"Make change our friend, not our enemy."

President Bill Clinton
Inaugural Address
The Chaos Institute

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Complexity and Evolution: Toward a Living Architecture
Dedication

To Gordon and Marissa
who were often far from me
but never out of my heart.
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Introduction

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Thesis

For centuries, man has attempted to solve great problems by breaking them down into smaller components which are then studied by isolated groups of specialists. The history of modern science has been one of increasing specialization and isolation to the point where nobody has the big picture, only a narrow channel of personal expertise. But today’s most pressing problems are global in nature and require holistic solutions involving cooperation among many disciplines, across physical, cultural, political, economic, and linguistic barriers.

Let chaos storm!

Let cloud shapes swarm!

I wait for form.

Robert Frost Pertinax

My qualifications to undertake this topic of research begin with a prior undergraduate degree in biological sciences, which is important for four reasons. First, that course of study exposed me to the shortcomings of the scientific method of inquiry. Second, it intensified an already deep appreciation of the elegantly complex morphology and dynamics of natural systems. Third, it led me to teaching and the study of educational psychology, where I learned the human mind is not a linear system. Fourth, I became an activist for a number of environmental and social causes of a global nature, having recognized the interdependence of all life on this planet.

More recently, I was attracted to books by Mandelbrot and Gleick which revealed a new scientific paradigm which resonates with what I have learned about natural systems. Those books led me on a pilgrimage to some of the hotbeds of Chaos research, most notably, the three institutions of higher learning along the Charles River, in Cambridge, Massachusetts. Through informal interviews with Chaos researchers, I have gained insight into their fascinating process of inquiry.

Complexity and Evolution: Toward a Living Architecture
The Chaos Institute

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Harvard Chaos scientists John Barrett, David Layzer, Bob Westerfield and Daniel Goroff explained to this interviewer the electronically interactive, cross-disciplinary nature of the new scientific community which has embraced a new paradigm of scientific inquiry. Massachusetts Institute of Technology Chaos scientists Joel (an assistant to Chaos pioneer Edward Lorenz), Dan Rothman, Jack Wisdom, and John Olson provided ideas on what a Chaos Institute in Cambridge should be able to do. Nicholas Negroponte, director of the Media Lab at MIT, was kind enough to explain new communications technologies and media which may be useful in such a facility. He also outlined various schemes to pull together the funds for such an enterprise.

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"It is an entire new world, a new kind of mathematics, a fundamental breakthrough in the understanding of irregularities in nature. We are witnessing its birth. Its future has yet to unfold."

Ian Stewart in Does God Play Dice? The Mathematics of Chaos.

Complexity and Evolution: Toward a Living Architecture
Complexity and Evolution

Toward a Living Architecture for the Third Millennium

Our minds hold an abstract model of reality synthesized from the objective data of our senses and the subjective programme of our society's myths, customs, and science. Art and architecture are further abstractions of this reality model. Because art and architecture are displayed in public, these individual artistic expressions become feedback mechanisms which influence the collective paradigm of a culture. One individual work of art or architecture can send shock waves throughout the evolutionary field. Evolution, whether it is genetic or synapitic, is a fuzzy, nonlinear, dynamic process. Unlike the simple linear charts in history books, the evolution of modern art and architecture is a complex adaptive process of millions of minds, each with millions of ideas. Unlike our dynamic mental models, art and architecture are physically frozen in time. Art and architecture are thoughts fossilized—fragments of the collective pool of ideas of the time—pieces of a culture's model of reality.

Somewhere in the middle of the 1800s, a crossover occurred. Mythology and religion, until that time, were the primary determinants of our cultural model of reality. Science and technology ushered in the new Industrial Age and a new model of the universe. Agriculture gave way to industry and people migrated from the farms to the cities causing massive urban problems and social upheaval. Hand work was replaced by mass production by machine. Animal power was replaced by steam engines, internal combustion engines, and electric power. Electric lighting extended the day, telecommunications and photography extended the senses. Iron, steel, and reinforced concrete allowed the construction of large-span structures. Rapid communications and transporta-

"I resolved to shun story telling. I would write about life... Nothing would be left out. Let others bring order to chaos. I would bring chaos to order, instead."

