

NEW CONCEPTS
IN COMPLEXITY THEORY

arising from studies in the
field of architecture

an overview of the four books of
the nature of order
with emphasis on the scientific problems
which are raised

christopher alexander**
may 2003

** For those who know Christopher Alexander primarily as an architect, it may perhaps be useful to draw attention to the fact that his education started in physics, chemistry, and mathematics, and that he spent a considerable part of his life as a working scientist. See endnote.

In writing this short overview for a scientific audience, it was very helpful to read preliminary comments made by Brian Goodwin, Ian Stewart, and Philip Ball who had just read selected pages from proof copies of Book 1. Their comments contained ideas and reactions that other scientific readers might share when first examining the four books of The Nature of Order. They were kind enough to draw attention, especially, to certain difficulties a scientific reader might have, in considering the problems introduced, or in making them useful to fields such as biology, ecology, physics, mathematics, or computer science, and extending to many matters currently covered by complexity theory. I have written this paper to make the connection to various scientific fields more clear, and to encourage comment and debate by working scientists.



P R E A M B L E

The four books of *The Nature Of Order* were written, originally, in order to lay a scientific foundation for the field of architecture. In writing them, over the course of the last twenty seven years, I found myself forced to confront unexpectedly deep problems, touching not only architecture, but other scientific fields as well. Some of these questions go so deep that they raise questions rarely, if ever, faced in the scientific community.

I therefore found myself trying to give answers to these questions; starting with answers at least adequate for the field of architecture. I was never writing directly from the point of view of physics, or mathematics, or cosmology, or biology, or ecology or cognitive theory. Yet all these fields are likely, in one way or another, to be touched by some of the findings I have made.

We thus have a situation, perhaps new, where architecture, generally, in the past very much the recipient of received wisdom from the natural sciences, is now generating new material, and new ideas of its own, which have direct bearing on the solution of problems now classed as "complexity theory," and doing so in ways which, though obviously helpful to anyone concerned with building, have not arisen before in the mother fields of science itself. To understand exactly what I mean, we might compare archi-

tecture today, with Grigor Mendel's garden of sweet peas in 1880. Sweet peas, then, were not part of science - merely a part of life potentially containing questions, originally unassuming in their content. Yet they implicitly contained questions and focused our awareness on new questions which became — years later — what we now know as genetics. That is the role that architecture, with its peculiar problems and challenges, might play for science today.

The situation is complicated by the fact that architecture itself (the field where I have most claim to expertise) has been in an atrocious muddle, intellectually. This muddle had to be cleaned up. And that was my main task during the last thirty years as a scientist; and as a builder of buildings and communities. (The huge difficulties in architecture were reflected in the ugliness and soul-destroying chaos of the cities and environments we were building during the 20th century - and in the mixed feelings of dismay caused by these developments at one time or another in nearly every thinking person, indeed — I would guess — in a very large fraction of all people on Earth).

Trying to come to grips with these difficulties, required construction of new concepts, able to cope with the massive and complex nature of the difficulties, and able to focus a ratio-

nal searchlight on questions which were, it seemed, largely beyond the reach of methods previously invented in other sciences. These difficulties arose, in part, I gradually discovered, from widespread but wrong-headed assumptions about the very nature of architecture — and, in considerable part, too, from the dry positivist view too typical of technical scientific thinking in the most recent era. But they also required new ways of thinking about issues which had not received much attention in the natural sciences, simply because there was no need for them in such fields as chemistry or biology.

Facing problems of architecture frankly, required conceptual breakthroughs in several areas, because one could not honestly confront the problems of design, without facing fundamental questions of human feeling, spirit, beauty, and above all two areas of content: the nature of configurations themselves, and the genesis of new

configurations (i.e. the processes by which buildings are conceived and made). So, whether I wanted to or not, I had to deal with these difficult matters, because they lie at the very root of architecture, and cannot be avoided: even though the scientific world view and establishment had previously not encountered them.

But this is where things get turned on their head — where it is architecture that informs science rather than vice versa. Architecture places a new kind of searchlight on certain new scientific areas of thought fundamental to the study of complex structures — and thus becomes relevant to a large class of problems recently beginning to gain attention in the scientific community itself. We therefore have the almost unprecedented case of architecture raising scientific concepts, questions, and answers, that bear on matters of hard science — but which have not, previously, been entertained.



BACKGROUND ON ARCHITECTURE

What are the essential problems of architecture that require a new focus, as it might be understood by any scientist who applied himself to the questions of architecture.

1. There are issues of value, that cannot be separated from the main task of serving functional needs. Thus, aesthetics — dismissed as subjective in much contemporary science — lies at the core of architecture.
2. There is the issue of context — a building grows out of, and must complement, the place where it appears. Thus there is a concept of healing (or making whole) and building into a context.
3. There is the issue of design and creation - processes capable of generating unity.
4. There is the issue of human feeling: since, of course, no building can be considered if it does not connect, somehow, to human feeling as an objective matter.

5. There is the issue of ecological and sustainable and biological connection to the land.
6. There is the vital issue of social agreement regarding decision making in regards to a complex system: this arises naturally when hundreds of people need to make decisions together - often the case in the human environment.
7. There is the issue of emerging beauty of shape, as the goal and outcome of all processes.

Considered carefully from a scientific viewpoint, these issues lead to certain questions, and to certain conclusions.

Architecture presents a new kind of insight into complexity because it is one of the human endeavors where we most explicitly deal with complexity and have to create it — not typical in physics or biology, at least not yet. Creation of software in computer science, is another such arena; and organization theory is another. In or-

der to succeed in this very difficult task, which poses challenges quite unlike those raised in physics or biology, I have encountered questions, and given solutions to problems, which I believe are not only useful in architecture (where they are demonstrably so); but that in part these solutions and new concepts are almost certainly transferable to help solve problems in physics, biology, and perhaps other fields. Although computer science and organization theory are the fields where this appreciation of complexity has first made itself felt, biology cannot be far behind: and even questions in physics, though apparently more simple, will (I firmly believe) ultimately turn out to depend on the same kinds of issues of complexity.

Let me give some numbers. We may understand by using the concept of mistakes. A typical house contains about 2000 man hours of labor. Studies suggest that in these 2000 man hours (including both design time and construction time) there is a potential for some 5 key decisions of adaptation, per hour. This means, if handled wrongly, there is opportunity for as many as 5-10,000 possible mistakes in the house — decision points where an error can be made. Or, on the side side, 5-10,000 cases where, if handled well, the house can have beautiful and perfect fit among its parts, and to its environment, and to its users' needs.

Of course an embryo contains a far larger potential for mistakes: 2^{50} or 10^{15} — a thousand trillion possible mistakes. But so far in the history of science, people have not actually confronted the necessity of generating mistake-free

adaptation; [i.e. they have not had to put theory into practice, beyond observing, what nature itself practices for us].

Architecture, because it is so ordinary, affects billions of people, and covers a huge volume of physical stuff, is, from a study point of view, and from a theoretical point of view, one of the first cases we have encountered collectively, as a civilization, where it really matters whether you do things right or not [with the emphasis on *do* — i.e. this is about practice mattering].

And it is here, for the very same reason, that new theory is forced into existence. The insights into complexity raised in these four books are related, without doubt, to the insights that have occurred in the last decades of biology, meteorology, etc. But they are different in kind. In those fields the scientists are passive as to the issue of creation. In architecture, we are the active proponents. We have more at stake. If we are wrong, we create a mess. And the insights we have gained, so far, though vaguely related to the insights gained in physics, chaos theory, and biology, are unique, more powerful, more practical — and if I may say so, far deeper in content than the insights gained in the passive sciences.

That is why we must start paying attention to architecture, as a major source of insight in the field of complexity. The creation of fine-tuned, well-adapted complexity — as encountered for example in architecture — must now take shape as a major topic of theoretical science. Our ability, or failure, to master this science, is crucial to our survival.

SOME EMERGING SCIENTIFIC
CONCEPTS BEARING ON COMPLEXITY
WHICH COME FROM STUDIES IN
THE FIELD OF ARCHITECTURE



1 / WHOLENESS AND VALUE AS A NECESSARY PART
OF ANY COMPLEX SYSTEM

What can be a measure or criterion of success for a complex system? If a self-respecting scientist was to tackle the problem of giving structure to the world, in the large — and that is essentially the problem of architecture — then regardless of what shibboleths may say, there must be a shared criterion of success. If science, as presently conceived does not have one that is useful for architecture, then regardless, we must, of course, find one. And for it to be shared, we need to find one which is essentially universal, yet capable of being shared by people of different faiths, cultures, and opinions.

The positivistic, value-free idea of art, which came from science, and the desire that science had to create a value-free science, pervaded most 20th century thought, and finally infected architecture itself - one of the silliest intellectual transfusions of all time - since of course architecture - by its very nature -- cannot manage without a common sense shared criterion of good quality.

Indeed, as we may see upon reflection, a variety of other scientific fields would also benefit if value were understood to be a necessary part of the study of complex systems. Biological systems cannot be viewed as value free, ecological systems cannot, land management and erosion control, and hydrological management in the large, also cannot manage without a criterion of what is

good. Nor, frankly, can an ordinary activity like gardening. Genetics is plainly in a situation today, where problems of value are beginning to surface. And software design, has run into the very same problem, and software engineers and computer scientists have begun to realize that a sense of value, if objective and careful, is almost the only thing that can get them out of the present mess.

The very first thing any scientist would do, if trying to make a sensible theory of architecture, would be to recognize that there must be, at the bottom of it, a shared notion of quality, of what we are, collectively, aiming for.

If everyone is trying to do something different in a town or community, different in kind, not different in detail of execution, then of course there will be chaos; just, indeed, what we have experienced in modern urbanism.

Yet for the last hundred years or so, there has been a taboo in the scientific community which virtually forbids a scientist (when talking as a scientist) from talking about value or quality as though they really exist. Instead, it has been an article of faith that good science comes only when we make abstract machine-like pictures that do not let our feelings or judgments of goodness get in the way.

This has been a useful article of faith, and has served science well for four hundred years.

But it cannot serve us well now. Why? Because, although it is a feature of non-complex systems that they can be studied without focusing on value, it is also a feature of complex systems that they can not be studied successfully in this way.

Although science (and 20th architecture, too) managed to get through the 20th century, by refusing to come to grips with this problem, in fact in the long run we cannot get on without solving it. It MUST be solved in some form. In the spirit of science we shall not expect to solve it all at once. But we must make an effort, make a tentative stab at it .. and try it out, and then see how we are doing, and improve what we have, until we get something workable.

Of course architecture in the 20th century also contributed to the taboo on talking about quality or goodness as though it really exists. Infected by positivism, by postmodernism, and by deconstructivism, and exhilarated by a phony pluralism of "anything goes," architects tried to get by, by saying everyone should do "their" thing. . . each person is entitled to his view, her opinion, and so on. All true enough as comments on the freedom of human beings. But not a way to do architecture successfully. You cannot throw the baby out with the bathwater in quite

this way, and go on to say there is no such real thing as quality in architecture. This attitude destroys truth to such an extent that it cannot make a successful environment.

So, continuing to repeat the mantra that we scientists should not mess with value, is becoming short sighted and silly. The fact that in architecture - if we keep our common senses - we MUST deal with questions of value, does not mean that science cannot benefit from architecture. On the contrary, it means, rather, that the existence of such questions in architecture - if sensible answers are given to them - is likely to be a source of inspiration and encouragement to other sciences which are suffering from the same problem.

But of course, acknowledging that it would be desirable to have a shared criterion of value is only the first step. That, by itself, does not get you to an operational process for establishing shared value, or to a sharable, operational procedure for evaluating a part of the environment, in a way that can get shared results. It seems to me that we would do best if we agree to keep this an open question, and not close off the possibility of it being solvable, merely according to scientific taboos.



2 / AN INTUITIVE MODEL OF WHOLENESS AS A RECURSIVE STRUCTURE

If we ask ourselves what kind of criterion of value we might be able to rely on, and especially what kind of criterion we might wish to rely on as a standard for the goodness of a complex system, it would be rather reasonable to say something along the following lines:

In a good system, we would expect to find the following conditions: Any identifiable subsystems, we would hope, would be well — that is to say, in good condition. And we would hope that the larger world outside the complex system is also in good order, and well. Thus, the mark

of a good system would be that it helps both the systems around it and those which it contains. And the goodness and helping towards goodness is, in our ideal complex system, also reciprocal. That is, our good system, will turn out to be not only helping other systems to become good, but also, in turn, helped by the goodness of the larger systems around it and by the goodness of the smaller ones which it contains.

Is this a platitude, perhaps too vague to be taken seriously, or worse, tautologous? Not at all. As we know from recursive function theory, sur-

prisingly simple ideas, when applied recursively at a variety of nested levels, can have profound and effective consequences - and, often, surprising ones. Both Ian Stewart and Brian Goodwin acknowledge the importance of recursive ideas, and say that in their view, too, recursiveness of qualities is likely to be a feature of all living structure.

So, although it appears to be circular to use goodness as a concept within the definition of goodness itself, this apparent circularity is only apparent, not real, and a recursive structure of this kind, if followed through, can have remarkable and deep results.

And, as a word of caution to the reader: Is this definition trivial, when applied in practice? Indeed it is not. We have only to imagine a row of houses, in which every house helps the street; and in which every garden helps every house, to see that even this simple description already takes us far beyond present day architecture. Clearly contemporary housing estates or tracts do not achieve this ideal, even according to the most intuitive judgments. So this seemingly obscure yet actually concrete statement is very much

about something, not merely a collection of empty words.

Indeed, if the world were marked by systems, large and small, of which this criterion (that each system helps the other systems, in concrete and discernible ways) could be said, the world would obviously be a much better place. Water, food production, vegetation, social conditions, families, education, roads, parks, the rooms in a house even, the very windows too, would all be better. This criterion is a deep one, and it behooves us to find a precise and reliable way of ascertaining what it means (in precise terms), and of applying the criterion to real cases, so that we can judge their successes and deficiencies.

The only problem is that we do not yet have a powerful mathematical representation powerful enough to achieve this, just as we do not yet have a satisfying mathematics of embryonic growth. In *The Nature Of Order* I have taken first steps — very tentative ones — towards just exactly such a representation, incomplete though it may still be.



3 / A MATHEMATICAL MODEL OF WHOLENESS IDENTIFYING WHOLENESS AS A WELL-DEFINED RECURSIVE STRUCTURE OF A NEW TYPE

There is a relatively long-standing tradition of talking about wholeness of spatial configurations and situations in the world.

