaotic system any region of phase space, no matter how small, contains an infinite number of different trajectories. We must use statistical methods to calculate the motion of the system. We can never know what exact point the system started in. Therefore the second law excludes the backward solution and establishes the Arrow of Time going into the future.

Another way of saying it is that all initial conditions with finite information content are allowed. Initial conditions with infinite information content are not allowed. This is called the infinite entropy barrier.

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FRACTALS: IMAGES OF COMPLEXITY

Complexity: A New Science For A Postmodern World
Lecture notes for week #9, June 3, 1998
by Larry Edwards, ledwards@sasq.net
Reading: Briggs & Peat: Chapter 0, Capra: Chapter 6

Fractals represent a new synthesis of art, science, and mathematics. This is amazing since fractals are in one way very simple objects. The are mathematical objects which have the special property of being self-similar upon magnification. Thus when we magnify a fractal we see the same pattern. A very easy to understand property has resulted in very different understanding of form, both mathematical and physical.

The great learning from fractals and other aspects of complexity theory, is that the old idea that simple relationships result in simple forms and complex relationships result in complex forms is not true in general. Fractals are an example of where a simple relationship results in a very complex form. We have seen this before in, for example, the logistics equation or in the three body gravitational problem. Conversely we have also seen how complex chemical reactions such as the BZ reaction can exhibit simple oscillatory behavior.

But let us continue with fractals. Now actually most people don't require that an object has to be truly self-similar at all scales to be a fractal. Sort of self-similar and then maybe not at all levels of magnification but often only over a range of magnification is good enough. One definition is the following. A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale.

The word fractal was coined by Benoit Mandelbrot in the early 60's. The root meaning is to break, to create irregular fragments.

Since fractals are mathematical objects they can be generated algorithmically, that is by following an algorithm, a set of equations or steps. Many mathematical fractals look amazingly like real objects. I showed you one example of these "fractal forgeries," this fern leaf. Show fern overhead.

Fractals have an interesting property: they are of non-integer dimension. Mandelbrot discovered this when he asked the question, "How long is the coastline of Britain?" I went through this in the first session. Remember? The issue is that the length you measure depends on the unit length you use, be it one hundred miles, one mile, one yard, one foot, one inch, or 10-8 inches. The fractal dimension of a coastline is a measure of the roughness of the coastline. The fractal dimension of a real object will vary as the measuring unit changes.

In the first session I showed you a classical mathematical fractal, the Koch snowflake. Show Koch overhead. Explain how to create it. This is a true fractal. It has a fractal dimension of 1.26... .Notice that the perimeter is 3 x 4/3 x 4/3 x ... which is infinity. But it is inside a circle with a perimeter of about 9 and area of about one. So the area of the Koch snowflake is less than one but it has an infinite perimeter. It is a two dimensional (geometrically) finite object with an infinite perimeter. How is that possible? This is one of the values of the concept of a fractal dimension. It allows us to talk about and have insights into such strange objects.

There are many, many fractals. They are all over the Web. Check out the file, sci.fractals FAQ on the course Web page.

The most famous fractal is the Mandelbrot Set. Here is a picture of it. Mandelbrot Overhead. It is closely related to what are called Julia sets. Julia Overhead. To understand how these relate we need to finish our math requirement. We need to go over very briefly complex numbers.

Complex numbers

Set up real and imaginary axes and explain. Go thru addition, subtraction, and multiplication (skip division). Do examples of iteration z1 - z02 + c.

Julia sets

Given a constant, c, do the above iteration for all z0. If the iteration for the starting z0 stays bounded then that point is a member of the set. Show Julia overhead. Some Julia sets have all their z0's connected. For some the z0's are disconnected. Amazing variety. Show computer program. So there is one Julia set for every complex constant c. So every point in the complex plane has an associated Julia set. That Julia set can be connected or disconnected.

Mandelbrot set

It is the collection of all values of the complex constant c for which the corresponding Julia set is connected. Back to Mandelbrot overhead. There is only one Mandelbrot set. There are an infinite number of Julia sets. At first glance it looks like we have to construct the Mandelbrot set by iterating all starting values of z0 for a given c. That is, it looks like we have to actually construct the Julia set for a given c and then see if that Julia set is connected. If it is, then the given value of c is a member of the Mandelbrot set. This would be an enormous undertaking. For every value of c (and there are an infinite number of them) we would have to do the iteration many times for an infinite number of starting values of z0 until we can determine whether or not the Julia set is connected.

Fortunately, Gaston Julia himself proved that all we have to do is to do the iteration for the single value of z0, z0 = 0. If the iteration is bounded, then the Julia set is connected and the value of c is a member of the Mandelbrot set. That is much simpler and doable on today's high speed computers.

Examples of Julia sets. Take c = 30. Start with z0 = 20. Diverges quickly so not a member of the Julia set. Then z0 = -20. Diverges quickly also. How about z0 = 0? Diverges quickly also. Can conclude that there are no real values of z which are members of the Julia set for c = 30. How about z0 = 2i? Diverges.