Kurt Vonnegut in Breakfast of Champions
"If you like fractals, it's because you are made of them."

Homer Smith quoted in Fractals by John Briggs

Computers and the telecommunications networks they are plugged into, have become extensions of our senses, our synapses, and they are accelerating the hyper-evolution of ever more complex thought processes. We seem to be moving rapidly toward a global mind. The hyper-evolving global mind has individual humans as neurons, fiber optics for dendrites, and microchips for synapses. Humans are spending an increasing amount of their time moving information from one to another. We were working for our genes, now we are employed by the global mind — ants belonging to the same synaptic nest. Increasingly, our space is not Euclidean space, we are tumbling into cyberspace.

It is time for architecture to come alive and free itself from its self-fossilization. It is time for architecture to respond to the complex, dynamic, hyper-evolutionary field in which it exists. It is time to reconsider the Euclidean and Platonic models of the First Millennium. What essence, what ordering principles, what values of the new model of reality can inform a living architecture for the Third Millennium? As Peter Drucker said, "... the best way to predict the future is to create it. "What feedback must we throw into the synaptic pool to counter the incoming waves and to create our own paradigm of the Third Millennium?"

**Chaos and Complexity**

Living systems all have the paradoxical properties of great complexity and great order. One would expect, based on knowledge of physical systems, the opposite to be true. But the order seen in living systems is of a peculiar kind which is just beginning to be understood. Enter the new theories of Chaos and Complexity...
Chaos Theory: A New Way to Look at the World

For centuries man has attempted to solve great problems by breaking them down into smaller components which are then studied by isolated groups of specialists. The history of modern science has been one of increasing specialization and isolation to the point where nobody has the big picture, only a narrow channel of personal expertise. But today’s most pressing problems are global ones and require holistic solutions involving cooperation among many disciplines, across physical, cultural, political, economic, and linguistic barriers.

Chaos theory is a new scientific paradigm which has universal applications to disciplines as diverse as meteorology, economics, medicine, mathematics, physics, communications, agriculture, ecology, and computer science, to name a few. Chaos research often involves multi-disciplinary effort and holistic rather than reductive science. It is an operational model for cooperative process in all fields, including architecture. In addition, the subject matter of the science of Chaos, nonlinear dynamics, suggests form for the buildings in which cooperative process occurs. Chaos theory offers insight into the order underlying our own minds as well as that of the global mind. It gives us a cognitive road map which may allow us to guide future hyper-evolution.

Unpredictability

The study of nonlinear dynamics or chaos theory allows us to see order in phenomena which classical science once held to be random, and allows us to see truly unpredictable behavior in systems classical science thought could be made predictable with continued application of reductive inquiry. Pioneering chaos research by MIT meteorologist, Edward Lorenz, revealed that long term weather prediction is impossible. Another dramatic example of how this new science is changing our perception of the universe occurred on July 3, 1992. An article published on that date in the journal Science marked the end of the predictable, clockwork universe of Newton and Kepler. Jack Wisdom, an astronomer, and his MIT colleague, Gerald Sussman, a computer scientist, announced that they had shown the solar system to be unpredictable. Our Newtonian calculations will be completely wrong after four million years. On the other hand, such seemingly random phenomenon like turbulence, earthquakes, and economics may not be as unpredictable as we thought. There is order in chaos and chaos in order.

Chaos theory arose from the broader theory of dynamical systems. Dynamical systems have two parts: a state (the essential information about a system) and a dynamic (a rule which describes how the state evolves with time). The evolution of the system can be visualized in a state space, an abstract mathematical construct whose coordinates are the components of the state. The intricately beautiful images which result from such mathematical visualization are pictures of a system’s behavior over time. This ability to represent complex behavior in simple visual form has already led to major discoveries in a very wide range of fields.

