CHAOS AND LIFE

Ralph Abraham

Interviewed by
Rebecca McClen & David Jay Brown

DAVID: Ralph, you're recognized as one of the leaders in the mathematical study of chaos. Can you tell us what it was that originally inspired your interest in mathematics and the mathematics of vibrations and dynamical systems?

RALPH: Well, I didn't get interested in dynamics and decide that's what I was going to study. It was just left foot, right foot, or some series of miracles. It happened like this.

I was an engineer and worked in a physics project, so I became a student of physics. Then one day a physics professor said in class that if you want to understand physics you have to study mathematics. So I changed to mathematics at that point. And I found a mentor, somebody who took care of me and helped me out, a wonderful man, Nate Coburn. I started studying what he was doing because he was my only contact in mathematics. One reason I responded to his program was that it had to do with general relativity. Einstein had been a household word when I was growing up. My father respected Einstein very much. It was said that only eight people in the world could understand Einstein. My teacher apparently could and was writing in that field.

I had taken very few math courses during that period. I remember two or three very influential courses. One of them was a differential geometry course taught by Raoul Bott who became a very famous mathematician. Some concepts were included in that course that I later found useful in dynamics. So I had some math background, but not the kind of background I would have had if I'd done a Ph.D under a famous professor of dynamics.

Then I was looking for a job. I had one offer for some place where I didn't want to go and at the last minute, before the school year began, I got a letter from Berkeley offering me a job. In 1960 there wasn't any big mathematical center there, but of course I took it.

After I got to Berkeley I was engaged in rewriting my thesis for publication. One day I discovered that they were having tea in some little room in the back of the building, and I had already been there for two or three months and hadn't met anyone. So I went to the tearoom to meet some people and to find out what was going on. And in this way I discovered a couple of people who later became my best friends in mathematics. They happened to be there in September of 1960, along with a lot of other people that I met.

Everybody had just arrived. Overnight, Berkeley had become one of the most important mathematical centers in the world - and I just happened to be there, apparently because of a clerical error.

One of the people I met that day at tea was Steve Smale. I was done rewriting and was looking for something new to do. So I said, "What do you do?" and he said, "Well, stop by the office and I'll show you." The next day I stopped by his office and we started working together. Later I found out that he was a really famous mathematician. He won the Fields Medal which is the mathematical equivalent of the Nobel Prize for doing the very work that he was showing me.

So I found myself on the research frontier in mathematics, working with some really wonderful people who all thought I was fine, because in this group there was no insecurity. It was just, "This is what we do and if you fit in, fine." So we worked together and had great fun. We had fantastic parties where we played music and danced and got drunk and we did a lot of creative work in what became a new branch of mathematics called 'global analysis'. And all this happened in just one or two years. Part of this program was "non-linear dynamics" as practised by mathematicians on the research frontier at that time, using tools called "differential topology". It's a far cry from what people are doing now under the name of chaos, non-linear dynamics, and so on, that you read about in stories like Jim Gleick's book CHAOS.

All that I did in those early days was mathematical. It could be explained to a lay person without some very hairy preparation, and I've tried to make that explanation possible in my four picture books called DYNAMICS, THE GEOMETRY OF BEHAVIOR. The third of these four books is devoted to "tangles". In 1960, Steve Smale and I would take turns at the board drawing these tangles and trying to make some sense out of them and figure out what was going on. Tangles are like the skeleton of a beast. If you go into the Museum of Natural History and there's a skeleton of a dinosour hanging from the ceiling, you can walk around it and from the skeleton you can imagine the whole thing. But if you saw the whole thing you couldn't see the skeleton inside without an x-ray machine. It's just like a blob. These tangles are the skeletons of chaos. We didn't discover them; they were known to Poincare in 1882 or so.

In 1960 we were just trying to figure out these skeletons and relate them to the eventual behaviour of all dynamical systems, which includes practically everything in the world that's: all kinds of processes, including the human process and the process of history itself. All these are dynamical systems, their skeleton are these tangles, and the tangles have aspects known under these words: fractal, chaotic, and so on. But they are much more: they are highly regular, they're dynamic, they're symbolic, they're mythical and they're beautiful. In fact,they're mathematical.

DAVID: Just so that everyone is familiar with the extraordinary work you do, can you briefly explain what chaos theory is about and what role you are playing in this exciting new field of research?

RALPH: Well, chaos theory is a small branch of dynamics which is a very important region of the intellectual frontier. It overlaps mathematics, the sciences, and computer science, but it's not any of those things. It's not a branch of physics or of mathematics - it's dynamics! So we have a really unusual area which is not mathematics and it's not science, it's not a department of the university and there are no dynamicists with titles acknowledged, it is a really central human activity and really important to our adventure of understanding the world around us. I would say that its position is mid-way between mathematics and science. Mathematics is not science - science has all these branches and mathematics is not one of them. Mathematics is completely separate in its philosophical outlook, and in the personality of the people who pursue it, who are somehow diametrically opposite to scientists. Scientists are bottom-up in their style of understanding and believing, while mathematicians are sort of top-down. Dynamics is a huge area in between, which comprises the encyclopaedia of mechanical models used to understand processes.