Try c = 1. z0 = 0. Diverges. Try z0 = 1 + i. Doesn't diverge (maybe).

Now look at these two Julia sets, c = 30 and c = 1. Both are disconnected because the point z0 = 0 is not a member. That is, iteration of the point z0 = 0 diverges, is not bounded. So neither one is a member of the Mandelbrot set.

Try c = -1/2. z0 = 0. Converges. So this Julia set is connected and c = -1/2 is a member of Mandelbrot set.

Here are some overheads of a zoom into the Mandelbrot set. Show other overheads of Mandelbrot set.

Zoom around Mandelbrot set on computer. Show corresponding Julia sets. Look in the area as suggested in B&P around with real part between 0.26 and 0.27 and imaginary part between 0 and 0.1.

I just want to make one more point before watching the fractal video. I want you to be alert to a certain kind of vagary. That is, the confusion, accidental or purposeful, between mathematics and the physical world. Briggs & Peat scramble the two together much too much for my taste. Let me just give you a few examples so you will be sensitive to the issue. One good example is on page 94 of Briggs & Peat where they state that the true coastline of Great Britain is infinitely long, the same therefore as the coastline of any island. This is, of course, not true for a real, physical island. It is true for a mathematical, rough island like the Koch snowflake. The problem for the real coastline is that the definition of the coastline changes each time you change the scale of measurement. If we establish just what is the coastline first, then we can measure it, in principle, accurately and it will not be infinite.

Similarly they mention an "ever branching" human lung on page 95. A human lung is not every branching. It branches over several orders of magnitude. Then it stops branching. The concept of a fractal dimension is very useful in understanding a human lung but its usefulness is exhausted at some point of magnification.

A similar confusion arises with the Peano curve they present. It covers the plane in the sense that any point you can name it will pass through. But at the same time there will still be an infinite number of points through which the curve does not pass. The question is of infinities and the time it takes to make the curve pass through.

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AT HOME IN THE UNIVERSE

Complexity: A New Science For A Postmodern World

Lecture notes for week #10, June 10, 1998

by Larry Edwards, ledwards@sasq.net

Reading: Kauffman chapters 7-12

"A butterfly is far more beautiful than our knowledge of our universe. But it may take that knowledge to appreciate the butterfly's beauty."

Since you are starting to think about what you will do for the final, this is a good time for a review. So I would like to take some time to pull together the various approaches we have been studying.

We have studied a variety of approaches to complexity or chaos theory: Prigogine's mathematical (baker transformation) and physical (dissipative structures and bifurcations) insights; the logistics equation; weather and the Lorenz attractor; and Kauffman's Boolean networks. One of the difficulties in reading four different texts is the issue of different vocabulary and approaches. Sometimes it is not clear just how all the approaches interrelate. So now is a good time to review and correlate all the approaches. Overhead on aspects.

Here is a brief summary of the aspects we have studied.

Math System	Physical System	Attractors?
Baker transformation	--	No attractors
Lorenz equations	Atmosphere	Lorenz attractor
Logistic equation	Predator-Prey	Many: period doubling x = Kx(1-x)
Brusselator	Brusselator	Many: waves, oscillations</TD
Boolean network	Genetic Network	Many, depend on N & K

Note that the systems with attractors, that is, all but the baker transformation, have internal feedback, both positive and negative. The baker transformation has no feedback and no attractors. A system must have feedback loops to have attractors.

Any dynamic system may have attractors. That is, its trajectory in its phase space may in time become limited to a subset of its entire phase space. (Question: what is time for the Baker transformation, for a Boolean network? Note that in these cases time is an operator. Time operates on the present and produces the future. This formalism is key to understanding Prigogine's formulation that formally breaks the time symmetry. You remember from the very brief session on quantum mechanics that the operators for momentum and position do not commute giving rise to the Heisenberg Uncertainty relationship. Similarly in this approach the time operator does not commute with the energy operator giving rise to a new uncertainty relationship. This breaks the time symmetry. More on that in the advanced course.) The system may have several attractors but will eventually settle into one. Which one will depend on the initial boundary conditions. The attractor may be a point attractor, a periodic attractor, or a strange attractor. So the system will be "stable" in that it settles into some "reasonable" trajectory.

A dynamic system may not have any attractors or it may have them potentially but not settle into any one given its present boundary conditions.

If we change the system boundary conditions, then the system will change. If its trajectory in phase space doesn't change at all then we probably were and are still at equilibrium or a point attractor. Most systems' trajectories, however, will change. The system could switch from an attractor to chaos, ie, no attractor; from one attractor to another attractor; from chaos to an attractor; or it could remain in the original attractor, ie, it was and is still stable. Examples from logistics equation. Logistics Overhead.

Now what is the process of changing the boundary conditions? Some parameter is varied: size, temperature, pressure, reproduction rate, concentration of some reactant, etc. This is what Prigogine calls a control parameter. In the logistics equation we vary the reproduction rate, K. A different K corresponds to a different system, that is, a different kind of rabbit (or trout). Logistics Overhead In the Brusselator reaction we may vary the concentration of one of the reactants.

If the system remains in its present attractor as the parameter is varied, then we say that the system is stable or homeostatic.

At some point in the continued change of the control parameter a point is reached where the current attractor is no longer stable. This is a bifurcation point. The system now can switch to a different state which is then attracted to a new attractor in phase space. There may be only one possible new attractor or many. Often there are two, especially in physical system. Logistical equation as example. Overhead. Actually this example is very general. It is called period doubling and is a very common bifurcation leading eventually to chaos. Note that the shape of a system's attractors are very dependent on the system's boundary conditions. That is, a far-from-equilibrium system's dynamics are very specific to its boundary conditions as well as to its internal processes, its identity.

Finally let's be sure we are clear on the difference between a dissipative structure and a strange attractor. A dissipative structure is a physical system which satisfies the following three conditions:

1. It is far from equilibrium.
2. Energy and matter flow through it.
3. It has a central self-amplifying, i.e., positive feedback loop in it.

A strange attractor is a form in phase space to which the trajectory of a system is attracted.

A living organism is a dissipative structure. If we were to plot its trajectory in its phase space, we would find it to be a strange attractor. There are many phase spaces we could pick for a complicated organism. For example, we could plot the momenta and positions of all the atoms or of all the molecules. In either case we would find that the trajectory does not go everywhere. That is, the atoms and molecules do not spread out over all space, at least until death. On the contrary, the atoms and molecules are highly correlated but not at all fixed. We could plot other variables of the organism: temperature, concentrations of proteins, etc. In all these cases we would find that the trajectory does not fill all of the phase space. It is very limited; but not repetitive.

Now you are looking around to apply these concepts to some discipline or system. I assume that you will be looking at human systems of thought or activity. The key will be to look for the feedback loops. If it were a physical system, then you would look for far-from-equilibrium and flows of energy and matter. But by definition human systems satisfy these two criteria. So the important one is the feedback loop. There must something analogous or homologous to positive and negative feedback loops. The negative feedback loop is that which somehow defines, that is, stabilizes the system so that it has an identity. For example, a whirlpool has an identity, even though it is composed of exactly the same substance as its surroundings.

There must also be a positive feedback loop. This determines the "sensitivity" of the system. As Prigogine says, matter at equilibrium is blind; at a bifurcation point it 'sees.' That is, under certain conditions a simple physical system is extremely sensitive to its surroundings and reacts to it. The positive feedback loop is what gives the system its creativity, its volatility, its unpredictability. In the example of the whirlpool the positive feedback loop is what starts it, what senses that the conditions are right to spring into existence, what roars away and, if unimpeded, would result in total destruction of the system. But then the negative feedback comes in and stabilizes the system.

So complexity is about systems, something identifiable in terms of its organizational structure. Let's think of some systems which may be complex, that is, may obey the "laws of complexity." Clearly a culture could be a complex system. There are negative feedback 'forces," citizenship, patriotism, language, for example, which give an identity to and constitute the system. There are many positive loops: styles, selection of enemies, language (both positive and negative feedback), etc.

For the rest of today's session we will go over the last half of Kauffman's book. It is quite appropriate because it concerns not just his theory of the role of complexity in the evolution of life but also his speculations on how his theory could be applied to the evolution of technologies. This is a good example of applying complexity theory to some other field.

The central subject of this development is Fitness Landscapes. They are very related to the Boolean networks we studied earlier. But they are one step more abstract.

Before going into fitness landscapes, let's first review Kauffman's main thesis. It is that Neo-darwinism is incomplete. Neo-darwinism holds that selection is the sole source of order in biology. Without selection there would be no order, only chaos. Thus any form that evolves under these circumstances is the product of chance, happenstance. "We the unexpected; we the very lucky." Life, especially we humans are lucky to be here. Any small accidental difference in the past would have resulted in a totally different world. Maybe we wouldn't be here; maybe we would in different form. Kauffman is looking for a understanding of the universe and of the evolution of life, similar to Prigogine, in which life and, in particular, human life can be seen as a natural expression of tendencies toward order in a far-from-equilibrium universe. Kauffman theorizes that some, perhaps most of the order we observe in living organisms comes from the order inherently manifested by a genetic regulatory network, especially when such a network is coupled with other networks. This is an understanding in which the origin of life, the order of ontogeny, the poised order of ecosystems are all "order for free." That is, the order is not determined by "the invisible hand" of selection but emerges from the dynamics of life itself.

It is important to remember, and Kauffman reminds us several times, that what he presents is a theory - a very audacious theory. His theory challenges a strong belief of most evolutionary biologists. In any case Kauffman presents a theory. It is not accepted. Indeed there is little, as yet, experimental confirmation of his theory except

for computer simulations. But it is a very enticing theory.
So what is a fitness landscape? Picture a flat landscape with a grid on it. Let's say the lines of the grid are 1 meter apart. At each intersection of the grid there is a positive number. Now imagine distorting the landscape so that each intersection of the grid is elevated to the height indicated by its number. Thus we have a vast series of sharp peaks, ridges, troughs, and valleys. The fitness is given by the numbers. So the hills are higher fitness. A genotype, a particular set of genes, that is, an organism is represented by a point on the grid. Adaptation is the process of climbing up hills, i.e., increasing fitness. Natural selection pulls an adapting population up toward the peaks. A mutation (random change of one gene in the genome) is a test by an organism looking for better fitness, a higher position. If the mutation results in better fitness, the entire population is pulled eventually to that greater height.
Conceptually this picture of a fitness landscape will do; but no fitness landscape looks like this. They are of much higher dimension. The dimensionality is the number of genes in the genome. For a very simple bacterium that is over 3,000. For humans it is about 100,000. So it gets a bit difficult to visualize; but the principle is the same.
Let's consider in some detail an artificially simple fitness landscape. Overhead page 165. We have a genome of 4 genes. So there are 16 genotypes. Each genotype is a neighbor to those genotypes which differ by one allele. We need four dimensional space to show this properly. So Kauffman shows a 4-D hypercube projected into 3-D space. It will have to do. Now here is the key. We need to assign a fitness to each genotype. Let's assign fitness at random. Note the fitness peaks. To adapt the organism wants to climb up from where it is. So starting with a given genotype a mutation is adaptive if it leads to a more fit genotype.
This is a random fitness landscape. No organism can evolve on a random landscape. The problem is local peaks. The organism cannot get beyond a local peak. Even worse, though local peaks are close they are hard to get to because the number of uphill possibilities drops by 2 after each step. No local clues exist to detect directions toward distant peaks. The higher a genotype is, the fewer hills there are to ascend and the fewer ways there are to get to them. So it takes longer and longer. The general intuition, as Kauffman puts it, is that not all complex systems can be achieved by adaptive search in a reasonable time.
There is too much variation on a random fitness landscape. Real fitness landscapes are correlated. The states close together have similar heights. There are clues as to which way to go up the fitness peaks. To model such a correlated fitness landscape Kauffman uses a model very similar to the Boolean network model of the genetic regulatory network, . The big difference in models is that K, instead of being the number of inputs into one gene, is the number of associated genes which contribute to the fitness of the gene in question. For example, suppose that one gene controlled how opposable my thumb is. Then the gene that affects my muscle strength will affect how useful my opposable thumb is. So that muscle gene is one of the K genes associated with the fitness of the opposable thumb gene. So we must assign, somehow, a fitness to each state of each gene.
The result is a correlated fitness landscape. Kauffman goes through the characteristics of these landscapes. An important characteristic is that the same gene may affect many other genes, some positively and some negatively, so that when it changes, there can be positive and negative adaptive effects. So the adapting organism must make compromises, seek optimal solutions, not perfect solutions. This model makes explicit the conflicts that must be dealt with in adaptation.
Most genetic mutation is one gene at a time. This is gradualism. It has effectiveness because it is limited to local peaks. To make real progress an organism needs a way to jump many genes to test far away from its present situation. The answer is meiotic sex, the mixing of genes from two different genotypes. Meiotic sex allows the changing of many genes simultaneously. Thus a population can test in big jumps as well as gradually.
A great advantage of Kauffman's NK model is that K is a tunable parameter. When K = zero each gene is independent. The landscape is very smooth. Mutations are independent of eachother and either raise or lower the fitness. In this kind of landscape it is easy for a population to move to the global maximum fitness. Just keep mutating and go with the mutations that increase fitness. Eventually the organism will reach maximum global fitness. The opposite extreme is where K = N -1. In this landscape every gene is linked to every other gene. It is a random landscape, completely rough. No evolution can take place on such a rough landscape. Kauffman shows computer experiments which show that the best roughness is found for K = 8 or so. Note that this is not the same as for the Boolean networks, where K = 2 was best.
One of the uses of this NK model is understanding a puzzling difference between the way life bloomed during the Cambrian and how it recovered from the Permian extinction. Some 550 million years ago there was what is called the Cambrian explosion. It was a great burst of evolutionary novelty. Essentially all the phyla of multicelled creatures came into existence then. Overhead on Biological classification. In something like 10

million years the structures of today's living world were invented. After the initial burst wherein the phyla were set, then classes, orders, families, and genera were filled in. That is, after the broad outlines of the new forms were set, then smaller changes were made becoming more and more detailed until the level of species. Kauffman's model is quite good at explaining this process. Long-jump (multiple genes) first, then middle, then local peaks.

Kauffman points out that technological evolution follows the same pattern. Take the example of the bicycle. Explain. Same pattern for many technological innovations.