Fractal Geometry and Strange Attractors

Some simple dynamic systems have state-space geometries which are regular and predictable and are called attractors. More complex systems, such as the weather have chaotic attractors called strange attractors. They have fractal geometry. A fractal is an object which reveals more detail as it is increasingly magnified. Mountains, coastlines, kidneys, trees, cauliflower, indeed, nearly all of nature’s wonders display fractal
geometry. Natural systems, such as the weather, cell growth, and the ecology of populations have state-space geometries which are fractal, as well. Nature is a nonlinear dynamic system, a system of which we are living, nonlinear dynamic components. In turn we are composed of nonlinear dynamic components which are themselves composed of nonlinear dynamic components which are... etc., ad infinitum.

Benoit Mandelbrot, who coined the term fractal and did much of the early work, believes fractal math includes, "any system of insides trying to survive in a system of outsides. Even a hurricane depends on and feeds upon the surrounding atmosphere where there is no hurricane. Fractals ARE (his emphasis) a description of whether or not insides survive in various outsides of interest. From that point of view they underlie every operating system in existence."

Self-Similar Scaling

When a fractal image is magnified, it not only reveals more detail, it reveals detail which is self-similar. A common example of a fractal is a cauliflower. Pull off a branch and you have a miniature version of the original form. Pull off a tiny bud and you have yet another version of the original form. Not only is the tiny piece similar to the whole, it tends to be in a similar proportion to the next larger piece, as was the branch before. This self-similar scaling can and has been used intuitively with positive effect in architecture throughout history.

Fractals tend to have complex symmetry and display and ever-changing proportional rhythm to their self-similar components at infinite scales. There is an infinite complexity to fractals held together by an obvious order. This is the patterning intuitively admired most in nature, art, music, dance, and architecture — simultaneous complexity and an underlying order. Perhaps that intuition is due to the resonance of consciousness with a fractally ordered brain.

The Butterfly Effect: Sensitive Dependence on Initial Conditions

Chaotic systems exhibit another interesting trait which relates to the nonlinear design process of the architect. They are subject to sensitive dependence on initial conditions. Edward Lorenz found, in his studies of weather prediction, what he called the Butterfly Effect. If he ran slightly different initial weather conditions through his computer weather model, he got drastically different weather just a few days later in the simulation than he did with the original numbers, which varied only a fraction of a decimal point. He later discovered, by studying the fractal image of his system, that two points initially adjacent to each other would begin to diverge exponentially as the system progressed through time. In one of the great intuitive leaps of science, he realized, on that first day in 1961, that long range weather forecasting, which hundreds of scientists around the world were working on, was doomed to failure. Lorenz dramatized the impossibility of long-term weather prediction by way of an example which has become as famous as Jurassic Park: a butterfly flapping its wings in Brazil could theoretically set in motion a series of events which would result in a thunderstorm in New York City. Our initial design idea, which may come from a whim or free association, can have a drastic effect on the outcome, which explains why no two people in a design studio have exactly the same project solution. It explains how one sub-microscopic genetic mutation can change the living skin of the planet and how one insult can lead to world war. Evolution and human history are subject to the butterfly effect — sensitive dependence on initial conditions, and are, thus, unpredictable.

We are living examples of sensitive dependence on initial conditions. If our parents had decided not to have sex the
night we were conceived, or if another of the 60,000,000 sperm cells had made it to the egg first, we would not exist. We are all products of incredibly unlikely occurrences that make winning the lottery look like a sure thing. Sensitive dependence on initial conditions may be nature's way of insuring diversity, which is the driving force of evolution in life and art. In order for change to occur, there must be something to change to.

Balancing that novelty is the apparent universality of chaotic systems. The fractal which represents the behavior of the weather closely resembles the fractal which represents the behavior of a dripping faucet. Normal human heart beats resemble the fluctuations of the stock market. The normal human heartbeat is regular, but the abnormal, fibrillating heart has a fractal pattern resembling that of the Lorenz attractor for the weather.

Chaos theory provides a theoretical foundation for those architects who have intuitively used natural forms as models for their work. Simple, static, linear, geometric shapes are unnatural and inhuman abstractions which tend not to resonate with the way nature organizes itself. In his book, Fractals: The Patterns of Chaos, John Briggs states:

Traditionally, we have used Euclidean shapes — circles, squares, triangles — to model figures and landscapes. It was a process that tended to generalize and idealize the natural world. Fractal geometry brings us perhaps a little closer to nature's infinite subtlety.

These same simple forms, however, when used in complex, dynamically ordered systems of self-similar scaling, do resonate with true natural systems and require our brains to synthesize the strange attractor. We find these compositions particularly attractive if they relate to our personal synaptic pool in such a way as to allow us to cascade ideas into new thoughts. Through the butterfly effect, these individual thoughts feed back into the global synaptic pool. In this way, yesterday's art becomes today's reality — today's reality becomes tomorrow's art — and the universe pulses with creativity. Recreation becomes re-creation.

Complexity Theory

Complexity theory deals with the emergence of order in complex adaptive systems. As noted earlier, all evolving systems show a peculiar trend toward greater complexity and, simultaneously, greater order. This is directly contradictory to the Second Law of Thermodynamics, which holds that systems move toward lower states of entropy and complexity. Each of the 100 billion neurons of the human brain has over 1000 potential inputs, resulting in over 60,000 miles of wiring. Its massive connectivity allows it to outperform the fastest electronic computers, themselves extensions of and inventions of the human brain. According to Roger Lewin, in his book, Complexity: Life at the Edge of Chaos, "the fastest computer clocks up a billion or so operations a second, which pales to insignificance beside the 100 billion operations that occur in the brain of a fly at rest." (Lewin, 163)

The human brain is an almost infinitely complex, dynamic, fractal, nonlinear computer which we have been trying to force into a linear mode for the past 3000 years. With all its complexity, the underlying order of the brain is elegantly simple. Indeed, the basic building blocks of all of living creatures, from bacteria to blue whale, are astonishingly similar and remarkably small in number. The complex process of protein synthesis which builds each marvelous living structure is controlled by a simple sequence of only four nucleotides on a strand of DNA. Protein is synthesized from long chains of only twenty differ-
The protein which made this paper and the protein of your iris are basically of the same simple parts.

According to complexity researcher, Chris Langton, "the science of Complexity teaches us that the complexity we see in the world is the result of underlying simplicity." (Lewin, 190) According to complexity pioneer, Stuart Kauffman:

We know that most of nature is composed of nonlinear complex systems. Some of those systems, even though they can be described by simple equations, diverge dramatically. They go chaotic. Some systems, a much larger part, in all probability, describe systems that don't diverge, but instead produce convergent flow, produce structure.

(Lewin, 186)

Toward a Living Architecture

In his book, *Lila: An Inquiry into Morals*, Robert Pirsig comes to the conclusion, "given a choice of two courses to follow and all other things being equal, that choice which is more Dynamic, that is, at a higher level of evolution, is more moral."

How can architecture become more fractal, more complex, more connected, more dynamic, more moral?

Self-similarity at all scales

First, subtly incorporate self-similarity at all scales, such that the building, like a mountain, resembles itself at all scales. No matter how closely you look, you see some detail which draws the eye and is self-similar in terms of proportion and shape to the whole building. There is a family of subtly related forms. Subtlety is important. The brains of those who experience the work must respond to it actively rather than passively. Nature's intricately interwoven order is never completely obvious and predictable.

The fractal silhouette of a distant leafless tree is as interesting as the fractal pattern in its bark as you stand a few inches away. There is complexity and diversity at all scales, united by an underlying order in which the parts relate to the whole. Architecture can be that.

Dynamically responsive to the context

The generator of form for the tree is partly in the tree, in the genetic blueprint packaged in each cell, and partly in the systems surrounding it. Trees are so responsive to the environment in which they grow that interpretation of their growth rings provides an accurate, highly detailed historical record of environmental conditions. In turn, trees also change their context, providing feedback in terms of shade, shelter, oxygen, food, etc. They are built from and interdependent with that which surrounds them. They are connected to their place and time, of their place and time, sensitively dependent on initial conditions, giving and getting feedback from their surroundings, nourishing and being nourished by their environment. Trees have a sense of continuity — growing from that which was there before and becoming that which will follow. Living systems are ecologically responsible. Forests are sustained, cyclical flows of resources where no such thing as waste is allowed to exist. Architecture can be that.

Convergence, Wholeness, Oneness

Wholeness cannot be defined, but it is a universally recognized quality of things natural. Paradoxically, things which are whole cannot be whole when removed from their context. A fern in a pot is not whole. A fern in a forest is totally integrated into the living fabric of its surroundings, with an infinite number of associations, alliances, and coopera-
tive ventures. It interacts with its bacteria, fungi, and nematodes in the soil next to its roots and with the same global biosphere as the famous butterfly in Brazil. A fern in a forest is whole. It has a membrane but it is not separate. It is not static. It grows and is part of a larger whole. It is one with its surroundings. It is greater than the sum of its parts — as is the forest. It is what Gregory Bateson called "a pattern which connects — a metapattern." It is not a static product of fragmentation, reduction, compartmentalization, or deconstruction. It has no endpoint. It is a dynamic process of synthesis and convergence which is endless and boundless in time and space. It is complex. It evolves. It is alive.

Architecture can be that.
The Chaos Institute

Concept

The basic concept behind the Chaos Institute is to create an architectural strange attractor, capable of pulling in a diverse group of experts and laymen from its surroundings. The program, the programme, the building layout, circulation patterns, the design process, and the physical components of the building will be designed with the characteristics of complex, non-linear, dynamic systems in mind. As a reminder, those characteristics are:

* fractal geometry
* self-similar scaling with repetition of form
* strange attractor
* sensitive dependence on initial conditions
* dynamic response to external systems through positive feedback loops
* diversity
* emergent order and synthesis of form from complexity at the edge of chaos

While the basic mission of the Institute is to facilitate research into Chaos and Complexity, it is not a dry, boring place with researchers cubby-holed into their own specialized departments, sequestered from the public. This will be a less formal research center where scholars can mix and play and show off. People passing through the Chaos Institute may not be aware of its scientific underpinnings, for it is to be a public place, a social place, where everyone can become a part of the research whether they are aware of it or not.

Complexity and Evolution: Toward a Living Architecture
The Chaos Institute

Context

The Chaos Institute is located in Cambridge because of the rich and diverse context. There are several world-class universities within walking distance of each other near Cambridge. Those with well-known Chaos experts, Harvard, Massachusetts Institute of Technology, and Boston University form a triangle within which a search for a site for the project was undertaken.

Universities have the potential for holistic endeavor, in fact, the Latin root of university means whole. There is a tremendous opportunity for interdisciplinary cooperation and cross-fertilization within a university. Too often, however, universities follow the reductionary model and each college and department holds its students hostage to specialization. In what ways could this diversity of brain power be channeled, amplified and interfaced with the surrounding community? How can the surrounding community be brought into the Institute and enjoy it without becoming scientists or college elite? How can the forms already on or around the site inform the design of the Institute? How can the natural nonlinear dynamic systems, such as the sun and the Charles River be brought into the Institute to further inform the process of holistic endeavor?

In this project, the physical, cultural and natural context not only inform the design, they will become the design. Just as the soil and the sunshine and the rain becomes the tree, this building will be grown from its context. The Chaos Institute is an experiment in hypercontextuality, emergent order at the edge of chaos.

Complexity and Evolution: Toward a Living Architecture
Site Selection

Primary criteria for site selection were established to some extent before journeying to Cambridge. First, it must be as centrally located as possible to the three universities. Second, it would be desirable to locate the Institute on the Charles River, a non-linear, dynamic system. It should be in a high pedestrian traffic area, ideally near a major transportation node, such as a bus station or subway stop. It should be theoretically feasible to develop the site without demolition of historic or otherwise valuable existing architecture or other landmarks.
The Chaos Institute

Site Analysis

The chosen site is occupied by a combination landscape nursery and produce market. Existing buildings are essentially sheds built as if they were not meant to be permanent structures. None of the structures have any historic or architecturally significant features. This establishment, "The Grower's Market", is more of a seller's market, with farmers nowhere to be found. In spite of its apparent lack of customers and shabby condition, one professor interviewed expressed concern about losing the market to a new institutional building. This initial condition informed the rest of the design process — keep the market, in amplified form, and make it the primary strange attractor of the complex. Use real growers. Eliminate the middle man.

This site possesses an incredible diversity of edges. (see Map) It is at the eastern edge of the Charles River, which is a recreational greenbelt with heavy pedestrian and rowing traffic. Memorial Drive, a heavily-used four-lane street blocks access from the site to the river greenbelt. To the north edge of the site, across Akron Street, is a towering married student housing residential complex done in brutalist concrete by Sert. To the east of the site, currently separated by an alley and a parking lot, is a quiet neighborhood of single family homes. To the south of the site, across Western Avenue, are the smokestacks of an operating power plant, with a commercial district beyond.

Framed by the Beaux Arts power plant and the modernist residential towers, the site appears as a missing tooth in the architectural dentition behind the wet lips of the river. It would be difficult to find a site with a greater diversity of seemingly incompatible edges. What better place to erect a building whose purpose is to capitalize on diversity and differences? All the edges are amenities in one way or another, and they cry out to be linked to each other in a nonlinear dynamic manner which results in a unified whole. If that synergistic unification can be accomplished on the site and in the building, perhaps it will infect the minds of those who study and play there as well.

Strong Points of Site:
* On the Charles River
* Easy Access to Massachusetts Turnpike via Western Avenue
* Walking distance to Harvard and Boston University (9-block walk to MIT)
* Bus Stop on site (on Western Avenue)
* Nearby hotels (across river)
* Clearing site would not remove anything architecturally significant
* Plenty of room
* Large nearby residential, educational and working population

Weak Points of Site:
* Long walk to MIT
* Difficult access to Charles River across Memorial Drive (there is a stoplight at Memorial Drive and Western Avenue, however)
* Zoned C-3 Residential

Complexity and Evolution: Toward a Living Architecture
The Chaos Institute

Program

A new non-profit consortium has been formed to build and operate the Chaos Institute, but it will draw its resources from some of the nation’s oldest institutions of higher learning, such as Harvard, M.I.T., and Boston University. Other partners include some of the newest high-tech research companies near the site as well as local, state, and national governmental agencies. Since the reason for the Chaos Institute’s existence is to bring diverse groups together to solve common problems, it follows that the consortium be a diverse group as well.

Users of the Chaos Institute come from all walks of life at all times of the day. It is a public place where local residents can shop for fresh fruits and vegetables, bargaining with the producer for the best price. It is a place for students and faculty of the three nearby universities to meet over a beer while watching the chaotic order of the market. It is a place where the curious can learn more about the new science of Chaos and Complexity, by participating in exhibits and observing presentations. And it is a place where chance meetings between some of the world’s best minds can occur.

Special facilities are provided to physically and electronically attract Chaos scientists from various disciplines and from various institutions surrounding the site and from around the globe. As one moves up through the levels of the complex, spaces become less public and more devoted solely to the specific needs of the resident Chaos Fellows.

Administrative Offices

Space for administrators to get out of the turbulence of the rest of the facility and work in more predictable flow is the goal. Long-range planning, personnel development, program development, fund raising, conference management and facilities management take place here. There is a local office network tied in the Institute network which is tied into the global network. In the conference area, a large wall-mounted screen and video camera facilitate videoconferences with members of the Board of Directors, prospective fellows, and Chaos experts around the world. White noise from the moving water of solar aquatic system waste filtering aquariums, masks conversations. The decor is nonlinear and dynamic.

Auditorium

The purpose of the auditorium is to provide a large group gathering space to share ideas generated by individuals or small groups within the facility and beyond. The back wall of the auditorium has viewing windows opening onto the market with external speakers. A giant high-definition television monitor and a Dolby Surround System are available for presentations and video conferencing. Four hundred seat desk tops are equipped with digital note pad computers which are networked to each other, to terminals throughout the building, and to the world beyond. The Control System can display any or all of the data or graphics pulled up on any computer in the room, in the institute, or in the world — in up to 40 independent windows at a time. In free-association mode, the Control System can search and display screens on the global network which relate to key elements of designated screens. The Control System has artificial intelligence programs for computer and human language translation to facilitate global communication across cultural and technological barriers.

Bookstore

In addition to book and art sales, this is the lab supply store, with an extensive supply and electronics department. