ERODYNAMICS

Ralph Abraham

Ed.: In 1989, Ralph Abraham was interviewed by Rebecca McClen and David Jay Brown. The full interview will appear as a chapter in a forthcoming book VOICES OF VISION by David Brown.

DB: What's going on in dynamics and why is it important?

RA: Dynamics 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! It is not a department of the university; there are no dynamicists with titles of "professor of dynamics." But in spite of the fact that it hasn't been acknowledged, it is a really central human activity and really important to our adventure of understanding the world around us. It comprises the encyclopaedia of mechanical models used to understand processes.

Dynamical systems theory, specifically the branch called complex dynamics, offers a strategy for re-synthesis of fractionalized scientific knowledge. It is central to what is called complex systems theory, and chaos fits into a part of it. 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 at the frontier of science at this moment; it is the crucial frontier for the solution of our global, planetary problems.

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 re-integration 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 mod-

"Projects: Symposium Report"

There are four categories of projects which I've worked on in 1989, which I want to share with you. Three of these I call social work, and the fourth could be called art works, or equally, a project of pure experimental mathematics. All are serious projects of applied or experimental math, and are interelated, by the common theme of relevance to world problems. They are exemplary of the field I call *erodynamics*.

Important to this work has been the use of one the world's fasted imaging processing computers (The Massive Parallel Processor or MMP for short). The MPP results have convinced me, once again, that pure mathematics is a highly efficient resource for social and environmental problem eling 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 physicist — 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 using a common strategy so that they can relate to each other. Secondly, it requires a wiring diagram to put them together. In this field a tremendous synthesis is now taking place, including conferences on the wiring diagram, which will provide a global model of the geosphere.

It is here that chaos fits in.

Chaos theory is a small branch of dynamics. The chaos revolution is important primarily because chaos is everywhere. For some reason there was a 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 there was a gap. But once it's filled, it will be perfectly normal.

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 available 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.

RM: 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?

RA: Attractors are organizing centers in dynamical systems only in terms of long-term behavior. They're useful as models for processes only when your perspective happens to be that of long-term behavior. Short-term effects are not modeled by attractors but by a dynamical picture called a phase portrait. The main features of a dynamical system 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-

modeling. One obtains results applicable to many different applications from a single experiment. Thus, with such problems in my mind for motivation, I find myself moving back to pure experimental mathematics but now leaving specific applications to the specialists in the various disciplines.

NETSCOPE

NETSCOPE, is a joint project with Bob Langs, and a group of psychoanalysts around the United States, who came to me with an idea that dynamical systems theory could be applied to bring psychoanalysis out of the scientific dark ages, and to give it a higher level of understanding, particularly of the therapeutic process, in which the therapist and the patient are involved in a dialogue. We obtained research sessions that were recorded with permission of the therapist and the patient, and over the last three years subjected them to analysis. We produced data that we could then treat with the methods of chaos theory and bifurcation theory to look for a dynamical model for the therapeutic process. My own motivation term behaviour, while the attractors determine the long-term behavior. (See *IS JOURNAL #7/8*, "Social and International Synergy") What is most amazing about attractors 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 behavior, but most of them look alike.

DB: 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? That what has appeared to evolutionary biologists as chance and randomness may actually be a higher form or order?

RA: No.

was more general: to study any two people in interaction, or at least, in conversation. Therefore, throughout the process of trying to geometrize this relationship, I insisted on a certain amount of symmetry between the two actors, so that the work could be applied later to other two-person interactions, such as partnership in