We can contrast the Cambrian explosion to the flowering of life after the Permian extinction some 250 million years ago when 96% of all species died out. No new phyla or classes emerged. The rebound was from the bottom up, not the top down as in the Cambrian. The difference is that some orders, families, genera, and species were left and so were available to evolve into other organisms. The major traits that were already highly fit were already developed. Only relatively minor fitness adaptations were available to the newly emerging organisms.

Next we will use the NK model to give a broader view of evolution. We start with the individual organism. Each individual lives in a niche created by all the other organisms as well as by the weather, water cycle, etc. So an organism lives in a niche created by the Earth as a whole. That niche is part of the ecosystem that the organism lives in. Within this ecosystem the species evolve in concert with the other life forms and to a lesser extent with the nonliving members of the community. In the NK model the fitness landscapes of the species are coupled. That is, as one species evolves on its own fitness landscape it deforms the landscape of another interacting species. Of course, it is mutual. Kauffman uses the example of a frog that mutates so that it has a sticky tongue. Suddenly the fitness landscape for flies changes dramatically. What was fit before may not be useful now. What was irrelevant before, like a slippery body, may be of utmost fitness now. Of course, if the fly mutates to fly faster, then the frog's fitness landscape changes.

As you might guess Kauffman models this coevolution by connecting the genes of the two species. So now we have a NKC model where C is the number of genes of the other species that are associated with the fitness of a particular gene of the first species.

There are two possible extremes in this coevolution: the Red Queen behavior, a persistent arms race or an evolutionary stable strategy and then stop altering genotypes. The first leads to chaos. The landscapes change so fast that neither genotype can increase its fitness. The second leads to order, very much order, in fact a frozen regime. In between, on the edge of chaos is the creative range. And it is evolution that takes the ecosystem there.

Living on the edge of chaos is a dangerous, creative adventure. Because all the species in an ecosystem are evolving on coupled landscapes their fates are intertwined. If a species goes extinct it may takes others with it. In fact, it is possible that it could take the entire ecosystem with it. These insights have been given a theoretical basis in the theory known as self-organized criticality. Most of the research has been done on sand piles. But there has been a lot of observations confirming the results in the evolutionary record.

Imagine a sand pile in the middle of the floor. We have an inexhaustible trickle of sand coming down through the ceiling. What happens? We get avalanches every so often. How big? From little to big. How often? From often to rare. Empirically it is observed that if we wait long enough an arbitrarily large avalanche will take place. Also it is not known when any avalanche will take place. The future is totally unpredictable. What is known that there will be lots of small avalanches and fewer big ones and only rarely a giant one. But we cannot predict whether the next grain of sand will launch a small or large avalanche.

It has been found to be similar with the extinction of species, both empirically and in computer simulations. We cannot predict when a species will go extinct. When it does we cannot predict whether it will go quietly into nonexistence or take another species with it or take the entire ecosystem with it.

I quote Kauffman's last paragraph of chapter 10, page 243. "Here is Panglossian world, or Hobbsian either. Perhaps here is the reality we have always suspected. Do your best; you will ultimately slip into history along with the trilobites and other proud personae in this unfolding pageant. If we must eventually fail, what an adventure to be players at all."

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THE NATURE OF LIFE

Complexity: A New Science For A Postmodern World

Lecture notes for week #11, June 17, 1998

by Larry Edwards, ledwards@sasq.net

Reading: Capra chapters 7-12

The question for today is "What is life?" In my ninth grade science class I learned, as best I can remember so long ago, that an organism is living if it reproduces. Then there was a discussion of whether or not a virus is alive. And finally the exception to the rule, hybrid creatures like a mule. Since then I have seen many definitions of life. James Lovelock, author of the Gaia theory, made a list of several definitions in one of his books. It seems that different disciplines of science have different definitions. For example, evolutionary biologists include the capability of evolution as a requirement. As I remember physicists included the production of entropy. Lovelock's point was that there is no universally accepted definition of life. Certainly that is a strange situation! No definition for a most fundamental process.

Capra develops his own definition of life. It is a simple and very insightful definition. He draws mainly on the work of biologists Humberto Maturana and Francisco Varela as well as that of Prigogine. Here is his definition: Overhead

A living organism is: autopoietic (self-making) in its pattern of organization; a dissipative structure; constantly engaged in the process of cognition.

Capra is a little redundant here in that he says that the autopoietic criterion is sufficient, but then says that all three are criteria. We won't worry about establishing a minimal approach.

Let's go over the first two briefly, check out some of the implications and then consider the third, cognition is some detail.

The distinction between the first two criteria, pattern and structure, is an ancient one. Capra defines the two terms as follows [Overhead]

"The pattern of organization of any system is the configuration of relationships among the system's components that determines the system's essential characteristics.

The structure of a system is the physical embodiment of its pattern of organization."