Since we have to understand processes in science, dynamics is very important. I do not think that chaos theory is quite so important. The chaos revolution is the biggest thing since the wheel, but I don't think it's fundamentally important. Dynamics is providing us with process models which are much more important than chaos.

The chaos revolution is primarily important because chaos is everywhere. For some reason there was an historical accident, and for six thousand years people repressed chaos to the unconscious. So there has been a totally unnecessary gap where there should have been chaos theory. And the filling of this gap is really a big thing only because the gap was there. But after it's filled, it is perfectly normal to have chaos models, and wheel models, and static models. It was very bizarre that among all these models there was such a huge gap. But now it's filled, now we're back to: 'No big deal, aha, fine, so it's chaotic.' But dynamics is offering more. It's offering bifurcation diagrams, catastrophe models. It's offering fantastically good models for processes. And few of these models would actually be there on the shelf for our use in trying to understand the world around us if we denied the existence of chaos - because chaos is ubiquitous in process. You can't model process very well if you're in denial about the existence of chaos. You're certainly not able to model any process which is full of chaos, and that's practically all of them, most especially those involved with life, love and creativity. So we do have something important in dynamics, and chaos has an important role in a sort of double negative sense. That's what's going on with dynamics.

As far as my work in it is concerned, I think it doesn't matter very much. Some people think I shouldn't waste my time at a computer terminal doing research on specific problems because my role is to go around saying what I just said.

DAVID: (Laughter) That's very good. What are some of the problems that you see with the present state of American mathematical education and how do you think improvements could be made?

RALPH: Well, I would say a good thing to do with mathematical education in the United States or in the world today would be just to cancel it and start over again from scratch, two or three generations later. The whole thing is in a really dangerous plight.

And I've been saying this for years and so have other people, but only recently the problem has risen to a scale of national prominence where even the president and the governor and everybody's saying, our kids are no good at mathematics'.

So we have a serious situation. First of all, mathematics is sort of akin to walking as a human experience. It's just really easy. I mean it shouldn't be easy, how can you tell somebody how to walk, you know? but people do find it easy and they naturally learn how to do it. They just watch, and by imitation they can do it. It's the same with mathematics! It's part of our heritage, all of us, to be genius at mathematics. It is a completely human activity. It involves the resonance between prototypical objects in the morphogenetic field and specific examples of similar forms in the field of nature, as they're experienced by human beings through the doors of perception. And as life forms a resonant channel between these two fields, it's just as natural as understanding anything, including walking, playing tennis, and so on. Mathematical knowledge is part of our human heritage.

Furthermore it's essential to evolution. Where there's no mathematical knowledge there can be no evolution, because evolution to a stable life-form requires a kind of mathematical, sacred guidance. This can be understood in many different images, the least controversial one being that there would be a harmonious resonance between all of the components, parts, sub-systems and so on involved in the life process. Where there is an inharmonious resonance, or dissonance, there would be some kind of illness whether the organism is a snail, a human, a society, or the all and everything that we know by the name history. So the harmonious resonance maintained during the process of our own growth, or social evolution, requires mathematical understanding. You may see the dissonance of the lack of mathematical understanding through the gross national product, or the number of wars, or the spread of AIDS, for example.

Another importance of chaos theory is in correcting a problem in mathematical education that has consisted, in part, of denial. People have been taught the non-existence of some of the essential mathematical forms, namely, chaotic forms. This kind of denial produces an educated adult somewhat less capable than an uneducated adult. So that education which functions in this way is not the same as no education. It's worse, because it destroys intelligence, it destroys functionality, it destroys harmony with the resonance of the all and everything which is necessary for health. Our educational system, in short, is producing sickness and contributing to the global ecological problems on the planet by destroying the native intelligence that children have, the capability they have to understand the world around them in its complexity, in its chaos, in its resonance and harmony and love, destroying it through the inculcation of false concepts and through the production of avoidance mechanisms connected with certain mathematical ideas.

It's a very serious problem. One possible response would be to revise mathematical education so that, within the same system, one would try to provide teachers who are more highly trained. That could only make matters worse, you see, since the teachers are already highly mistrained. Many have already been taught to hate mathematics and so they can only teach hatred for mathematics. They don't really have any idea what mathematics is. For them, it's a knee-jerk response of this dark emotion, so retraining them more wouldn't help. Rather than revision of the schools - which are full of false ideas and bad habits built into the field on a deep level - the most efficacious, practical solution would be the construction of a new educational system outside the usual channels of the school system. This is not too radical, as we have all been brought up to think of our real education as going on outside the school system. In school, for example we do have music classes, yet if parents want their children really to know music, they provide a separate teacher outside the school. We also have religious instruction and dance instruction outside the school - anything that you really want to learn is studied outside of the school. And so also it may be with mathematics.

