**TALK by ralph abraham: calpoly, physics colloq, 3/89**

# CHAOS

**There has been a dialectic between chaos and cosmos, and between order and disorder in our culture and in the history of consciousness for at least 6000 years. (The use of the word chaos in the popular sense is not necessarily related to its use in the technical sense.) Without fail, this dialectic emerged into public controversy from time to time. The advocate of disorder, particularly in the solar system, but also in human affairs -- in politics, science, the natural world -- is always the villain, and the controversy usually ends with burning the advocate of chaos at the stake. An example of this dialectic is the social phenomenon of witch burning.**

**Sir Isaac Newton's views were widely published, but he prevented the publication of his deeper secrets so successfully during his lifetime that it was delayed for more than 250 years after his death. It is only in the past 20 years or so that his secrets have been revealed. To begin with, he was an advocate of chaos. Though he did not believe in the stability of the solar system as a consequence of his laws, F = Ma, he did believe in it on the basis of something else: Bible fundamentalism. In mid-career, after establishing F = Ma and its various consequences, and particularly his derivation of Keppler's third law, he became the master of the mint, and his endowed chair at Clair College at Cambridge, called the Lucasian Chair of Mathematics, was vacated; he was the second person to hold it. The first had been his teacher Barrow, and Barrow stepped aside as soon as Newton had his Ph.D.**

**He received an enormous salary and had almost no teaching to do -- one lecture a week, to which no one ever went because, I suppose, his lectures were so poor. When Newton was promoted to master of the mint, an even better position, because now he no longer had to give even one lecture a week, he stepped aside in favor of his best pupil, William Whiston, who became one of the really important figures in the history of celestial mechanics.**

**About the time that Izzy Newton became Sir Isaac, William Whiston became Poor Will. Here's what happened. Newton held a secret seminar at his house, and William Whiston, along with a few other famous luminaries, discussed heretical secrets about the instability of the solar system. News of these meetings was not supposed to pass their door, but William Whiston, Isaac Newton's best student who became the third occupant of the Lucasian chair, had a big mouth. Wherever he went, he blurted out anti-Trinitarian heresies and talked about a certain kind of instability of the solar system. Today, we would consider this quite reasonable, as it was caused by the passing of comets. He believed that the length of the solar year was modified from 360 days to 365 in 1000 BC or so by the passage of a comet. He believed that the formation of the solar system began with the first line of Genesis: And God created out of nothing, and that this Genesis creation myth began with the passage of the comet. Thanks to his big mouth, William was put on the carpet by the boss of his university and told to either deny all his anti-Trinitarian heresy, or leave. Whiston claimed that what he said was the truth and cited academic freedom in his defense. They called meetings of the campus committee on academic freedom to determine whether he should be allowed to speak freely, or would have to leave. Isaac Newton was on this committee, and he said nothing. He allowed**

**Whiston to go down in flames, and forever after -- this happened in 1710 AD -- William Whiston was known as poor Will. He moved to London, England, where he made a living as a hippie, giving backrubs and casting horoscopes. Only a century earlier, he would probably have been burned at the stake.**

**This long digression will, I hope, help to illustrate the parallel between 1710 and today, as well as with all the other revolutions in the history of science and of consciousness that have to do with the dialectic between cosmos and chaos. All of them, in the past 6000 years, ended in the same way. There is an orthodoxy of order, of cosmos, and of chaos that has been rejected by the church, by the scholastic doctrine of the Middle Ages, and by the scientific establishment that replaced it. To this day it holds the position of authority in the world of ideas.**

**Our intellectual history has been going on for a million or more years, and this last little section of six thousand years or so is no big deal, but we live in the period that began with the destruction of the goddess and the removal of chaos from the orthodoxy, and this is the main reason why the chaos revolution is so important today. Once you grasp this, it is easy to accept the idea that chaos is okay -- science won't be destroyed, and the solar system might even be more stable because it is chaotic. It is thought to be chaotic by the most orthodox of conventional sciences.**

**This switch occurred only in the past year or two. It was brought about by the digital simulation of the orbit of Pluto for 832 million years, by the world's best integrator of celestial mechanics at MIT, called the digital orrery. We have no direct evidence, because the discrimination of the stability of the solar system would require five million years of integration. It's really an academic question, but it's the best answer we have at present. There is a suggestion that the dynamics of the chaos revolution as a paradigm shift is analogous to the Copernican revolution. This was the paradigm shift studied by Thomas Kuhn as the basis of his theory of paradigm shifts, published in his book on scientific revolution. He began as a physicist, but became interested in the history of science, and early in his career he made a very detailed study of the Copernican revolution, in which many people were burned at the stake. At first, it met with resistance, but later it was accepted. It (the Copernican revolution?) actually existed much earlier. Was it a revival of the archaic world of the ancient Greeks? This still remains an outstanding puzzle in the dynamics of the history of consciousness.**