The simplest way to understand these definitions is by an example. We'll use Capra's example of a bicycle. First is its pattern of organization. There must be functional relationships among its components for it to be a bicycle. The wheels must be connected appropriately to the cranks. The head set must connect to the wheel, normally the front wheel. Etc. All these relationships must be present for it to be a functioning bicycle. If the chain were connected to the saddle so that the saddle spun as the biker spun the cranks, we would immediately recognize that it is not a bicycle, even if it looks like a bicycle.

The physical embodiment of the bike's pattern of organization is the components. The components can vary considerably and still make a bicycle. There could be one saddle or two, big and small wheels, even three wheels, and it would still be a bicycle. What is important is that the components embody the relationships that make a bicycle. If components were weird, say a square wheel, we would recognize the pattern of organization as a bicycle but we would hesitate to call it a bicycle because the structure is wrong.

I want to point out here a possible confusion. The pattern vs structure is not quite the same as form vs matter. The components of a bicycle have a structure. They are not formless matter. The pattern vs structure question is one of whole vs parts where the parts are structures in their own right.

So the first criterion is that a living organism has a pattern and that pattern is a network, a network of parts which all function to maintain themselves and the whole. This is autopoiesis. A living organism is constantly creating itself. As Maturana and Varela say, "the being and doing of [living systems] are inseparable, and this is their specific mode of organization." Take a cell as an example. It has various parts: nucleus, mitochondria, chloroplasts, etc, which continually make each other and thereby make the whole. All the parts are engaged in this activity. The cell is self-making, autopoietic.

Since all components of an autopoietic network are produced by other components in the network, the entire system is organizationally closed, even though it is open with regard to the flow of energy and matter. This organizational closure implies that a living system is self-organizing in the sense that its order and behavior are not imposed by the environment but are established by the system itself. Living systems are autonomous but they are not isolated. They interact with the environment but these interactions do not determine their organization. They are self-organizing.

Autopoiesis is a process of processes of production of components.

A crystal is also a set of relationships among processes, molecules or atoms. Each of these molecules or atoms

are busily making themselves. But these processes (molecules and atoms) do not produce other components only themselves. So a crystal is not autopoietic. A crystal is not living, according to this definition.
The second criterion is that a living organism is a dissipative structure. We are quite familiar with dissipative structures so we don't need to spend much time on this. We know the definition of a dissipative structure:

- far from equilibrium.
- energy and matter flow through it.
- contains an essential positive feedback loop.

Before going over the last criterion, cognition, let's consider a few examples to see if we like these criteria.
Is a H atom living? A hydrogen atom is not autopoietic because the components, the electron and proton, do not make each other. They make themselves, but they do not make each other.
Is your fingernail alive? No. Your fingernail does not make itself. It is part of a living organism but it is not a living organism. Generally living organisms are composed of parts some of which are not living. For example, the nucleus of a cell is not a living organism. Multicelled organisms like you are composed of cells which are living organisms, but also may contain parts, like your fingernail, which are not living. Actually in the case of your fingernail we can say that it is dead. It once was living but is no longer. So it is dead. So the whole can be living while the parts are not. This may sound strange but it is normal. Remember life is an emergent phenomenon. The whole is greater than the sum of the parts. In this case the difference, the greater than, is life. The parts are dead; the whole is living.
Is your DNA alive? No. It does not make itself. DNA is part of the genetic regulatory network, which is a production process of a living organism. When combined with the other production processes of a living organism, DNA is produced, but only within a living organism. DNA does not make DNA by itself.
You have heard of "The Selfish Gene" I am sure. Many speak of the body as the genes' way of getting around. This is biological reductionism at its finest (or worse, as you please). As Maturana and Varela write, "The error lies in confusing essential participation with unique responsibility." DNA is essential for life but not uniquely responsible. Many other aspects of living organisms are also essential.
Is the universe living? Now this is tricky. It is certainly autopoietic, self-making. But it does not satisfy the normal definition of a dissipative structure: there is not matter and energy flowing through it (as far as anybody knows).
But we must be careful when we try to extend concepts and definitions to the entire universe. Conceptually it seems easy to do. You just make the concept as big as you can. But we do not understand the fundamental structure of the universe. We can play with concepts at the universe level but we must take any conclusions we come to very lightly.
The universe is alive because you and I are alive and the universe is an undivided whole. But we cannot say whether or not it is a living organism.
One of the arguments that a creationist makes for the existence of God is in the statement that if you went to a planet and found a watch, then you would conclude that there is a watch maker. Therefore there must be a life maker. But we might say, "Oh no, life makes itself. A living organism is autopoietic, self-making." But we would be slightly misrepresenting the situation. In these first two definitions we have not determined how the living organism came into existence. The first two criteria concern the properties, the dynamics of an existing organism. How organism came to be is another issue.
It is in Capra's third criterion, cognition as greatly expanded by Maturana and Varela, that is introduced the idea of changes in organisms in time, i.e., evolution. But again the concept is the evolution of living organisms. The question of how life started originally is not addressed.
I raise this little aside to emphasize that self-making is in the present. Cognition, as we shall see, does give insights into the past. But both deal with existing organisms. Neither deal with the origin of life, how life was created.
So now we come to cognition, the process of life, the continual embodiment of an autopoietic pattern of organization in a dissipative structure. This is identified by Capra as the process of knowing, mental activity. This is a very significant extension of what is normally considered mental activity. Maturana and Varela developed this concept over the last two decades in several key publications. The one that Capra most refers to is the book, "The Tree of Knowledge." This concept of cognition and the associated theory is called the Santiago theory because both Maturana and Varela were at the University of Santiago.
Capra puts this forward as the solution to the centuries old Cartesian division between mind and matter. In this understanding mind is not "the thinking thing" (res cogitans) of Descartes but a process, the process of life. Mind happens in the brain as well as elsewhere, in fact everywhere, in organisms; but it is not necessary for an

organism to have a brain for mind to exist. It is not even necessary for an organism to have a nervous system. It is only necessary that the organism be living. Mind is the process of living.

The key to understanding this, according to the Santiago theory, is structural coupling, repeated interactions of an organism with its environment leading to structural changes within the organism. Again it is important to keep in mind that the organism is autopoietic, autonomous. The environment can perturb the organism but the actual response, the change in the organism is determined internally, a product of the internal dynamics of the organism. Each response an organism makes is a structural change, a change in the organism's structure. Note it is not a change in the pattern of organization of the organism but a change in the structure. Every response of an organism to its environment is a structural change triggered by an environmental perturbation.

This constitutes a clear difference in the response to a given perturbation by a living or non-living system. Gregory Bateson used to point out that kicking a stone and kicking a dog elicit two very different responses. Now, a structurally coupled system is a learning system. Continual structural changes constitute both learning and adaptation, key characteristics of the behavior of organisms.

Note that within this theory the behavior of an organism is determined, not by the environment but by the organism's structure. And the determinism does not mean predictability. It does mean a great restriction in possible responses, but a particular response is not generally specified.

One way to think of this is to see an organism as a dissipative structure always very close to bifurcation. Large perturbations will almost invariably trigger a certain kind of response. Small perturbations, ie, normal life, will bring the system to a variety of bifurcation points where the response is not predictable.

The organism specifies which perturbations will trigger which structural changes. Thus the organism, in M & V's words, "bring forth a world." That is, by specifying which perturbations trigger which responses the organism is creating a world from the environment. This world is not a representation of the environment. It is also not independent of the environment. The organism brings forth a world based on its structural couplings with the environment.

[Overhead of mental representation vs solipsism.] It is necessary to walk or think a fine line here. The two extremes are on the one hand, that cognition involves a transfer of information from an independently existing world and results in a representation of an external world; and, on the other hand, that no such independently existing world exists and all cognition is internally generated. The one extreme is that the nervous system operates with representations of the world. The other extreme is that the nervous system functions completely in a vacuum, where everything is valid and everything is possible. These two extremes have been discussed for a long time. Today the tendency is toward the representational view, mainly due to the influence of the computer on cognitive researchers.

The Santiago theory holds that both of these extremes are traps, that an organism does indeed receive input from the environment, but it is not information but a perturbation. The response of the organism is determined by the organism's internal structure. So the response is internally generated but it is triggered by an external perturbation. Tree of Knowledge pg 74 "The cell unity classifies them and sees them in accordance with its structure at every instant."

Awareness of the environment is common to all organisms. All organism bring forth a world from their interactions with their environment. At a certain level of complexity an organism can also bring forth an internal world. In other words the organism can be aware of being aware. Capra uses the word consciousness to describe this mental capability. An organism is conscious if it knows that it knows. So consciousness is the special faculty of self-awareness.

There have been lots of studies done on animals to try to understand empirically this characteristic of consciousness. Maturana and Varela describe one experiment in which researchers put various animals in front of a mirror. Cats and dogs behaved as though the reflection was a different animal. Then they lost interest. Among primates a macaque behaved similarly, displaying most aggression. A gorilla will appear amazed and interested but eventually ignore it. The macaque and gorilla were then anesthetized and a small colored dot painted between their eyes where they cannot see it without the aid of a mirror. The macaque repeated its former behavior. The gorilla, on the other hand, put his hand on his forehead to touch the colored dot. We might have expected him to try to touch the colored dot on the gorilla in the mirror; but he touched himself, his own colored spot. Is the gorilla conscious?

There have been many experiments with animals in this field over the last several decades. Some of the most controversial have been around the subject of language. Do chimpanzees talk? Do they language.