I think that one practical solution to this challenge to create a school outside of school would be a new breed of learning machines based on computers, educational software, and digital video. Even programs like Hypercard on the Macintosh, for example, could provide alternative education that could be approached by individuals without teachers. So far, however, the creation of educational software has proved to be a very unrewarding activity for authors. And in spite of all different kinds of alternative funding agencies, nobody has seen this as a very important problem, although the National Science Foundation, the American Mathematical Society and similar organizations have convened conferences to discuss possible solutions of the crisis in mathematical education. The most promising alternative solution at this time has not been funded. And so there are very few existing alternatives for children now. Maybe after another generation or two there will be.

REB: The principles of chaos theory and other mathematical ideas appear to echo in the myths and philosophies of some ancient cultures; the Greeks had a Goddess of Chaos, for example and the I Ching is full of references to such ideas. What level of understanding do you think earlier civilizations had of these concepts and how was this expressed?

RALPH: Well, the repression of chaos began with the patriarchal takeover six thousand years ago. So to look at an example of a high culture accepting chaos as part of their mythological pantheon and in their arts and behaviour, one has to go back before that takeover. And the most common example of such a culture is Minoan Crete. This culture was excavated by Sir Arthur Evans, and his reconstruction of the temples and religion, etc., have since been seriously questioned by archeologists. In short, there was a controversy as to what were their arts, their social patterns, and so on.

A lot of things are known through mythology that are traced back to Crete. One thing that's known from paintings is the dance with bulls. There were the Bacchic mysteries, derived from the Orphic, the Dionysian and so on. Following this backwards, like tracing roots or Ariadne's thread, you come to a certain mythic kernel which would be associated with Minoan Crete. I wouldn't say these are expressions of chaos. They might be, but there are so many differences between our culture and the Cretan culture. We know something about Dionysian ritual: the importance of music in ritual, the dichotomy of religious ritual into two types, outdoors on the open plain and indoors in a cave. The mystic revelation that came with Gaia sees the planet as an organism, and the plain as its surface. Gaia is very chaotic, so if you reject chaos, you reject Gaia. It goes together: the orphic trinity of Chaos, Gaia, and Eros.

That's what I suggest to you to think about. Gaia as the Earth, the love of the planet, the integrity of life-forms; Chaos as the essence of life: more chaos is healthier; Eros as human behaviour in resonance with Chaos and Gaia. It's rumoured that the Minoans had a very high degree of bisexual activity, licentious behaviour and wild parties. This may be the quality of the genders in a partnership society as described by Riane Eisler.

REB: Why do you think it was that later Western Culture tended to view chaos as an undesirable quality in nature?

RALPH: Well, that's a very big question, and speculation can't be taken too seriously, but I think that this has to do primarily with the patriarchal takeover. The repression of Chaos, Gaia and Eros is characteristic of the patriarchal paradigm, which turned out to be the dominant one in our recent history. And it could be that sexual repression is somehow its key.

Human society is an evolving system - including its psyche, its mythology, its cultural structure. This evolution is punctuated by bifurcations, mutations caused by the planetary equivalent of lightning: comets. Comets were probably very important in the history of consciousness; they still are. There are some mutations where changes are made in the memes, the cultural genetic structure. Then there's a kind of natural selection which goes on when two societies are in conflict over a common goal, due to seasonal inundations and so on, and in this conflict one would be selected not just by military strength, but perhaps through the stability of its social structure.

And in the long run, in evolutionary history, there are dead ends. A lot of species become extinct without the necessity of a comet or of global catastrophe, but just because they're the wrong idea to begin with. It seems likely that the human species is the wrong idea to begin with and may not succeed in having a stable long-lived civilization on this planet. We know that Egyptian society lasted for three thousand years and that's a fine record for a society. Since the Renaissance we're not up to one thousand years now, and we'll see how long this goes on. I'm not placing any bets. It may turn out that there are some structural flaws that are endangering the future of human habitation on this planet. The planet is in symbiosis with the human infection. This could be a very good symbiosis; it could mediate some sort of divine plan on a cosmic scale with the actual material of planet Earth, and that includes the consciousness of the human species. There is a certain promise there, I don't deny it.

However, archeologists coming from another star-system in the future may say that a structural flaw in our society resulted in the advantage of patriarchy over the partnership model. It could be that the basis for the stability of our violent society is the nuclear family, so that the repression of Eros, Gaia and Chaos - the repression of the Bacchic, the Orphic, the Dionysian - by the patriarchy was chosen by people who had grown up in a nuclear family. And when two civilizations came into contact, the one that had the nuclear family won. This is just one possibility among many, in answer to your question why chaos was rejected.