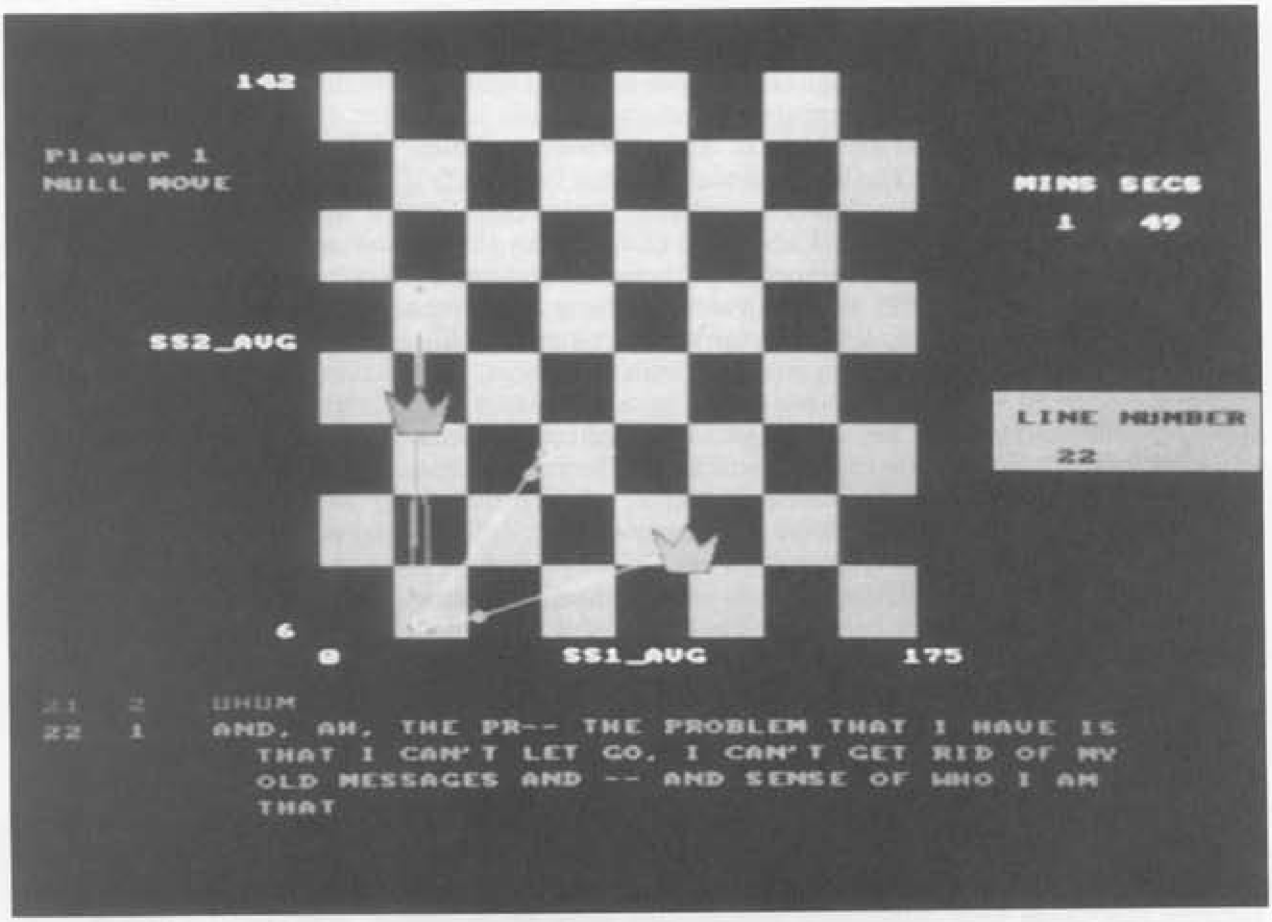

Figure 1. Interpersonal Chess.

I think that the understanding of dynamical systems theory presented in popular books is extremely limited. 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.

RM: 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?

RA: 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, perhaps, a monarchy before and a democracy afterwards. The monarchy was very steady, with institutions that you can depend upon, and so was the democracy. In the middle, you were constantly overrun by the troops or guerillas of one side

work, love, and family.

One project, now it its third year with Marsha King, is *Interpersonal Chess*. Our model is characteristic of the social sphere. There are really a lot of indicators, or observable variables. This year we made a computer graphic program to display the data. In order to see them, I invented a metaphor based on the game of chess. Figure 1 shows superscore one, *displacement*, on the horizontal axis, and superscore four, *anxiety*, on the vertical axis. The pieces move at the end of each ten seconds of speech.

INTERNATIONAL SYNERGY

INTERNATIONAL SYNERGY, is a complicated mathematical model derived from Ruth Benedict's concept of synergy as it applies to a society or tribe. She studied 60 tribes, most of them in the South Pacific and some in North America. Her idea was to take into account, on the one hand, a group with group goals and rules and so on, and on the other hand, individuals with their individual values and goals. When individual goals agree with group goals, the group had or the other. 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, but of a completely different shape. 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 much less chaotic than expected.