In the Santiago theory language has a special definition. Let's start with communication. Communication is defined, not as the transmission of information, but as the coordination of behavior among organisms through mutual structural coupling. So an autopoietic entity structurally couples with its environment which includes another autopoietic entity, another organism. And vice versa. If the interaction results in mutual structural coupling, then there has been communication. Capra gives a beautiful example of Maturana of two parrots in a dense forest engaged in a mating song. It sounds as if one bird is singing; but actually one bird sings the first part of the song and the second completes the song. The parts vary as the bird get closer together. Remember they cannot see each other. The duet is unique to the couple.

Language occurs when there is communication about communication. Maturana has a story to illustrate this. Every morning my cat meows and runs to the refrigerator. I follow her and give her some milk. One morning I don't follow her because I know there is no milk in the refrigerator. She meows and meows. Now if the cat were to say, "Hey, I've meowed now three times. Where is my milk?" That would be language, communication about communication.

There has been considerable research on chimpanzees in this area. Maturana and Varela are convinced that chimpanzees have been taught to language. Most researchers in linguistics are unconvinced.

We, humans, exist in language. We weave a linguistic network in which we are embedded. To be human is to exist in language. Maturana says, "The world everyone sees is not the world but a world, which we bring forth with others."

Maturana theory of consciousness is very different than others. According to Maturana we can understand human consciousness only through language and the whole social context in which it is embedded. Consciousness is essentially a social phenomenon.

At this point I would like to hear your thoughts on this Santiago theory. I know I have given a very simple presentation of it. But it is enough to get the basics; perhaps not enough to understand their view on consciousness as a social phenomenon. I would like to hear your thoughts on the idea of an organism "bringing forth a world."

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SUMMARY LECTURE

Complexity: A New Science For A Postmodern World

Lecture notes for week #12, June 24, 1998

by Larry Edwards, ledwards@sasq.net

This course has been about the establishment of a new relationship between humans and the universe. Chaos theory or complexity is a radically new way of perceiving the universe. It is also a radically old way. It is a shift from quantitative to qualitative, from determinism to general understanding, from order as the source of creativity to chaos as a source of creativity.

Complexity is about emergent phenomena, the emergence of new forms and capabilities out of previous forms and capabilities. It is the very opposite of reductionism. This new science presents both empirical and theoretical evidence of very fundamental incompleteness in the reductionistic approach to understanding the universe. Complexity is about the development, the evolution of wholes. It is concerned with the basic formulation of the Universe, maybe even its very structure. It provides insight into what animates matter into life. It opens our western mind to a new relationship with the complexity of life that has existed on Earth for 4 billion years as well as the complexity in which we live out our individual and cultural lives.

It sets a context in which we can understand emergent phenomena not as epiphenomena, not as cosmic afterthoughts, but as a deep flow of the universe as a whole. Matter is an emergent property of energy. Life is an emergent property of matter. Mind is an emergent property of life. Consciousness is an emergent property of mind.

Complexity is the science of emergence.

Let's summarize what we have learned in our brief study of this new science.

1. Real world dynamical systems:

- are generally non-linear;
- are deterministic but not predictable;
- exhibit a sensitive dependence on initial and changing boundary conditions;
- can exhibit and maintain order far from equilibrium through the production of entropy;
- are correlated such that time symmetry is broken;
- are often homologous over a wide range of dynamics;

2. A new understanding of the evolution of life is developing. Some, perhaps most, of the order we observe in the living world is a manifestation of the complexity of genetic regulatory networks. The laws of complexity spontaneously generate much of the order of the natural world. It is only then that selection comes into play, further molding and refining.

3. A new understanding of the nature of life, mind, and matter. Living organisms are autopoietic. Cognition is the process of life. Mind is the process which takes place in the matter of a living organism.

4. Real world objects are often better represented as fractals rather than geometric objects.

I could summarize much of the course in one act: my drinking water. Water is not living. But given the appropriate boundary conditions, it springs into life, into consciousness. It is complexity, the science of emergence that gives us insights into how such an incredible property of the universe operates. Hopefully during this course you have gained some of these insights.

Our Great Work, as humans, has always been to have a deep relationship, to enter into communion with the universe. To fulfill our humanity we must establish a meaningful relationship with the cosmos, not only at the personal but also the cultural level. Then, out of that comes our spirituality. In the last several centuries we have lived more and more in a culture of ideas, abstractions. These are very powerful, to be sure, and with them we have been able to accomplish great works. But we now live disconnected from the powers of the Earth, from the storms, from the weather, from the waters, from the night, from danger. Our culture and our cultural myths are of transcendence, of being outside of. Our great mythological powers are outside the Earth and we, ourselves, also stand outside, over the Earth. These myths tend to obscure the temporality of our existence. Consistent with this mythology scientists have constructed, over the last 400 years, paradigm, a world view, an abiding mythology in which time is not real. Time is an illusion. Such a paradigm was totally consistent with our cultural mythology of a transcendent God. Ilya Prigogine, representing the field of complexity, says "Look around you. What is your own experience? Time is real. Time is not only real; it is dominant." If we are to base our spirituality on what is real, then we must live in time. We must live and think in the real, in how the universe actually functions.

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