It has been recognized informally, sometimes more strongly, that wholeness is the key to many naturally occurring events, phenomena, and aspects of system behavior. For example, Bohr's insistence that the key to quantum mechanics lies in the dependence of the movement of electrons on the configuration and behavior of the whole; Bohm's discussion of the wholeness of a quantum experiment as the origin of the behaviors of electrons in the field; Goldstein's discussion of the human organism; Wertheimer's

and Kohler's discussions of gestalt phenomena in figure recognition and cognition. The term has also, in recent years, been used in a variety of religious and therapeutic contexts. However those, almost always well intentioned, have rarely, if ever, been clear.

As a result of experiments I conducted at the Center for Cognitive Studies at Harvard in the early 1960s, I became convinced that wholeness, "the wholeness we see," is a real, well-defined structure, not merely a cognitive impression. That the thing we recognize as the "gestalt" of a figure, the pattern of flows in a hydrodynamic field, the "something" about an individual hu-

man face which seems like that person's wholeness, and which we recognize instantly, is - in each case -- a describable mathematical structure.

However, there was no then-existing mathematical structure I knew of, which was able to capture this "something" or which could embody it.

After several years of thought, as to how this structure might be represented, I came to the conclusion that the crucial issue lay in the nested system of wholes that cover the space. By a whole I mean any relatively coherent spatial set, with the understanding that different wholes may have relatively different degree of coherence. The

wholeness, then, of a particular configuration, is an ordering on the different overlapping and nested wholes and systems, according to their degree of coherence - in short the relative coherence of the entire system of sets and subsets in a part of space. I became sure, slowly, that this system of sets with relatively different levels of coherence, was the clue to the kind of structure which would capture "the" wholeness.

The wholeness is that global structure which pays attention to, and captures, the relative strength of different parts of the system, paying attention both to the way they are nested in one another, and how the pattern of strength varies with the nesting.



4 / OBJECTIVE MEASURES OF COHERENCE IN COMPLEX SYSTEMS, AND THE UNAVOIDABLE RELATIONSHIP BETWEEN STRUCTURE, FACT, AND BEAUTY

There is a sense in which Philip Ball and I differ profoundly. The substrate of his view of science — at least as it comes across in the interview — seems to be that science is about facts, and therefore it cannot be concerned with aesthetics, because aesthetics is inherently concerned with matters of subjective human judgment, except insofar as aesthetics is considered a matter of cognition. Possibly Ian Stewart, too, shares some such view — at least some of his comments on Jencks suggest that may be so. My view is that aesthetics is a mode of perceiving deep structure, a mode no less profound than other simpler forms of scientific observation and experimentation.

How true is it really that aesthetics is non-factual? And, I would ask, especially, how true can this be, as our scientific efforts move into the new territory of highly complex structures?

Consider the relatively simple question of coherence. Within complex structures the relative coherence of different parts, different systems, is paramount, and plays a paramount role

in their behavior. But there is a very thin line - in fact, I would argue there is no substantial line at all -- between the issues of relative coherence of subsystems in a physical-mechanical system, and the more complex distinctions of coherence in an aesthetic entity - the phrasing of a piece of music for example.

We routinely study relative coherence in crystals and economic systems. For example we can analyze the cleavage planes by seeing that some portions of the crystal are relatively more coherent than others, and that fractures will occur between the more coherent parts. We can analyze the subsystems of an economic system by studying inputs and outputs and decomposing the matrix. Such things can be analyzed by a variety of mathematical techniques all depending on numerical analysis of relative degrees of connection within, and between the subsystems.

The relative coherence of more complex entities — the relative beauty of one column in a building, versus another, uglier column — is susceptible to precise observation, and can be made

a part of science by new kinds of experiment, using the human observer as a measuring instrument. If we can construct these experiments in such a way that we get agreement among different observers, and thus obtain hardnosed observations of relative coherence in these more complex cases, in what way is it helpful to call these judgments subjective?

I believe it is retrogressive, and will merely close the door on study of more complex phenomena, to state that we should ignore such observations as necessarily subjective. Rather it seems to me that they must be studied, if we are to understand the newly complex systems we aspire to deal with within 21st-century science. At the very least we should leave the possibility open.

Indeed, as I have suggested in the books, wholeness itself is a cousin-like structure to topology - akin to structures in topology where we have a system of nested overlapping sets, some "open" and others "closed." In the case of topology, there is a two-valued measure for the different sets, τ or \circ , open or closed. In the definition of wholeness I have offered, we have systems of nested, overlapping sets which can take an infinite set of coherence-values from \circ to τ along the continuum of least to maximal coherence. The wholeness, so defined, describes a vast family of structures that comes from differentiated relative coherence, and shows (at least aims to show) how that structure of relative coherence then creates (by recursion) the coherence of the larger structure.

Obviously, this structure cannot be studied - or even thought - without introducing the idea of coherence as an objective concept. It is in this sense - possibly disturbing to scientists unused to the idea of recursion - that the conceptual framework is recursive.

Further, the issue is greatly complicated by the fact that the relative coherence of one set, depends on a recursion of values which are given to its subsets. I am only too aware that we do not yet have a nicely worked out mathematical

model for this idea. But, albeit preliminary, it is in any case a mathematical model of a new type - and one suggested by architecture.

Wholeness itself, for example, cannot be discussed without making evaluative statements. So where will science be, if it cannot effectively discuss wholeness. Wolfgang Kohler recognized this problem about seventy years ago . . . but hardly anyone reads Kohler any more.

Scientists speak constantly as if there is some kind of great divide between fact and aesthetics -- the one the province of science ; the other the province of subjectivity and art. Yet the whole purpose of my four books, is to demonstrate that we cannot have an adequate world view without a single view of science that embraces both what we now think of as fact, together with what we regard as aesthetic facts and observations.

Where after all, did the idea come from that aesthetic judgments are subjective? The ancient Greeks did not think of them as subjective. Nor did the Romans. Nor did the ancient Chinese. Nor did the great artists of Islam. Indeed the idea that aesthetic judgment is subjective is a relatively recent arrival on the scene of human thought, and one which was recently fueled by the positivist and mechanistic way of thinking less than 100 years ago - which scientists themselves are now rejecting.

There is no need for such arbitrary pronouncements. Indeed, such pronouncements will kill genuine scientific investigation in advanced complexity theory, not help it.

After all what is science? It is the study of what really happens, how the world works. Done in such a way that agreement can be forged by clear thought, and by empirical procedures. That is the picture I have provided. There is clear thought about structure; and there is empirical basis and procedure specified, which allow people to form agreed on shared observations, and thereby to reach — at least tentatively and roughly at first — shared understanding, and reliable results.



5 / FIFTEEN GEOMETRIC PROPERTIES AS NECESSARY AND
INEVITABLE GEOMETRIC FEATURES OF REALITY
IN ANY COMPLEX SYSTEM

The possibility, which is set out in *The Nature of Order*, that wholeness is built, essentially, from fifteen features of space, comes very close indeed, to Brian Goodwin's "science of qualities." These fifteen features are described at length in chapters 5 and 6 of Book 1, where they are described as they arise in artifacts, and as they arise in natural systems. Goodwin has made a compelling argument that qualitative features are observable, and objective in the sense that they are apprehended by many observers. He implies, but does not exactly say, that these features - macro-features of systems which are not necessarily to be described by numerical parameters - do control vital aspects of behavior, interaction, and dynamics. Thus they are not only important because they are there, but also because they often play a controlling or decisive role in the behavior of the systems where they occur.

This corresponds closely to my own view. In the description of functional behavior given in Books 1, 2 and 3, again and again, it is the fifteen properties which play a decisive role in the way things work. This is, I believe, because the 15 properties describe the way that centers are made more alive. Any interaction, in which one coherence interacts with another, will often circle around the way that centers in mutually interacting systems support one another, or modify one another - often to create a new wholeness. That this should happen when the properties come into play, is only natural, since it is these properties which cause the functional behavior of the aggregate. There is, in my view, a link between the larger, more qualitative aspects of systems, and their functional behavior.

Thus, in the properties described in Book 1, and in the dynamic aspect of these properties

(the transformations described in Book 2), we gain insight into the dynamical emergence of new structure and new behavior.

Let me give an example. Boundaries, and especially thick boundaries with substance, can play a role in helping the goodness of a center, or in strengthening a center. This happens because, if two systems are interacting, the boundary condition is often turbulent or a source of possible confusion. When the boundary zone itself has dimension, it can then take on an "in-between" structure, which mitigates or smoothes out the potential interacting processes in the inner and outer zones. Familiar examples are to be seen in the very thick boundary around a living cell (which contains so much vital functionality), in the edge ecology between a forest and a lake, or in the corona of the sun which mitigates the interactions of the sun's interior and the processes taking place further out in the near vacuum beyond.

The boundary plays a huge role in the effect and behavior of any system made of other systems, since the system will literally be riddled with such boundary layers and boundary zones. Although one cannot say that every center must have a boundary of this kind, it is certainly one of the ways in which a living center gets its stability and strength, and capacity to interact with other systems.

Not surprisingly, then, a transformation which gives a given entity such a boundary zone — not a very difficult kind of transformation to induce mechanically as part of any developmental process — is likely to create a niche for desirable effects. The transformation which preserves and enhances structure, by introducing boundaries, is likely to bring with it a variety of positive effects. Thus evolution, ontogeny, planning, building, and design, are

all likely to benefit (at the very least in a heuristic or probabilistic fashion) from such transformations.

The idea that there can only be a limited

number of these transformations, and that there is a calculus of these fifteen transformations as the driving force of all emergence, must of course be a matter of enormous interest.



6 / A MEETING POINT BETWEEN COGNITION AND OBJECTIVE REALITY?

Ball especially, and to some extent Stewart too, come again and again to the notion that what I have described is really all about cognition; that is, about the structure which appears in our minds - not the structure which appears in the world. As such it may have something to do with cognitive theory, but sheds little light on the "hard" sciences as a commentary on how the world is made.

This is a very deep issue, and in some respects it is the central kernel of my claim that *The Nature of Order* is about science and about the nature of the universe, not merely about human cognition or psychology.

Let us begin with the idea that it is in any case indeed *also* about cognition. Here Ball and Stewart would agree with me, I think. The idea of wholeness as a recursive structure made of locally occurring centers, that centers are made of other centers, and the idea that the fifteen properties are the main glue that makes sense have coherence . . . these are all legitimate concepts for cognitive theory. So, too, is the concept that the more coherent a thing is, cognitively, the more it will be seen as a picture of the self, or of the soul - as a subjective experience of the knower.

And indeed much of this material had its beginnings in work I undertook, forty years ago, in the Center for Cognitive Studies at Harvard, where I was then working experimentally on problems of cognition under Jerry Bruner and George Miller, with Bill Huggins, Harris Savin, Susan Carey, and others.

I myself, when I am in my most sober and pessimistic mode find the cognitive interpreta-

tion useful, mainly because when we think of the results this way, it is then quite certain that they all make sense within a familiar mechanistic mode of thinking. It is a failsafe way of looking at the theory, because it is unassailable, verifiable, and poses no deep and unpleasantly disturbing problems of ontology.

But that does not mean that it is true, or that it is the most interesting or deepest way to understand the scientific meaning of the facts I have presented. Obviously, if the facts are facts about the universe, they will indeed also show up in cognition, and the cognitive interpretation will hold up. It is, therefore, an entirely safe interpretation.

And of course, one could also have a theory of architecture which is cognitive in origin, and based on cognition for its foundations. This would, however, be rather narrow -- even arbitrary. After all, why should we pick a cognitive theory of architecture? Why not an anthropological theory, or an ecological theory, and so on.

More important, the theory sheds practical light on issues which have no connection with cognition. For example, structural design is made easier and better, when viewed from the point of view of this theory. The flow of forces in a complex system of structural members, can hardly be dismissed as a cognitive problem. The forces have real behavior and real existence, outside of ourselves. If this theory of wholeness and unfolding leads to good results, and enables us to find structures which elegantly and cheaply resolve the forces, we have crossed over into questions of physical reality. Yet, it is just so. Accu-

mulated evidence from my laboratory shows, in case after case, that it is so.

Similarly, problems of traffic flow are made more solvable, from within this perspective. Although traffic flow is, remotely, a cognitive issue, this is once again stretching the point. Here again we find the theory giving us useful, sometimes penetrating insights into realistic problems of design in a physical field that is largely independent of human cognition.

The flow of water in an ecologically sensi-

tive landscape, is also helped by concepts from this theory. Once again, this subject, in recent years an object of considerable study in ecology, cannot be considered a cognitive problem. It is a problem about the complex living system which occurs in a hilly terrain on the earth's surface. Yet, again, there is convincing evidence to suggest that the concepts of wholeness, centers, fifteen properties, and structure-preserving transformations, shed useful light on ways to organize water and riparian areas in a terrain.



7 / A NEW, EXPERIMENTAL WAY OF DETERMINING DEGREE OF COHERENCE, DEGREE OF LIFE, AND RELATIVE VALUE

In *The Nature Of Order*, an entirely new empirical procedure, very different from traditional forms of experiment - has been proposed. It has three characteristics:

(1) The procedure asks a person to evaluate, experimentally, through subjective self examination, the degree to which a certain system, or thing, or event, or act enhances the observer's own wholeness.

(2) It turns out that people are able to carry out this process.

(3) It turns out that there is a very considerable degree of agreement in their findings.

It appears then, that after centuries, there may exist a reliable and profound empirical method for reaching shared judgments about the degree of value inherent in a complex system. For reasons that are discussed extensively in *The Na-*

ture of Order; and especially in Books 1 and 4, there are powerful reasons for thinking that the value which inheres in wholeness reflects on physical reality. It is not like the kind of trivial social agreement we get when a hundred people say, "Yes we all love Big Macs best," something we might loosely call merely intersubjective agreement. It is a different kind of agreement, which reflects on real physical systems, and is more akin to the agreement several different cancer specialists might share when they say that a certain person's haggard features suggest the presence of an undetected tumor. This is not at all like the agreement shared by the Big Mac enthusiasts. It is a judgment, not an opinion, and is a judgment about reality which can be tied to the presence of definable underlying structures. Just so with the cases I describe in *The Nature of Order*.



8 / THE SCIENCE OF COMPLEXITY MUST MAKE ROOM FOR
SUBJECTIVITY, NOT IN THE SENSE OF IDIOSYNCRACY
OF JUDGMENT, BUT AS A CONNECTION
TO THE HUMAN BEING.

Philip Ball says my "definition of life" as given in *The Nature of Order* is "utterly subjective." What does he mean by this?

To untangle this statement, one must distinguish sharply, between two meanings of "subjective," two quite different ways in which the word is used.

(1) We can call a judgment subjective, and mean that it is idiosyncratic: that is, it is a product of one person's mind or ideas, and not part of shared canon, or capable of being part of a shared canon. That of course, is a valid criticism of anything purporting to be scientific, since the essence of science is the achievement of judgments that can be shared, and established according to well-defined experiment.

(2) We can also call a statement subjective, if it engages, or includes, the personal subjectivity of the observer, the I-ness or consciousness or feeling of an observer. This is fairly commonplace in science. It occurs for example, in Chomsky's famous opening of structural linguistics, when he used his own perceptions of what is grammatical, knowing that others would make roughly the same judgments he made: and that structures perceived therefore had objective standing, even though subjective in the way they were experienced.

Now, it is certainly true that *The Nature of Order* is filled with examples of this second kind, since union of system behavior with the subjective experience of the observer is fundamental to

what I have to say, fundamental to the idea of wholeness as something not merely present in an objective material system, but also present in the judgment, feeling, and experience of the observer. In short, cognitive/subjective experience is affirmed by objective reality.

In accusing me, if that is the right word, of subjectivity, Ball implies that some bad science has crept into Book 1 (subjectivity of type 1); when in fact it is only in the second sense that my comments are subjective, but not in the first.

Possibly one of the most important notions in a valid theory of architecture, is that the judgments of fact, about quality, reside in reachable feelings in any human observer. Indeed, the neutral observations we need, in order to reach adequate discussion and comprehension of wholeness, are observations of a type which *can only be obtained when we agree to use the observer's feeling of his or her own wholeness, as a measuring instrument*. Yet, subjective as it sounds to our mechanist ears, this is nonetheless objective. It opens the door to a new standard of observation, and a new methodology of measurement. In architecture, anyway, where my observations have been most careful and extended over several decades, I can say positively that valid and profound results, and findings, cannot be reached without meeting this condition.

I strongly suspect the same will turn out to be true in the other scientific disciplines dealing with complexity.



9 / LOCAL SYMMETRIES AND SUB-SYMMETRIES

In a coherent structure we are likely to see a well-developed system of local symmetries and

sub-symmetries. Thus, complex systems will be marked by a preponderance of local symmetries,

usually appearing in a framework of larger asymmetries. I have always been interested in Ian Stewart's discussions of symmetry, symmetries, and symmetry breaking, and have myself spent quite some time making calculations about symmetries, and trying to find out how they appear in complex systems, and how they influence the structure of complex systems. Moving on to mathematics, I will now give an example from symmetry, which shows something of the kind of power, in very exact mathematical terms, which the wholeness structure has potentially within its scope.

A number of years ago, I made a series of carefully controlled experiments to study simple configurations of black and white squares, and to obtain estimates of their relative simplicity and coherence. To do this I used experiments designed to measure ease of perception, ease of giving a name, speed of recognition, ability to remember, and so on - a variety of cognitive measures, each susceptible to precise experiment.

Several findings:

First, the strong correlation between all these measures, although they are cognitively quite different in character and process.

Second, very strong overall correlation among subjects: meaning that what different people see as simple or coherent is measurable, and does not vary enormously from person to person.

Third, that differences of perception disappear altogether when we induce people to see configurations in their wholeness. Experiments show that such a holistic mode of perception is achievable, natural, and that once it is attained it is stable and reliable.

Armed with the results of these experiments, I set out to find a common factor which explained the rank ordering of coherence among the different configurations. It took two years to discover it. Finally, it turned out that when you count the total number of sub-symmetries in the pattern (not the overall symmetry, but the set of all local symmetries in connected sub-regions of the configuration), the most coherent patterns are those that have the largest number of local sub-symmetries within them. This does not mean they are globally symmetrical configurations. It is a totally different kind of quality.

Now, what is interesting about this quality, is that it is plainly a deep structural feature of the configurations - not something about the way they are seen, but something about the way they are.

Further, the presence or absence of this kind of coherence is strongly correlated with appearance of structure in nature, in buildings, in crystals, in fluid flow, in plant colonies and so on. And, indeed, it is not far from that observation to the observation that transforming a structure to increase its density of local symmetries, is one example of the kinds of structure-preserving transformations I have described in Book 2. There is no way this can be dismissed as cognitive.

It is mathematics: and it is mathematics of real physical structures that unfold in three dimensional space. But it departs in an interesting way from present conceptions of mathematics, and once again provides insight into the kinds of developments which may be expected, when one starts working with the model of wholes and wholeness that I have described.



10 / DEEP ADAPTATION AS A CENTRAL CONCEPT IN COMPLEX SYSTEM THEORY AND IN ARCHITECTURE

I define deep adaptation as the type of spatial adaptation which occurs between neighboring

elements and systems, and which ultimately causes the harmonious appearance and geomet-

rical cohesion we find in all living matter. Deep adaptation is the process whereby the landscape, or a system, or a plant, or a town, proceeds by a series of spatially organized adaptations in which each part is gradually fitted to the parts near it: and is simultaneously fitted by the whole, to its position and performance in the whole. This concept, greatly needing elaboration, is possibly the most fruitful point of contact between the theory of complex systems, and the problem of architecture (it is the subject of a new book, now in preparation). Interestingly, neither biology, nor ecology, nor architecture, nor city planning, so far have a profound or illuminating model of this kind of adaptation: mutual adaptation among the parts *within* a system.

Adaptation, as a general idea, is a vital concept, for example, in John Holland's writing on complex adaptive systems. But sophisticated as Holland's work is, the adaptation he describes is nearly always described as the process by which systems of numerical parameters are brought within certain numerical ranges. Complex adaptation is then described as adaptation for many variables, at once, often interacting. But little of this kind of thinking has yet allowed us to form a good mental picture of what an adapted system really is, *structurally*, when it occurs, nor how we might picture it in detail for ourselves.

What does adaptation among parts typi-

cally look like in a landscape? What physical structure does it have, typically, when it has occurred in a system? Well of course, that is what my effort to describe living structure in Books 1 and 2 and 3 of *The Nature of Order* is all about. I have tried to focus on the physical character of a highly adapted or co-adapted system. But this is a first attempt, hardly paralleled at all, by contemporary writing in physics, or biology, or ecology.

As a result, not only is our understanding of adaptation limited: we are naive, almost like infants, when it comes to inventing an adaptive process which creates suitably complex, beautiful, and sophisticated well-adapted structure in almost any real-world system: among others, highly adapted structures in a farmer's field, or in a town, or in a street, or in a room.

In Wolfram's *A New Kind of Science*, for example, fascinating as it is, and ostensibly about complex system theory, there are 1200 pages discussing the richness of step-by-step recursive systems of rules. Yet there is hardly a word (actually, there is not one single word, I believe), on the question of how such rule systems, for all their richness, might be aimed at the production of good structure.

How can we even say that we have a theory of complex systems, when we have so little to say about the most crucial point of all?



11 / THE ABSOLUTE NECESSITY FOR SUCCESSFUL ADAPTATION TO BE ACHIEVED BY GENERATIVE MEANS

Philip Ball remarked in his discussion, that he believes I may be right that the processes of architecture (and construction) would need to be dramatically changed, in order to help create a living world.

I found this comment reassuring when I read it, since it seems to me to illuminate one of the deepest points of contact between architecture and science.

The idea that complex structures can only be made successfully by generative techniques is obvious in biology, but not yet obvious in architecture. Nor is it obvious in organization theory, or in computer science, hardly even in ecology where it has perhaps made some headway. Yet in all these cases generative methods must in the long run be applied if we are to succeed in creating living structure on the surface of the Earth.

I had an extraordinary discussion recently with a consultant in management theory, who was interviewing me. I discussed with him the idea that adaptational complexity - hence the richness and depth of structure needed in a complex organization - can only be achieved by generative means. We were discussing the case of architecture, where it is also something almost hidden from view, and has been replaced with the silly and impossible idea that good design (on the drawing board) can make up for step-by-step adaptation.

My interviewer was enthusiastic. We spoke about human organizations, and I asked if it was commonly understood that a complex organization would only be created step by step, that is to say, generated; and asked how this was working in contemporary American corporations. "Oh, we only talk about it," he said. "Even though it is obvious, almost no one actually does it, or tries to generate a living structure of a human organization by these means."

I tried to push it. "Are there not at least the

ories, ideas how to do it, floating about in the most advanced circles," I asked. "No, no one really tries to do anything like that," he said. "It is just a theoretical idea."

So to him it was obvious, necessary, true . . . yet for all that, it has not yet been placed on the agenda of practical action in the business world, a place where innovation is usually rapid and inventive.

Wolfram has done a great service by placing attention on the impact of generative methods, and on the extraordinary richness of generative schemes, and generated structures. I have made similar inroads in a different sphere. In Book 2, I have described a new class of generative sequences for architecture: and have argued, I think truly, that living structure cannot be attained in any sphere, without such generative sequences.

The difference between my generative schemes and Wolfram's is that mine are uniformly based on one target: the target of generating living structure. They are not morally or ethically neutral.



12 / THE EFFECT OF STRUCTURE-PRESERVING TRANSFORMATIONS ON THE WORLD AND THEIR ROLE IN THE UNFOLDING OF WHOLENESS

In my view, possibly the most significant single scientific idea in *The Nature Of Order* is the concept, first presented in Book 2, of a structure-preserving transformation. This concept arises, naturally, from the concept of wholeness. Once we have a concept of wholeness which is not vague mumbo jumbo, but a coherent and in-part mathematically definable structure for any given configuration, we are then able to ask, of any change, or modification of this structure, or for any evolution of that wholeness, whether the new wholeness emerges and continues naturally from the previous state of the structure, or if it is in some sense a violation of its previous structure.

In any case, complexity theory itself certainly has the knowledge and vision about the importance of dynamic approaches to adaptation. Genetic algorithms, annealing algorithms, and the entire theory of computationally derived dynamic structure, all attest to it. Yet, where in complexity theory, is there a straightforward, common sense exposition of the general principles underlying the successful adaptation of a complex structure, in real time, as a real practical matter?

Possibly the most important lesson of the discussions in *The Nature Of Order*, lies in the way that the concept of a structure-preserving

transformation or wholeness-preserving transformation — fundamental to the proper design or planning or construction of any building which has life — may turn out to be a foundation stone, in the end, of the whole science of complexity theory.

I believe it is clear to us, intuitively, that it is very hard to reach a well-adapted state of any system we are trying to meddle in, or build. It is certainly clear as a topic in theoretical biology where Stuart Kaufmann, for example, has tried to show how this happens in a typical biological system. To my knowledge, the difficulty of finding good configurations in a landscape, or in a street, or in a building — equally difficult problems — have not yet been widely acknowledged by architects. This is mainly because in architecture the “goodness” of different configurations has not yet been accepted as a matter of *fact*. That makes it

impossible, of course, even to ask how hard it is to find the good configurations.

However, in *The Nature Of Order* I have established, I believe, that the goodness of an environment is a matter of fact (you would need to read the whole of *Nature of Order* to understand why), not of subjective aesthetic judgment. This has therefore allowed me, perhaps for the first time, to ask concrete questions about the type of process — of design, or of construction, or of planning, or of step-by-step urban renewal — and to ask what kind of processes might enable us to get a higher rate of success in reaching good structures in our surroundings.

Here I have had some considerable success — and, as in other cases mentioned in this paper, it seems to me that the scientific community might learn a great deal about complexity, by focusing on the character and technique of this success.



13 / THE HUGENESS OF CONFIGURATION SPACE AND THE WAY THE TRAJECTORY OF A COMPLEX SYSTEM CAN REACH ADAPTATION

It is very difficult to find or design, or plan, complex structures of the type of complexity typically encountered in buildings, neighborhoods, gardens, even rooms. There are many possible configurations. Only a few of them work well, and only very few of them show the subtle co-adaptation among the parts which creates true harmony, or truly good functional behavior.

Kaufmann has spoken eloquently about the fitness landscape and the problem of finding the good solutions. This problem exists because the good solutions are so tiny, like specks of dust in the vastness of a configuration space. The relatively rare living structures, viewed as points in configuration space, are so small and so far apart, that the chance of finding them by search, by design, is almost vanishingly small. It is to all intents impossible.

In Book 3, I have given a numerical estimate of the relative number of good (well-adapted) configurations compared with the number of all possible configurations. In one calculation I reached the conclusion that the ratio of successful, well adapted, configurations to all possible configurations is a staggering 1 in $10^{12,000}$. This is so sparse (remember, there are only 10^{44} molecules in the ocean, and only 10^{80} particles in the known universe) — that one can hardly imagine how a system ever finds these few isolated configurations.

Of course, the way it works in nature is not by *search*. The system does not wander about in configuration space, looking for these tiny and very rarely occurring configurations. Instead, it just goes there. The grain ripens. The corn forms. The stalks are threshed. The

flour is milled. The stubble is ploughed back into the soil. One thing follows another, and in a particular way which leads from one good configuration to another, and in such a way that any natural process gradually leads towards and homes in on the good, well-adapted configurations.

Kaufmann has begun an effort to make this process precise by means of autocatalytic sets, and by showing the kind of path such a system takes, and that it leads, more likely than not, to the well-adapted configurations. Of course his work is incomplete, and he leaves us wondering just *how, exactly* does this work.

My own view, based on thirty years of trying to solve this problem with buildings, is that the technique which must be used, is a new technique that focuses on emergence via well-defined structure-preserving transformations. It takes us to the sweet spots in configuration space by a series of transformations based on the fifteen properties identified earlier. These transforma-

tions, when calculated properly, and when carried out in a disciplined manner, have the power to reach the very rare and hard-to-find good solutions by stepwise transformations, where a search procedure or a design procedure just simply cannot reach it in a finite amount of time. In other words, design cannot succeed in producing optimal or sub-optimal solutions. Systems of well-oriented transformations performed over time, can work, do work, and are the only tools for creating deeply adapted living structure in towns and buildings.

What this means, in practice, is that as a structure evolves, we guide its evolution by particular sequences of structure preserving transformations: these are the transformations defined by the fifteen properties. In case after case, I have shown that effective adaptation occurs when it is guided by carefully chosen sequences of these fifteen transformations, applied one after another, to the product of the previous transformations.



14 / MORE ON ADAPTATIONAL SUCCESS AS A SPECIAL KIND OF TRAJECTORY THROUGH CONFIGURATION SPACE

There has been mention of Stu Kaufmann, and his innovative ideas. It may help put the present discussion in context, if I make a few remarks about the nature of his achievement, as I view it, and how it pertains to the scientific problems raised in *The Nature of Order*.

In all complex systems, the key question is: How does the complex system receive its order? It occurs in the growth of an organism, and its trajectory as it becomes fit for its environment; it arises in the breaking of a wave to produce the beautiful configurations captured by Hokusai; it arises in the evolution of organisms, and in the attempt to find a genome which is well adapted; it occurs in architecture, and the attempt to make a building, or a place in a town become well-adapted.

What is common to these cases, is the extraordinary numerical problem which every adaptive system faces.

In *The Nature of Order* (Book 3 appendix) I have made a crude estimate comparing the number of possible configurations in a given building design problem, with the number of those possible solutions that are likely to be well adapted — hence to have living structure. The ratio of these two numbers is truly astonishing.

In my estimate there are, in all, $10^{2,000,000,000}$ possible configurations; and of these there are approximately $10^{1,998,000,000}$ good configurations. The absolute number of configurations both in the “good” pile and in the “all” pile, are immense — immense beyond imagining. There is therefore no shortage of good solutions to any

given problem. But it is the ratio of the two numbers which staggers the imagination. The ratio between the two numbers is, in rough terms, about $10^{12,000}$. Further, although there are huge numbers of possibly good configurations, these good ones are sparsely scattered throughout configuration space, they are certainly not nicely grouped in any one part of configuration space. What this means is that the problem of finding the relatively good configurations is, in principle, a problem of staggering difficulty. It is not merely like finding a needle in a haystack. It is not even like finding a single particle, among all the particles in the known universe; that would merely be a problem of finding one particle among 10^{80} . This problem is inexpressibly large by comparison. The compactness of the written arithmetic expression $10^{12,000}$ belies the true immensity of the actual number.

This task is so huge as to be almost unimaginable. But we may imagine it like this. Consider the number of water molecules in the earth's oceans: about 10^{40} . Suppose then, that we initiated a process which allowed us to find one of a million specially marked molecules, among

these 10^{40} . Let us imagine now, that we stand on the surface of that one molecule, and once again, we imagine that one molecule like earth's ocean, with 10^{40} of its own miniature particles, and again we have to find one particular tiny particle among the 10^{40} , which is a good one. Now we have searched for something with a rarity of 1 in 10^{80} . Let us now jump down again, and again treat this second earth as the real earth, and once again, now find our way to a particular particle which has a rarity of 1 in 10^{120} .

Let us now continue this procedure again and again and again. In order to find a particle with rarity of 1 in $10^{12,000}$, we have to perform this extraordinary jump into as yet smaller universes, no less than three hundred times: we have to perform this jump into a domain as large as the molecules in the earth's ocean, no less than three hundred times, one after the other. Only then do we get near to our objective.

And remember, this search for the needle in this gargantuan haystack is not an extraordinary task. This is, arithmetically, what happens in *all* adaptation. It is a process which happens every time that successful adaptation takes place.



15 / WHOLENESS-PRESERVING TRANSFORMATIONS ARE THE
PRIMARY WAYS THE TRAJECTORY OF A COMPLEX SYSTEM
IS ABLE TO REACH SUCCESSFUL ADAPTATION.

How can a complex system find its way to the good configurations? In a theoretical sense, we may say that the system walks through configuration space, taking this turn and that, and always arriving at a well-adapted configuration.

The huge question, of course, is How this walk is controlled: what are the rules of the walk, that make it lead to good adaptation? Although a few, very preliminary answers have been given to this question, no good ones have yet been given. This is, perhaps, THE scientific question of our present era.

In particular, in architecture, it is essential that we find practical ways of traversing config-

uration space! What this means, in common sense language, is the following. There are far too many possible configurations for a given design problem. We cannot hope to find good, or well adapted designs, merely by looking for them. Instead, we must have processes which — when applied to a given starting point for a design problem, or for a planning process — will take us to good answers.

Nature has a way — built into the majority of systems, of finding its way to a well-adapted state for any given complex system — at least for most cases. We do not have a way. For buildings — and indeed for any complex system —

this is the most fundamental practical issue of all. And for all the complex systems on our planet, that is the most vast, and most significant problem of our era.

In general we may characterize this task, as a task of walking through configuration space, until we reach good results. The assumption is that there are (indeed, there must be) some kinds of paths through configuration space which can get a system to the good places. When configuration space is smooth like a softly hilly terrain, one can get to the peaks, generally, by walking uphill until you get to the top: if I get to the top of one hill and it is not high enough, I walk to another hill, and go uphill further. These hill-climbing procedures only work on smooth hilly terrain, with not too many hills. Kaufmann argued correctly, that real configuration space is not nicely behaved like this, and so he attempted to give an answer as to how an adaptive system does get to the infinitesimally rare points that represent good adaptation.

Stu Kaufmann has made similar calculations, and published a few years ago, in his monumental work on theoretical biology where he showed that in principle, anyway, certain kinds of movements in the fitness landscape (as he calls configuration space), which may indeed home in on "good" areas - and has offered a number of in-principle explanations suggesting the emergence of living systems is probable, not improbable, because of constrained movements in configuration space which lead autonomously towards well-adapted systems.

I applaud his work, and have been inspired by it. However, that said, one must also acknowledge that Stu has not yet given specific explanations, which describe, through such and such detailed mechanisms, how any specific features that appear in living organisms actually arise. His explanation is at a very high level of generality, and though convincing, leaves the hard work of figuring out how it really works, to create the geometrical configurations we observe, to others.

This is of particular concern to me. In the world of building one really does face the entire

configuration space - since we can nowadays do virtually anything, and natural processes are not steering us towards regions of the configuration space. The fact that we, as creators of buildings, have to find the tiny, nearly invisible needles in the vast configuration haystack, makes our practical task still harder.

I have therefore spent much of the last twenty years, trying to find out what practical methods there are, for helping us traverse configuration space, and for finding genuinely profound and well-adapted buildings. It turns out that the fifteen properties associated with wholeness, described at length in Book 1, provide a substantial part of the answer. In Book 2, I have shown how living structure arises when reached by a series of movements in configuration space which are "structure-preserving" paths. This involves the use of the fifteen properties as transformations, not merely as geometric properties. When we have a random configuration, and are trying to improve it step by step, we are most likely to reach zones of living structure (the good spots in configuration space), as we apply these transformations successively. The repeated use of these transformations -- intensifying centers, emphasizing alternating repetition, increasing density of local symmetries, and so on -- have immediate beneficial effects. These are real explanations, which have practical effects in real practical buildings. And what it amounts to, in informal language, is that the transformations represent a coded and precise way that aesthetics - the impulse towards beauty - plays a decisive role in the co-adaptation of complex systems.

If I am right, the consequence of my arguments go further, and would seem to suggest that adaptation - the successful movement around configuration space - cannot succeed unless it uses this technique. Indeed, I believe the structure-preserving transformations are likely to have real practical effect on our understanding of evolution and ontogeny. In these fields, too, I believe it will turn out that these concepts are indispensable, and give answers to presently open questions.

It might be said that these fifteen transformations coupled with the idea of structure-preserving transformations, do in part finally accomplish what Stu Kaufmann has not yet attempted. They give us real (and practically workable) indications of how to reach the tiny “good” zones in configuration space, by traversing the space, step

by step, in an incremental manner.

This might be powerful enough, in principle, to help us act as nature does — to create adaptation and beauty in complex systems, not only efficiency — and to restore to the landscape of Earth what we have been busy, for two centuries, unintentionally taking away.



A SUMMARY:
THE ROLE OF BEAUTY IN THE SCIENCE OF COMPLEXITY

All in all, to wrap up, this might be said: The beauty of naturally occurring patterns and forms has rarely been discussed by scientists as a practical matter, as something needing to be explained, and as part of science itself. Yet the fifteen transformations, if indeed they provide a primary thrust in the engine of evolution, and in the many engines of pattern formation, give us a way of understanding how beauty - aesthetics - plays a concrete role, not an incidental role, in the formation of the universe.

I believe the fifteen transformations I have discovered will turn out to be naturally occurring, and necessarily occurring in all complex systems. The laws leading to their existence, will turn out, I think, to be inevitable or necessary results of the unfolding of wholeness, under the right conditions. And I believe, too, that our 20th-century notion that mechanical effects, without the guiding influence of these fifteen transformations, can create the beautiful structures we encounter in the universe, is simply wrong. In other words, it is the action of wave motion, mitigated by the fifteen transformations, that creates the beauty of the breaking wave; it is the operation of natural selection, mitigated by the action of these fifteen transformations, which generates discernible and coherent forms in the play of genetics and evolution; I believe it is the operation and unfolding of the most ordinary flower or stem of grass, mitigated

by the operation of the same fifteen transformations, which generates the beauty of the flower. I believe that it is the same fifteen transformations which mitigate and channel the crumbling and heaving and bending of the geologic strata which generated the beauty of the Himalaya; and these fifteen transformations, too, which mitigate the action and swirling of the vortices on Jupiter, or the rippled piebald configurations we call a mackerel sky.

I know this must seem a fantastic claim, especially since we have learned so much in the last two centuries, by invoking pure mechanism, unguided and un-channeled. But we should remember that our current claims for the success of contemporary methods, are indeed only claims, not yet proven to be sufficient. Indeed, in the writings of each of the three scientists interviewed -- Brian Goodwin, Philip Ball, and Ian Stewart -- there is from time to time very frank acknowledgement of certain subtle, unsolved problems, usually residing in the more holistic aspects of the emergence of certain truly complex wholes. All these subtle problems have to do with certain phenomena for which one cannot quite give believable operational rules to explain, or predict their occurrence. Nor can one typically create the truly beautiful new configurations - except when we know already what they are - in which case we can of course always give after-the-fact explanations of how they got

there. As an architect, I am particularly aware of this problem, since, by trade, I am always trying to get to new, beautiful configurations, which have not been seen before. And I have learned how to do it successfully.

I am therefore particularly interested in the fifteen transformations (which I have described as the "glues" of wholeness), as the most powerful heuristics in configuration space that I know of, because it turns out that these transformations do have the power to help reach new, and truly beautiful configurations, and I believe they do also have predictive force in helping to understand how naturally occurring complex adaptive systems find their way to truly beautiful new configurations.

Why do the creationists keep on making their fuss about evolution? I do not think it is only because of religion, but rather because some of them are aware that this problem of emergent beauty is not really solved. Why does Dawkins engage in such intense hand-to-hand combat with the creationists - something one would think hardly worth the ink? Is it not because of his own failure to acknowledge, more frankly, that the larger question of emergence of new, and beautiful configurations in evolution is not yet solved - at least not in the sense that computer simulations, using the algorithms of selection as currently understood, could yet arrive at truly beautiful new configurations and thus demonstrate the truth of the ideas of evolution as we currently understand them? Approximations to beautiful configurations can be simulated, yes - just as in the case of snow crystals. The real thing - just as in the case of snow crystals - not quite yet.

The successful evolution of new biological forms is, in my view, undoubtedly modified by transformations able to move toward structures that are inherently - that is to say, geometrically - coherent. I believe this process accompanies nat-

ural selection, and is the crucial missing part of current explanations: a vital component in the gamut of selective pressures. We need more frankly to acknowledge such a possibility, and in my view scientists who aspire to realistic explanations, like Dawkins, should stop dueling with creationists (which is far too easy), and instead try to focus on this geometrical problem at its root (which is much harder). I believe the fifteen transformations I have described go some distance to laying a path toward the solution of these difficulties.

Most scientists, and most lay people, share intuitions (not always acknowledged) which ascribe something great to the action of the universe. Roughly expressed, these intuitions rest on intuitive assessments that some deeper coherent, and more whole-oriented transformations, coupled with the action of the ordinary mechanisms we understand, and strengthening and reinforcing the wholeness which exists, can give birth to new and beautiful configurations from the wholeness which exists. What the arguments in *The Nature Of Order* attempt, is to make these intuitions precise, and susceptible to experiment.

And let me underline the point: The fifteen transformations defined in *The Nature Of Order* are rooted precisely in the qualities which make things beautiful. That is how I found them. And that is why they work.

Is it not preferable (and more likely) that some relatively straightforward process of the kind I have described, rooted in beauty - yet definable and in principle mathematizable, as these transformations are -- is acting to help produce global, whole-oriented structures, rather than ascribing their appearance to creation, or to luck, or to blind chance, or to the action of purely local, over-simplified, equation-driven processes?



CONCLUSION

The richness of these concepts, their associated questions, and the inherent interest of some tentative answers to these questions, do indicate a new source of stimulation for the classical hard sciences - all of which, for the moment, emanates from architecture.

I wonder if it may not be worth making the following comment, on the mental world which scientists inhabit, and on a possible way of extending that world, to the benefit of us all.

I said at the outset of this paper, that scientists only rarely make things, and even the talk about complexity current in the last two decades, chooses very limited forms of complexity, looked at from very limited points of view.

Yet the rich source of scientific concepts and explanation I have sketched, suggests that it is the real adaptational complexity of the everyday world around us, which is potentially a rich source of science: and also a profoundly fitting arena for scientific effort.

If the house, the garden, the street, cities, landscapes, works of art, were to become normal objects of our interest, and that the creation of such things, instead of being split off as "art" or "planning" were to be given the deep affection, passion which it deserves — if, in short, the aims of science would move from analysis and hypothesis making, to a larger view, in which making were also to be included — would we not then have a more beautiful science, one which really deals with the world, one which not only helps us understand, but which also goes to a deeper level, and begins to encompass the wisdom of the artist, and begins to take its responsibility in healing the world which unteionally it has so far created, and which it has, sadly, and unintentionally, so far helped to destroy.

In such a world, scientists would do better, the profound questions of health, wholeness, nature, ecology, and human joy, would be part of a single world view, in which it would be recognized as part of science - scientia - that is to say, knowledge - and in which scientists and artists together, speaking a common language, would take part in this joy, to the benefit of all humankind.

But, of course, this could not be the dry-stick view of mechanizable questions such as traffic flow, or strength of materials. They would have to embrace the real questions, the hardest questions, of the relationship between human joy and health, and the geometrical organization of the planet, as a source of life, at every scale.

That would, indeed, change science for ever.

Of course there are some who would say that work of this kind is wholly inappropriate for science, and that they prefer a vision of science which is more modest, small in scale, and deals only with potentially and immediately answerable questions. As someone who was myself also nurtured in that English empiricist tradition, I have much affection for that view.

But in any case, even if one takes Philip Ball's sensible, modest and empiricist view, it cannot be denied, I think, that the questions raised in this paper, are important scientific questions by any standard at all, that the means of solving these questions exist, are new but workable, and that, to make progress in existing and now coming fields of scientific enquiry these questions must be answered. Even the tentative, and necessarily partial answers to these questions which I have given, do open new doors, and mark new paths of enquiry and offer empirical solutions to problems in the natural sciences.

note

Professor Alexander's education started in the sciences. He was awarded the top open scholarship to Trinity College, Cambridge in 1954, in chemistry and physics, and went on to read mathematics at Cambridge. He took his doctorate in architecture at Harvard (the first Ph.D. in architecture ever awarded at Harvard), and was elected fellow at Harvard University in 1961. During the same period he worked at MIT in transportation theory and in computer science, and worked at Harvard in cognition and cognitive studies of wholeness and value. He became Professor of Architecture at Berkeley in 1963, taught there continuously for 38 years, and is now Professor Emeritus at the University of California. He is widely recognized as the father of the pattern language movement in computer science. He was elected Fellow of the American Academy of Arts and Sciences in 1996 for his contributions to architecture.