**Perhaps a better analogy would be the discovery of the wheel. The discovery of the wheel took place a long time ago, but it happened to coincide with the shift that made chaos unacceptable. [PLEASE ELABORATE.] The wheel was worshipped as the divine figure by Plato and others. The process of its invention occupied many thousands of years. The wheel concept, or at least the concept of a cycle of states repeating periodically, what we would call a periodic cycle, emerged into consciousness at least 25 thousand years ago. There are prehistorical records of observations of the lunar cycle. It seems that the concept of the wheel emerged, or came into consciousness, at the most abstract level first, through the study of the sky. This may have something to do with the fact that the sky-god was awarded a higher status in our pantheon when it became a monotheistic system, while the earth goddess got second place.**

**Apparently the wheel concept started out at a very abstract level, and then it trickled down to more and more concrete levels of understanding until it arrived at the actual wheel, which is not just a rolling disk but has an axle on which it turns. The first mechanical wheel, a disk with an axle, appeared around 4000 B.C. It was a pottery wheel. Later, it was adapted to the farm cart, and that made the urban revolution possible, because it allowed the farm to be located farther from the village. After that came the chariot wheel and the weapons of war, leading to the domination of the western world by the one god patriarch of the religion of the people who invented the chariot.[WHO WERE THEY?]**

**The historical dynamic of the invention of the wheel could perhaps be mapped onto what's happening now as some kind of model. The chaos concept also first emerged into consciousness at the most abstract level. The work of Falkeray, a century ago, was never known outside the world of mathematics before a kind of amplification of _____ that already existed in the history of consciousness, provided by the computer revolution. Once computers existed, it took only a very short time before people started drawing chaotic dynamical processes on computer graphic screens. The concept was visible on the screen and made it acceptable to anybody who saw it, which was a lot of people. It was an amplifying factor that brought it down to more and more concrete levels, because the program running on a computer is also a model -- a little more concrete than a mathematical model or the actual chaotic process.**

**The traditional demonstration of the chaotic process is the famous dripping faucet, which, due to the laboratory equipment existing in most lecture halls where chaos lectures are given, became the standard demonstration for the study of chaos theory. The most sophisticated mathematical ideas in chaos theory arose in the laboratory of Rob Shaw and are recorded in his book "The Dripping Faucet". This happened some time in the late '60s or the early '70s. It may or may not be a coincidence that the primary materialization of the chaos concept or its reemergence for the first time in 6000 years coincided with the social phenomenon that we know as the '60s. Time will tell.**

**We already have a history book of the chaos revolution called** *Chaos: The Making of a New Science* **by Jim Gleick. It has a chapter on Santa Cruz, primarily about Rob Shaw, who is featured extensively in a video program with his very high tech dripping faucet. The chapter about Rob Shaw says "Only in Santa Cruz." I believe that this is no coincidence. Wasn't Santa Cruz the capital of hippie culture in the '60s? The cultural manifestation of the 60s was a resurgence of the main features of the early Neolithic society that was destroyed by the patriarchal take-over. The last successful cultural offshoot of this early Neolithic society was Minoan Crete. Minoan Crete had various features built into the fabric of its culture, among them chaos, equality of the sexes, partnership of the genders, and other characteristic features that are radically different from the corresponding features of the society in which we live. The characteristic features of Minoan Crete tend to reemerge from time to time, welling up from the collective unconscious whence they were relegated by the orthodoxy of the church. At such times, some Neolithic aspects emerge like the tip of an iceberg, and then they are repressed again.**

**The '60s was one of these times, the troubadours of the 12th century Renaissance was another, and so was the Florentine Renaissance in 1450.**

**This view of the history of consciousness is promoted in several recent books, the best one being *The Chalice and the Blade* by Riane Eisler, an archeological-anthropologist who studied the early Neolithic cultures. It provides a two-model description of society, two basic, different organizations of society. She calls one dominator society, where one of the two genders dominates as in patriarchal and matriarchal societies, and the other she calls partnerships or gailanic societies. I believe that chaos is one of the characteristics of the culture, which is always trying to renew itself by some unknown process, and is always suppressed by some kind of witch-burning craze.**

**The one in the ’60s was the first of these GR-waves (Gailanic resurgence waves) to occur since the computer revolution. When that perturbation was introduced into our culture, it was, for the first time, backed by the enormous amplifactory power of the computer graphics, and also of video and electronic communications. That is why it took over. And now that it has taken over and we have all seen the program, it is very simple to understand. Our understanding of it was there all along. The only thing that’s changed is that now we accept it instead of continuing to repress it into the unconscious. A sort of double negative is the only reason to really be interested in chaos.[PLEASE EXPLAIN]**

**There was a 6000 year gap in the history of science concerning the important role of chaos, and now this gap is filled. I don’t think chaos will be suppressed again, because, thanks to computer graphics, we now have the means to persuade people that chaos is good, that it is good for you, and that it is more stable than order. There is a Nova program on chaos that makes this point forcefully in the context of mammalian physiology. It demonstrates that the healthy animal’s EEG, the EKG, the EMG is very chaotic. The sick animal’s _____ is less chaotic. When it is almost ordered, that is to say, periodic, the animal is dead.**

**I mentioned a book by James Gleick, named *Chaos: The Making of a New Science.* This book is extremely popular. 200,000 copies have been sold. I think one reason for this is that each and every one of us has a deep secret longing for that which is denied us, i.e., acceptable chaos in ordinary life. Chaos is the essential ground of creativity, of poetry, the arts. The advance of consciousness requires chaos. It’s the health of the spirit, it’s chaotic, and when it is suppressed, you want it, and when somebody stands up and says it’s okay, most people will have a kind of unconscious positive reaction. It’s like love. It’s good. And if it’s in some other town, it is particularly good.**

**I feel that the book’s subtitle "The making of a new science" is a mistake. I hate to say that this book is popular because of a dishonest title, but Chaos is not a new science. It is not a science at all. It is mathematics. Chaos theory is a branch of mathematics. It has implications for every science that implies mathematics. If you are dealing with a complex science like social science, for example, where all the data is chaotic and all the mathematical models are Fourier series or something, it is not too useful. But in general, mathematics is going to be much more useful now that it admits chaos theory, particularly in applications to truly complex systems.**

**Physics is by definition the study of the simplest systems. Physics comes from the word _____, which means nature as it is, including particularly plants**

**and organic foliage. But it has come down to us as a branch of science, which means that you look for the simplest systems, like the falling apple, and study that. The growth of the apple on the tree, that's for later generations. Chaos theory is not a new science, but the title of Gleick's book is** *Chaos: The Making of a New Science.* **This may be literally correct, in that every science will be changed by chaos theory, since it provides better mathematical models for its more complex and therefore more interesting and challenging systems. It tries to study the target ones, which aim at the future generations that are the more complex ones.**

**Behavior is always chaotic, because chaos and complexity go together. When every branch of science has been renewed or revitalized -- maybe it already happened in physics, in atmospheric science, in hydrodynamics, and in astronomy -- then that _____ of science revitalized _____ mathematical models, that would be a new science. It wouldn't be chaos theory, it would be science affected by mathematics. But I digress.**

**What is chaos theory? Journalists can carry on just as I have for hours and for pages without ever saying what it is, and I am going to outdo them now for a couple of minutes to give a little introduction to a science I call chaostrophy. I call it a math strategy because, like probability and statistics, it has to do with time series analysis. If the numbers in your time series are all the same, you know that it is an homeostasis process and comes to a constant. But if it doesn't come to a constant, then it changes, and you hope that it might be periodic. So you whip out your FFT algorithm and put the data in one end, and out the other end comes the power spectrum. If there are a lot of spikes and no baseline, then you say it's a periodic process. But 99.9% of the time you get a continuous power spectrum, and it is a chaotic process. What can you do with this?**

**There is a new strategy for dealing with data which comes from chaos theory. You have a dynamical system, that means a system of first order, ordinary differential equations, autonomous, defined with equations -- smooth, you know. From this you make a computer simulation and you get data. It is a compact program, a finite program that produces an infinite amount of data if you wait long enough, and no matter what you do, you can take almost any function as long as the dimension of this is 3 or more, this is a vector, x's, that's 1x, 2x, 3 or more, and when you get at the time t mark you get x mark. Let's pretend this is three-dimensional so I can make 3 columns, and that's t1, x1, I'll call them xyz. And here I'll make this a capital. Time series. Always comes out chaotic.**

**[GRAPHICS? I DON'T UNDERSTAND ANY OF THIS]From the study of this came a way of looking at this data derived from mathematical models, which then could be applied to any data, whether it came from a mathematical model or not. If a regular picture came out of the time series by looking at it in this particular way described as chaostrophy, if, in other words, some kind of order arose within the chaos, then you would think, well, there must be a mathematical model within the apparent disorder of the data -- the kind of order that differential equations always seem to provide if you know where to look. I simply want to describe a way of looking. You only need that to arrive at the theory. In the simplest case you have the times and one number that's been measured in the laboratory, so you can just consider this an example. We could simplify it even further by supposing that the data came not from random**

**observations in the field but from laboratory observations made at regular intervals on purpose, so that the t1 is t0 plus delta t, or t not a 0, t1 is delta t, t2 is 2 delta t, and so on. In that case, we have only one column of figures to put into the machine, so let's fix ti, tk equals k times delta t, and then we put into the machine one column of numbers, x1, x2, x3, and we are going to get out a picture. This will take place in a computer with a graphics _____. The first step is to copy this column over again next to it, so that there will be two columns, so let's make one little change, where this top number is dropped down, the second number is written on the top. You take this and _____, x1, x2, x3. Now this list has an end, it is a finite list, so _____ _____ you can chop that off. I made a list that is one item shorter than the original list, and now it has two columns. I'll just regard this as point in the plane and plot it. This is another point on the plane. ____ _____ one at a time, and do this with your own computer, you might as well plot them after equal intervals of time delta t on some numbers _____ _____ _____ ____.**

**Well, we can arrange things; there's a smallest and a largest in the first column, and there's a smallest and a largest in the second column, which would be about the same, I suppose, so we'll take a square region adequate to the plane, and just plot the points in there. That's it, you're done; that's chaostrophy. Now if this yields any kind of regular picture, you'd be astonished; I've seen this done with this kind of data. The surf in Santa Barbara can be measured with some kind of pressure device, and the White Cliffs of Dover, with their stratification of marine limestone, can be measured to show the age and thickness of the strata as an indication of the temperature. You can get a time series from the White Cliffs of Dover, from the annual flooding of the Nile, the periodic reversals of the earth's magnetic field, and from what you would have to identify as the most chaotic possible disordered mess of data. In most of these cases, a regular picture can be derived.**

**Probably the most convincing example of the wonders of order in disorder is the heartbeat of a person with a heart disease. At the very end of the Nova program there are examples of two or three different groups of heart surgeons working with this technique. Chaoscopy, a strategy coming from chaos theory, and the study of dynamical systems can be applied to any data ____ ____ to data in every field as a new species of time-series analysis. In many cases, though not all, it shows an amazing order. There are some resistant cases that haven't been managed as yet. One is the coral grove in the Indian Ocean. Another is historical climatology. Unfortunately this technique would require thousands of items of data.**

**There is more new-style time series analysis which results in a recognizable picture from chaos theory. You can look this up in a picture book of chaos theory like my pictorial dynamics work, and recognize it as familiar in this context. Many people have experimented with many different equations in the last 20 years, functions described as polynomials and what-not. They found the pictures and published them in some kind of atlas, where the same picture keeps coming up over and over again, no matter what the context. [?] First order, second order, three dimensions, four dimensions, infinite dimensions, hydrodynamics, icing models -- so many different systems that have been studied through pictures keep recurring. After analyzing your data, you might look up the literature of computer graphics and see an equation that behaves more or less like this picture.**

**I think of these equations as some kind of model for the natural process which produced that data. But there is more. There is a technology which is a kind of artificial intelligence program that runs on large computers. It can take the data and not only plot this kind of thing but figure out some equations which, by some criteria, are the best ones to recreate that data. The most efficient method is probably with neuronet. Neuronet looks at the data, chooses some equations, creates some data and compares it. If the comparison is not very good, it changes the strength of the connections, networking the _____, then does it again, and so on. It learns how to not only reproduce the data with the same kind of pictures seen through a chaoscope, but compares and feeds it back to the neuronet. Long term memory. Not only that, but it can go on producing more data. In other words, it does some kind of prediction.**

**It is a given in chaos theory that you can't predict in the sense of quantitative predictions. The way in which prediction has been interpreted in the past 6000 years does not work because of the well-known problem of sensitivity to initial conditions. [PLEASE EXPLAIN] That means that you start out two simulations of the process from the given equation, very very close together, and then they diverge exponentially rapidly, and pretty soon you don't know anything. What you do know is the picture. If you have a picture for the data drawn this way, there's a fuzzy region in the two-dimensional plane, in 3-dimensional space. Attached to it is a cloud of points indicating a certain probability density. It is very unlikely to find the system down here because the dots are all clouded up. Maybe it is very unlikely to find it out here because the dots are very thin. Now suppose that that picture, complete with the probability density, not only describes the existing data, because it is a part of the existing data, but it also describes the future data which you are going to measure 2000 years later when you drill in the Indian Ocean again. Then you'd have a prediction in some kind of statistical or probabalistic sense.**

**One kind of prediction that you'd have if this were true, is that the future of the system is not going outside that rectangle, even if within this rectangle the dots were equally distributed. You understood that you could never predict where in that rectangle the solar system was going to be, but the fact that you know the solar system is going to be in that rectangle 2000 years hence would be somehow deeply reassuring. This is the kind of prediction that chaos theory gives you. When traditional prediction fails, has to fail, will always fail, there's nothing you can do to predict a natural system in the classical sense. A comet is going to come and that's it. The application of chaos theory to natural domains does promise a new kind of prediction, which says yes, they are falling in love, yes, they are getting excited, yes the arms race is getting out of hand, but it is not going to infinity. It is still going to fall back on itself, and therefore, it's like when you have a lovers quarrel in exactly the same pattern for the tenth time, you don't get as scared.**