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 characterized by chaos or not. I guess it might, according to some measures and observations, and might not, according to others.

For the sociosphere, then, 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.

In the future, as global planet models become more successful, global social modeling will begin. The individual components still have to be modeled, such as the political and ec-

what she called *high* social synergy. But when individual goals are in opposition to group goals she called it *low* social synergy. I wanted to apply this concept to a tribe of nations, such as the League of Nations, or the Nuclear Club. I also feel that the transformation from a competing tribe of individual nations to a cooperative political and economical network may be envisionable within this modelling.

The first conceptualization of this project is described in *IS Journal #7/8 (1989)*. Admittedly, the model is hard to understand, so I decided to show the simplest society, of just two nations. As an example, in that paper, I present a binary system, in which each nation is modeled on a well-known dynamical model called the *cusp catastrophe*. I just couple two of them together.

DOUBLE CUSP

DOUBLE CUSP is an experimental study of a further simplified version of this two nation system. Before my paper on synergy, I had published a similar idea, a double cusp model for the arms race, in a paper called "*Mathematics* onomic systems of individual nations, their interactions, and so on. They have to be made into 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.

DB: 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?

RA: 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 does not 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 pro-

and Society: A Proposal" in the *IS Journal* two years ago. After this paper came out, I had a call from someone in the intelligence community in Washington. He said, "Do you know about Kadirov's work in Moscow? Well, we have an inhouse English translation. I'll send it to you." It turned out that in 1985 this Soviet systems scientist had come up with the same model for the arms race, which he studied extensively in computer simulation. When I saw his results, I realized the model could be improved by an application of pure mathematics called singularity theory. This year, a project to study the improved model was funded by the Los Alamos National Lab. This is an ongoing joint project with Gottfried Mayer-Kress, Alexander Keith, and Matthew Koebbe.

In this project of experimental mathematics (that is using computer graphics), we found a mathematical result which goes beyond what traditional mathematical analysis could have provided. In the modelling, there are two control variables for each nation: one variable is the perceived cost of a war, and the other is the extent of the fear of war

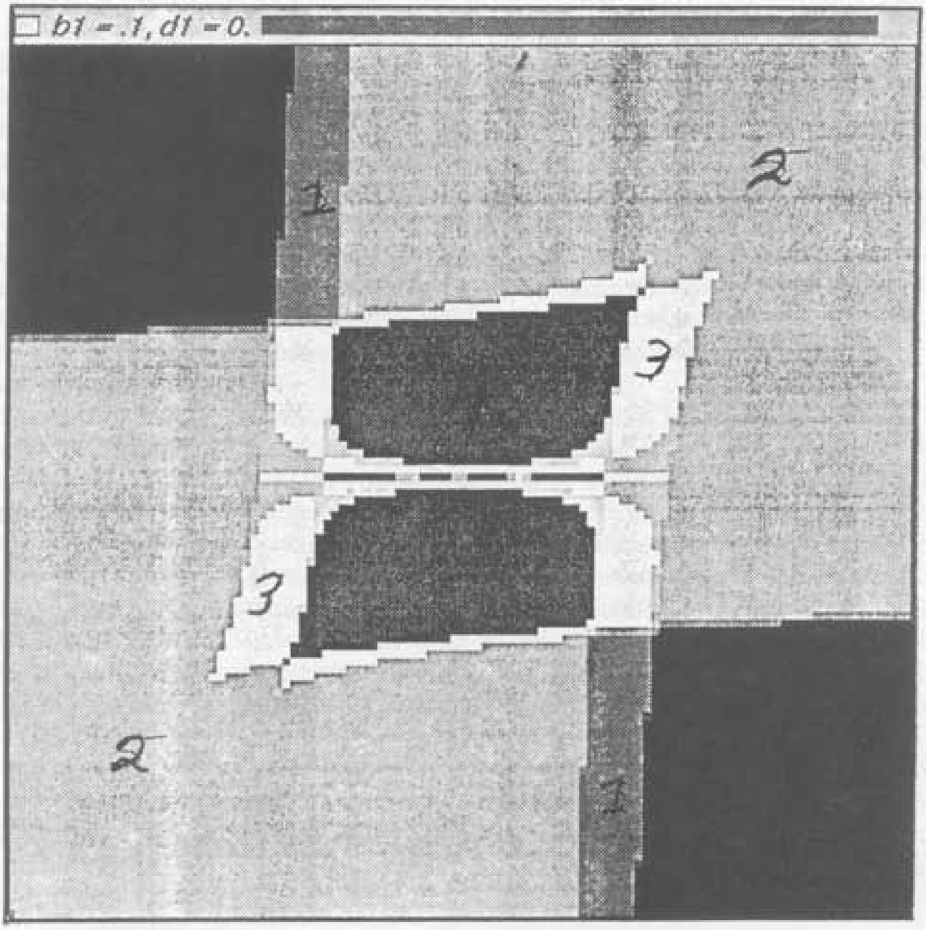

Figure 2. Bifurcations of the Double Cusp.

cess 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? 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

or the coefficient of paranoia toward the neighboring country. The state of each nation is measured by its armament. Altogether, for both nations, there are these six variables, including the strengths of coupling of the controls of each to the states to each other.

Figure 2 shows some of the results of our studies of this six-dimensional space.

more general kind of model we cannot say where we will be in the twenty-first century. Or if we'll be.

DB: 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?

RA: 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? From the perspective 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 recognized 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 context 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 about such things as how your mythology, your perceptual filters, function so as to limit your perception of the natural world to a certain paradigm in your consciousness. Such models, which I think are the essence of your question, would have to do with a more linguistic or symbolic approach rather than at the mechanical model level.

DB: Can you say more about your interest in resonance and its relevance to your work?

RA: I would like to understand how a person is in morphic resonance with a field. This interest grew out of my stay in India in the early 1970s. As you know, I spent part of that time living in a cave, which led to certain experiences. If we could say that experiments with computers represent mathematical research, you could see the evidence of the effects of these experiences on my current work. I came back from India in Jan-

Two dimensions are eliminated by fixing values for two of the control parameters. In the figure we are looking at a four-dimensional sculpture, a solid object in four-dimensional space. It is sectioned by a plane, at points in a complimentary plane. The sections are shaded in this way. Looking in the upper right corner you see some little squares that have several different shades. There is the dark gray, which means not bistable or tristable but quadrastable. There are four different states because they are double cusps. That is the area where one nation could have hawks and doves, and the other nation could have hawks and doves so you could have hawks hawks hawks, doves doves doves. That's the dark gray. And then the medium gray has only 3 states. The lighter gray has two states, and the lightest has only one state, which happens to be Kadirov's oscillator. If you are two nations in an arms race and you get in this oscillation, it is extremely expensive, because you are constantly dumping out all of your arms and then re-arming again. Of course, if this model is applied to a two peruary, 1973, and by January 1974 I had already become involved in experiments with chaotic resonance. This has dominated my research up to the present day. My computer experiments involve the concepts of vibration, harmony, resonance, and mathematical models for these phenomena.

If the metaphors of morphic resonance 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.

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. Let's say the vibration of two strings were chaotic instead of periodic, which means they would sound raspy and noisy instead of harmonious and sweet; could there then still be a sympathetic vibration of one caused by the nearby chaotic vibration of the other? 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.

Before this work with vabrations and resonances, we were involved with the general, skeletal structures of chaos. And resonance and these skeletons are related in that the theory of chaotic resonance is based upon an understanding of the skeleton, the so-called homoclinic tangles, as I've attempted to explain in my four picture books, ***Dynamics: The Geometry of Behavior*** — the third of which is on 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 behavior of all dynamical systems, which includes practically everything in the world: 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

son relationship, then that particular zone may correspond to the excitement of romance. We have models that could be applied to a wide number of different situations.

ORDER FROM CHAOS

ORDER FROM CHAOS, may be regarded as an application to the field of visual music, via digital video, of an branch of experimental dynamics called cellular dynamata. It is a supercomputer simulation of MIMI, the Mathematically Illuminated Musical Instrument, an ongoing project funded by the International Synergy Institute. This year, I received another form of support for this work, which was very exciting. It was the gift of essesntially unlimited time on one of the world's fastest image processing computers, the MPP, for Massively Parallel Processor. This is used at NASA headquarters on the East Coast, and is used for improving pictures that come back from satellites and space missions. I learned about this from my friend, Jack Corliss, during his stay there as a Research Associate of the National 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.

DB: Could you define beauty in a mathematical way?

RA: 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 provide 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

Reserach Council. As he informed me, the MPP has been only rarely used because only one person, John Dorband, can program it. We absorbed him into our team and did an experimental simulation of 16,000 computers all in a state of chaos.

Figure 3 is a single frame from a video of the MPP simulation of the toral logistic lattice. This experiment

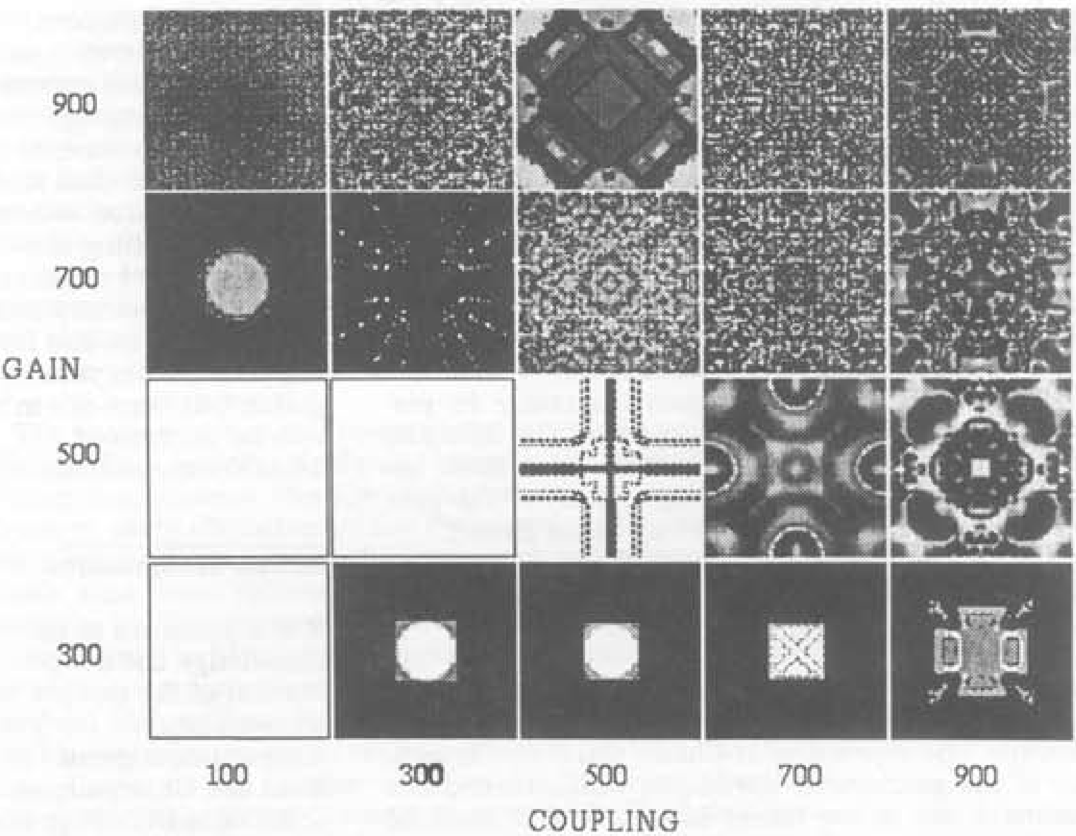

Figure 3. Order From a Field of Chaos.

mathematics, another is music, and then of course, mysticis — 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.

*RM: Speaking of mysticism, 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?*

RA: The repression of chaos began with the patriarchal takeover six thousand years ago. To look at an example of a high culture accepting chaos within their mythological pantheon as well as in their arts and behaviour, one has to go back to before that takeover. The most common example of such a culture is Minoan Crete. This culture was excavated by Sir Arthur Evans, though his reconstruction of the temples, religion, and society have since been seriously questioned by archeologists. A lot of what is known comes from mythology. From paintings we know of the dance with bulls. There were also the Bacchic mysteries, derived from the Orphic. Following this backwards, like tracing Ariadne's thread, you come to a certain mythic kernel associated with Minoan Crete. We know something of Dionysian ritual: the importance of music in Dionysian ritual, the dichotomy of religious ritual into two types, outdoors on the open plain and indoors in a cave. I wouldn't say these are expressions of chaos, but might be. The mystic revelation that came with Gaia is to see the planet as an organism, and the plain as its surface. Gaia is very chaotic, so if you reject chaos, you reject Gaia. They go together: the orphic trinity of Chaos, Gaia, and Eros.

Think about it. Gaia as the Earth, the love of the planet, the integrity of life-forms; Chaos as the essence of life — the more the chaos the healthier; Eros as human behaviour in resonance with Chaos and Gaia. It's rumored 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.

RM: Why do you think later Western Culture viewed chaos as an undesirable quality in nature?

RA: That's a big question. 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 — including its psyche, its mythology, its cultural structure — is an evolving system. This evolution is

amounts to taking 16,000 sophisticated computers, loading them each with a program from chaos theory, a chaotic attractor, throwing them on the tabletop at random, and allowing each one to be slightly influenced by four nearest neighbors. Out of that mess come these very regular patterns such as this. You could say that this is a model for genesis, the creation of the world from chaos, or a model for self-organization in a society after a chaotic transformation. We started with a very symmetrical pattern. This figure shows just one frame from a movie which is changing chaotically in time, at the same time that it is chaotic in space. When you are watching the movie, you are experiencing a trajectory in a spatial domain, like flying your plane, your glider, but here, it's in a special domain of 16,000 dimensions.

Acknowledgments.

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punctuated by bifurcations, mutations caused by the planetary equivalent of lightning. Consider comets. I would say comets were highly important in the history of consciousnes —still are. Comets effect mutations in the memes, the cultural genetic structure. Another mode of effecting change is by a kind of natural selection. This occurs when societies conflict over a common goal, due to, say, seasonal inundations and so on. In this conflict one would be selected, not just by military strength, but perhaps through the stability of its social structure.

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 start with. It seems likely that the human species is the wrong idea to start 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 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. I don't deny it, there is a certain promise there. 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 partnership. It could be that the root structure 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, like the Italian Renaissance, the age of the troubadors in the Twelfth Century, early Christianity, the Pythagorean Academy in Croton — were all episodes of the temporary resurgence of Orphic ideals that were followed by their massive and violent repression by the conservative society. Burning people at the stake seemed to be most appropriate to the patriarchal society, for repressing revivals of the preceding partnership form that involved 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 eventually broke up. A number of break-ups were caused by patriarchal, sexual jealousy. The Sixties came to an end.

DB: Would you say we are making progress?

DOUBLE CUSP; the gift of MPP time and other support from the Computer Systems Research Facility, of the NASA Goddard Space Flight Center, and from the Nonlinear Science Institute of the University of California at Santa Cruz, for ORDER FROM CHAOS. I dedicate this overview paper to Ken Boulding.

RA: I'd like to answer that with a story.

Actual communication with an animal is a rare experience for most of us. Some people are more sensitive to animals than others — they have a favorite pet, for instance. I myself have a special love for animals — which is one of the reasons that I'm a vegetarian. 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 I spent a lot of it alone, going on long treks on my skis, communing with animals and trying to figure out where they had been by the study of their tracks.

Anyway, much later when I was offered the opportunity to swim with John Lilly's dolphins, like most hippies, I had bought it, that dolphins were more intelligent than people. They had had the brilliance to flee to the sea a long time ago, and have lived there in peace ever since, except for tuna fishermen. I knew that they had 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.

I went to John Lilly's place in Redwood City for a routine swim with Rosie and Joe. They were very violently playful. 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 a little 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. Interesting — 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 thought up an experiment in telepathy. I swam out of the tank into a little nook to get my act together. I had the idea of lying still in the water, and fantasied they would both lie still as well, one of them facing me so that we were co-linear, head to head on a straight line, and then we would just exchange thoughts without any further ado.

Keeping this picture in my mind I swam out to where they were thrashing around in the water. 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 my experience down in the log book just as I told you. Not long after there was a revolt among John Lilly's crew over the question of conditions in the tank. That's progress.

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