The chaos societies had moon festivals such as we had in the Sixties. This is no coincidence, because the Sixties, the Italian Renaissance, the Renaissance of the troubadours in the twelfth century, early Christianity, the Pythagorean Academy in Croton - all these have the common aspect of temporary resurgence of Orphic ideals, followed by massive and violent repression by the conservative society. All these have been foci in history for burning people at the stake. Of all the forms of terrorism, burning people at the stake seemed to be the most appropriate for the patriarchal society, in repressing revivals of the preceding form involving the goddess. In the Sixties, which was one of these Orphic revivals, we got to experience what life was like in Minoan Crete, in the Garden of Eden. We had moon festivals, and people abandoned themselves to their feelings, to Chaos, to Gaia, to Eros. Many of these groups, which experienced the Garden of Eden, eventually broke up. The Sixties came to an end. A number of break-ups were caused by patriarchal, sexual jealousy.

REB: The trend of science towards reductionism led quantum physicists to the realization that the whole does not equal the sum of its parts. Now chaos theory seems to clarify this statement by saying that this is because we cannot know the sum of all the parts. What do you think are the implications of this idea in how we may arrange and organize information in the future?

RALPH: This is exactly the reason why I said that chaos theory isn't very important, except as a kind of double negative while on the other hand, dynamical systems theory does offer something very important. We need to understand whole systems, and whole systems cannot be understood by reduction. The terrific gains in understanding made by the reductionist scientist will, I'm sure, be used in the future to understand whole systems by means of some process of synthesis. The reduced understanding of the biochemistry of the adrenal cortex, for example will be synthesized into models of whole systems, such as the stress response and the immune system. The technology for modeling whole systems is on the frontier of science at the moment; it is the crucial frontier for the solution of our global, planetary problems.

Dynamical systems theory, specifically the branch called complex dynamics, offers a strategy for the re-synthesis of fractionalized scientific knowledge, and an understanding of complex whole systems. Complex systems theory has replaced chaos theory on the fashion pages of the science newspapers of our day. And I think the fascination of intellectuals with complex systems theory is not going to be a short-lived flash-in-the-pan. This is somehow the real thing. Our challenge now is the reintegration of the sciences after their dissolution in the Renaissance into an understanding of whole systems, particularly planetary systems, that is to say the hydrosphere, the lithosphere, the atmosphere, the biosphere and the noosphere. Within the lower spheres, a new direction called global modeling is already under way. Global modeling tries to put together reductionist models people have made for the oceans, for atmospheric phenomena, and for solar radiation. Individual models made by reductionist scientists of these different areas - the oceanographers, the atmospheric chemists, the solar physicists - are being synthesized into one global model. This global synthesis requires two things. First of all it needs models for the separate components or organs of the planetary system to be made in a common strategy so that they can relate to each other. Secondly, it requires a wiring diagram to put them together. In the field of global modeling a tremendous synthesis is now taking place, including conferences on the wiring diagram, which will provide a global model of the geosphere.

For the sociosphere, we must start from scratch. We don't yet have many specialists producing mathematical models for society, although there are a few outstanding pioneer first steps. There are for example the archeologists and anthropologists worrying about the demise of the Mayan civilization in Central America in the Fifteenth and Sixteenth Centuries, because it was so complex and there are so many hypotheses, and it was such a controversial question, they tried to resolve it by building mathematical models. There are now a number of competing complex dynamical models for the Mayan society, taking into account the food chain, the weather, the population, and the distance between ceremonial centers. All these factors are built into different competing models. Then they run them and try to see which one wins the best relationship to the archeological data. And thus a model system can be created, because Mayan civilization was relatively small. This pioneering first step might lead to similar models for larger societies; for ancient Greece, for example, or for the downfall of Rome, where many more factors and more people were involved. Navigation, naval trade, the effect of inventions like better clocks for navigating: all these things might be included in the model.

So in the future then, as global planet models become more successful, global social modeling will begin. Then individual components have to be modeled, such as the political and economic systems of individual nations, their interactions, and so on. They have to be made in a common strategy, so they can be connected together. And then one has to extrapolate from the Mayan models and gain wiring diagrams for these different component parts, including psychological and medical factors. In the reductionist physical sciences, we will only have to connect existing components together, following a diagram, to get global models. For the social sciences we'll have to start from scratch. We're going to have to make models for the organs, do experiments in simulation with various wiring diagrams, compare with data, improve the component models, the global models, the data, and so on. After many circuits of this hermeneutical circle we might create a global social model. Then the global planet model and the global social model have to be connected together. There's also the mythological and the spiritual dimension and the understanding of the world of the unconscious. In other words, the whole thing has to take place once again in the noosphere, and then that has to be connected up. Eventually, we hope to get some kind of model for understanding what - if any - are the effects of choices we could make - if there are any - upon our long-range future. This may never happen, but if it did, mathematics would be of use to Gaia in creating the future, through the direct, conscious interaction with the evolutionary process. This seems to be our challenge.

DAVID: Could you tell us how your travels in India and the experiences you had in a cave there have influenced your outlook on life and mathematics?

RALPH: What I had done that was respected by mathematicians in the way of frontier research work was ancient history by the time I went to India and lived in a cave. So, to answer your question, I should first of all identify what I've done since then that could be regarded as mathematical. I would say that the computer revolution has presented enormous opportunities to mathematics, to the profession and to the individual mathematicians, which have not yet been seized. Many mathematicians have rejected the significance of computers, so far. But if we could say that experiments with computers represent mathematical research, you could see the evidence of my stay in India in the cave on my outlook on mathematics.

My computer experiments involve the concepts of vibration, harmony, resonance and mathematical models for these phenomena. We would like to understand how a person is in morphic resonance with a field, if these metaphors have any function from a perspective of pattern modeling, which is what I think mathematics is all about. The processes where this kind of metaphor is proposed - whether in the Indian Samkya philosphy or in Rupert Sheldrake's theories - are always in a living, biological, mental sphere. So the data, if there are any data, would necessarily be chaotic. So first of all we would have to extend or map the notion of resonance from the circular sphere where the concepts first evolved in the context of chaos. When you have two strings of a guitar, you pluck one and the other one vibrates by so-called sympathetic vibration. This vibration is understood as a non-chaotic phenomenon; it is just oscillation. Each point on the string vibrates, left, right, left, right, left, right. So from this, which I'll call the circular or periodic domain, the concepts have to be extended to the chaotic. If the two strings were chaotic instead of periodic, which means they would sound raspy and noisy instead of harmonious and sweet, then could there still be a sympathetic vibration of one caused by the nearby chaotic vibration of the other?

I came back from India in January 1973. By January 1974 I was already involved in experiments with chaotic resonance, and this has dominated my research way up to the present day. For example, one discovery we made is that the Rossler attractor, which is one of the simplest of chaotic forms, does have sympathetic vibration as one of its characteristics. So after India I concentrated more on vibration and resonance, whereas before, we were involved with the general, skeletal structures of chaos. And they're related in that the theory of chaotic resonance is based upon an understanding of the skeleton, the so-called homoclinic tangles, as I've tried to explain in my picture books.

REB: Could you tell us about your experience with John Lilly's dolphins?

RALPH: Well, I think that people who live in cities are not much in tune with animals. Actual communication with an animal is a rare experience for most of us. And some people are more sensitive to animals than others. They have a favorite pet, or they just really like animals. In my case, I grew up on the edge of town in Vermont, where they have, as it is said, two seasons: winter and July. Winter is very long, and a lot of times I was outside playing in the snow, usually alone. I used to go on long treks after school and on weekends on my skis, communing with animals and trying to figure out where they had been by the study of their tracks. And to this day I have a special love for animals, which is one of the reasons that I'm a vegetarian. I'm not only a vegetarian, but vegetarianism has a very great importance for me. It's a big thing, not just another habit.

Anyway, I like animals, and so I was very keen to swim with the dolphins. I had bought it, like most hippies, that dolphins are more intelligent than people. They had had the brilliance to flee to the sea a long time ago, and there they have lived in peace ever since, except for a few tuna fishermen. So I had a sort of double setup to have a good experience with these dolphins, and I had read a little bit about other people's experiences swimming with them. I knew that they have a very strong connection to the Orphic trinity of Chaos, Gaia, and Eros. They're connected to Chaos most directly through the experience of hydrodynamical turbulence, that is, white water. Now white water is the most perfect chaotic thing we have: you hear it, you see it, you feel it - it's chaos personified. Dolphins know Chaos. They also know Gaia. They can find their way over great distances in the sea, their playground is thousands of miles across, they explore it all, they know their way around. They can sing and speak to each other over tremendous distances. Through their sonar communication apparatus they have a global sense which transcends our own. And then as far as Eros is concerned it's rumored that they're loose, they're sexy and they like to get it on in the water.

So that's the background. I went to John Lilly's place in Redwood City for a routine swim with Rosie and Joe and had a fantastic experience with them. They were very violently playful. I had communicated nothing, I was just there, and I wasn't adequately prepared for what they actually do. They like to take your hand into their mouth and press, but not too hard. You have to have some sort of faith that they're not going to bite you, because they have very strong jaws and sharp teeth. So I was kind of scared of this mouthing game. And then they had the flying body game. They would go down to the bottom of the tank, which was pretty deep, turn around, get ready and let go with their maximum acceleration and velocity, heading straight toward you, turning aside only at the last minute to brush gently against your side. It was kind of heavy; they were very heavy with me.

I was trying to figure out what to do. Should I grab on and go for a ride?
I tried that; they slowed down and became more gentle. If I played with one, the other one appeared to be jealous, but it was all a game. There were a lot of interesting things, very much like playing with people, or at least children.
But I was a little scared because I'm not that great a swimmer and they were very good swimmers. My faith had flaws that day, I suppose.

Then I decided to try a mental experiment. We know they're mental - they have memory and intelligence and language and so on. So I proposed an experiment in telepathy. I swam out of the tank into a little nook or cranny to regroup. I had this fantasy of lying still in the water, and they would both lie still as well, and one of them would face me in the water so that we were colinear, head to head on a straight line, and then we would just exchange thought without any further ado. They were thrashing around in the water. So keeping this picture in my mind I swam out again, and they both became totally still, just as I had visualized. I believe it was Rosie who got into position: on a line, still, head to head and so on. And then I thought, 'O.K., let's exchange a thought'. Booom! Loud and clear came a thought. She said, 'Do you think it's nice in this tank? Would you like to live in this tank? It's too small; it's ugly; it's dirty. We want out!' So I said, 'Wow, yeah, I can understand that; I'm certainly going to get out pretty soon and I wish you could too'. Then we played a little bit more and I got out. I wrote in the log book about this experience just as I told you. Later there was a revolt of John Lilly's crew over the question of conditions in the tank.

DAVID: Have your experiences with psychedelics had any influence on your mathematical perspective and research?

RALPH: Well, yes. I guess my experiences with psychedelics influenced everything. When I described the impact of India and the cave on my mathematics I could have mentioned that, because there was a period of six or seven years which included psychedelics, traveling in Europe sleeping in the street, my travels in India and the cave and so on. These were all part of the walkabout between my first mathematical period and all that has followed in the past fifteen years. This was my hippie period, this spectacular experience of the G.R. wave, or the gylanic revival <after Riane Eisler> - of the Sixties.

I think my emphasis on vibrations and resonance is one thing that changed after my walkabout. Another thing that changed, which had more to do with psychedelics than with India, was that I became more concerned with the application of mathematics to the important problems of the human world. I felt, and continue to feel, that this planet is really sick; there are serious problems that need to be faced, and if mathematics doesn't have anything to do with these problems then perhaps it isn't worth doing. One should do something else. So I thought vigorously after that period about something I had not even thought about before: the relationship of the research to the problems of the world. That became an obsession, I would say.

DAVID: Why do you think it is that the infinitely receding geometrically organized visual patterns seen by people under the influence of psychedelics resemble computer generated fractal images so much?

RALPH: Well, I don't know if they do, really. You know there's a theory of the geometric forms of psychedelic hallucinations based on mathematics by Jack Cowen and Bard Ermentrout. It has to do with patterns of biochemical activity in the visual cortex which is governed by a certain model having to do with neural nets. This model has geometric patterns in spacetime, dynamical patterns, which are patterns that any structure of that kind would have. So these two mathematicians see psychedelic hallucinations as mathematical forms inherent in the structure of the physical brain. Now I'm not very convinced by that, but I think it's kind of an unassailable position. One cannot just argue it away on the basis of one's personal experience. What I think about psychedelic visuals is not so different, except that I would not locate them in the physical brain. I think that we perceive, through some kind of resonance phenomenon, patterns from another sphere of existence, also governed by a certain mathematical structure that gives it the form that we see. I can't speak for everyone, but in my experience, this form moves. Now the historic pictures that they show us don't move. And the mathematicians of fractal geometry have made movies and they don't move right. So I think that the resemblance between fractals and visuals is very superficial.

I do have a general idea about the mathematics of these patterns. I call them spacetime patterns, and they're fractal perhaps as spacetime patterns. But the incredible symmetries, the perfect regularities, I think, are based on some other kind of mathematics. It is called Lie group actions. And there are reasons why this kind of mathematical structure is associated with the brain. But even if you believed in the internal origin of these patterns in the physical brain and in the Lie group action approach, some kind of mathematical source could be expected for these visions because they look so mathematical. They have regularity and perfection. How can an image of something perfect appear in the brain? It just doesn't make sense. So I suspect these visuals are actual perceptions.

REB: Dynamical systems are arranged by organizing agents called attractors. Could you explain how these abstract entities function and how they can be used in understanding trends in biological, geographical and astronomical systems?

RALPH: Well, attractors are organizing centers in dynamical systems only in terms of long-term behaviour. They're useful as models for processes only when your perspective happens to be that of long-term behaviour. Short-term effects are not modeled by attractors but by a dynamical picture called a phase portrait. Its main features are the attractors, the basins, and the separatrix which separates basins. Each attractor has a basin, and different basins are separated by the separatrix. It is said that mathematicians study the separatrix and physicists study the attractors, but the overall picture has these complementary things that have to be understood. The separatrix gives more information about short-term behaviour, while the attractors determine the long-term behavior. What is most amazing about them is that there aren't very many. And that's kind of surprising because there's so much variety in the world. I would have expected more variety in the mathematical models for the long-run dynamical behaviour, but most of them look alike.

REB: When an attractor disappears due to sudden catastrophic change, the system becomes structureless and experiences a term of 'transient chaos' before another attractor is found. How have you applied this idea to cultural transformations?

RALPH: Well, that's actually a commonly expressed idea which might turn out to be unfounded. People - including me - want to use this aspect of dynamical systems theory called bifurcation theory to model bifurcations in history. History is a dynamical process and it has bifurcations. And here we have a mathematical theory of bifurcations, so let's try it. That makes sense. But the bifurcations that are known to the theory, as universal models of sudden change in a process, are not usually characterised by this transformation from one equilibrium stage to another through a period of transient chaos. That's very exceptional in the theory, and I don't know if natural systems show this characteristic either.

Let's say you could collect data about a civil war where you had maybe monarchy before and democracy afterwards, and the monarchy was very steady with institutions that you can depend upon, and so was the democracy, and in the middle you were constantly overrun by the troops of one side or the other, or by guerillas. If this whole history were reduced to data and then you applied the rigorous criteria of dynamical systems theory to these data, and measured the degree to which it's chaotic, you might find that the monarchy had a chaotic attractor as the model for its data, in the democracy there is also a chaotic attractor of a completely different shape, and in between you don't have chaos at all; the transient is not transient chaos but is transient something else, or it's transient chaos but it's much less chaotic.

You know that heart physiology shows more chaos in the healthy heart and less chaos in the sick heart. I think it's dangerous to take the casual aspects and implications of these ideas of chaotic theory and start wildly trying to fit them into some preconceived perception of external reality. A better idea is to get some data and try to construct a model. There's no lack of numerical data about social and historical process. For example, the total weight of mail sent in mail bags from the American Embassy in Russia to Washington, D.C. is known for over a century. Political scientists have an enormous amount of data. I think the serious applications of mathematical modeling to the political and social process will proceed in the numerical realm. The result might not fit someone's preconception based on an intuitive understanding of these chaos concepts. So I don't know if social change is going to be characterised by chaos or not. I guess it might, according to some measures and observations, and might not,according to others.

DAVID: Do you see the process of evolution as following a chaotic attractor, and if so does that mean there is a hidden order, so to speak, to evolution? And that what has appeared to evolutionary biologists as chance and randomness may actually be a higher form or order?

RALPH: No. I think that the understanding of dynamical systems theory presented in popular books is extremely limited and a lot of physicists for example have studied attractors exclusively while as I said the mathematicians have been studying the separatrices. Attractors are very important in modeling physical processes in some circumstances, and that is very fine, but when you're speaking about evolution, if you want to make models for an evolutionary process, then probably the best modeling paraphernalia that mathematics has to offer you are the response diagrams of bifurcation theory. Bifurcations have to do with the ways in which attractors appear out of the blue, or disappear, and the way in which one kind of attractor or size of attractor changes into another. These transformations appear in scientific data and in mathematical models in a much smaller variety of transformation types than you would suspect.
And dynamical systems theory, at the moment, is trying to accumulate a complete encyclopedia of these transformation types called bifurcation events. Bifurcation events assembled in some kind of diagram would provide a dynamical model for an evolutionary process. Therefore, the actual attractors involved are almost of no interest. From the bifurcation point of view it doesn't matter if the process is static, periodic or chaotic. What's important is whether the attractor appears or disappears. And here there is plenty of room for chance and randomness.

And so as bifurcation theory becomes better known, I think the style of making models of process will undergo a radical and very exciting revision. The main point of my books, *Dynamics: The Geometry of Behaviour,* is to present the beginning of the bifurcation encyclopedia as far as it is known to date. There are about twenty-two different events there.

DAVID: Do you think it's possible to form, or have you already formed a mathematical theory to explain the phenomenon of how consciousness interacts with the material world?

RALPH: Well, no. There are models, specific mathematical models, for different perceptual functions of human mammalian physiology which represent the frontier of neurobiology today. One example is Walter Freeman's model of the olfactory bulb. These models are mathematical objects known as *cellular dynamical systems,* which include neural-nets and excitable media as special cases. These mathematical models for perception pertain to the question of how consciousness interacts with the natural world. And they comprise a conceptual frontier today. In that context, what would an idea be? In the context of the olfactory bulb, what is a smell? So it turns out that from the perspctive of reductionist science, along with its mathematical models, a smell is a certain space-time pattern on the olfactory cortex, a pattern of excitation. The cortex consists of a sheet of oscillators side by side vibrating. A certain pattern in their frequency, phase relationship, and amplitude, is a smell. There is a certain picture, where inside a region there is a larger oscillation, and outside, a smaller one. This picture is recognised as a smell.

This kind of modeling does provide the possibility of making a simple model for the natural world, a simple model for consciousness, and a simple model for the interaction between the two. The interaction model, in this cellular dynamics ccontext, is based on resonance. A lot of my work has to do with vibration and resonance phenomena in this context and has provided a specific mechanism for the transfer of a space-time pattern from one such medium to another. However, these mechanical models may be too simple to provide intuition as to such things as how your mythology, your perceptual filter, function so as to limit your perception of the natural world to a certain paradigm in your consciousness? Such models, which I think is the essence of your question, would have to do with a more linguistic or symbolic approach rather than at the mechanical model level.

DAVID: Could you define beauty in a mathematical way?

RALPH: Well, people do say mathematics is beautiful, and some mathematical objects are certainly beautiful. Whatever beauty is, if you could define it in some way, it would include mathematics within it somehow. If you define it, for example, in terms of cognitive resonance, then mathematics provides the ultimate opportunity for cognitive resonance because the bare bones of cognition itself are represented by these mathematical objects. The strongest resonance of forms takes place in certain special areas, precious little rings of human experience.
One is mathematics, another is music, and then of course, mysticism - the three M's, three crown jewels of beauty. But I wouldn't know what the experience of beauty really is, and I certainly wouldn't think a mathematical definition would be appropriate.

DAVID: From chaos theory we know that small errors in calculation can grow exponentially in time, making long-term prediction difficult. With this in mind do you think it's possible to forsee what life for humanity will be like in the twenty-first century?

RALPH: This idea of the exponential divergence, the so-called sensitive dependence on initial conditions is very much misunderstood. When a process follows a trajectory on a chaotic attractor, and you start two armchair experiments, two processes, from fairly close initial conditions, then indeed they diverge for a while. But as a matter of fact what is happening is that both of the trajectories go round and round. You can think of yarn being wound on a skein. So they diverge for a while, but pretty soon they reach the edge of the skein, and then they fold into the middle again. They always come back close together again. They have a certain maximum separation, it might be four inches or something, and that's it. That's not very scary. They do not diverge indefinitely and go off into infinity. That's exactly what doesn't happen with chaotic attractors and that's why chaotic attractors might be very reassuring to people who would otherwise have anxiety about chaos. Because the chaos in a chaotic attractor is very bounded and the degree to which things go haywire is extremely limited. So that's the good news, and after you know the process for a while, you know it forever. Chaos is very much the same as the steady state, it's not scary at all.

Now if our evolutionary track, this species on planet Earth going into the twenty-first century, for example, were modeled by a chaotic attractor, then we can answer the question where will we be in the twenty-first century. Because it would be pretty much the same mess as now. But it's not modeled very well by a chaotic attractor. A better kind of mathematical object for modeling an evolutionary process is a bifurcation diagram. In this context, a chaotic attractor is changing in time. There may be bifurcations, for example, a catastrophe, a comet or something. Who knows? And it may be that some bifurcations occur under the action of parameters controlled by us, such as how much energy we use, how much waste we make. And that's why bifurcation diagrams are more interesting than chaotic attractors for modeling our own process. Under this more general kind of model we cannot say where we will be in the twenty-first century. Or *if* we'll be.

REB: Why do you think that the understanding of chaos theory is vital to our future?

RALPH: Well, this fantasy of the importance of mathematics has to do with the idea that we might have a future, that we might have something to do with it, and that conscious interaction with our evolutionary process is possible and desirable. And in this case, things will go better if we understand our process better.

The importance of chaos theory to our future is that it provides us with a better understanding of such processes, the behaviour of complex systems such as the one we live in. This is due to the fact that chaotic behaviour is characteristic of complex systems. The more complex the system, the more chaotic its behaviour. And if we don't understand chaotic behaviour, then we can't understand the complex system that we live in well enough to give it guidance, make informed decisions, and participate in the creation of our future.

DAVID: O.K., final question. Would you tell us about any current research projects that you're working on?

RALPH: Well, I have an ongoing project with visual music which is just one of a family of related projects having to do with chaotic resonance in cellular dynamical systems. If you had a cellular dynamical system such as a two-dimensional spatial array of three-dimensional dynamical systems, and the state of each of the dynamical systems in the two-dimensional array were visible as a color, then you'd see the simultaneous state of this complex system as a colored picture, and the evolution of this system as a movie of colored pictures. This is experimental dynamics and graphic art, all at once.

Complex dynamical systems have very high dimension, they are really hard to see. The conventional methods of scientific visualization, an important field in computer research today, only work for low dimensional systems, for simple systems. But we want to understand very complex systems. So we have to develop a technology to visualize complex systems. And I believe that this kind of development will take place not only in the physical sciences, but more in the biological sciences, even more in the social sciences, and much more in the domain of the visual arts. So my current research is on the frontier of cellular dynamical systems, chaotic resonance, and the visual arts.

DAVID: Thank you so much for your time. We really appreciate it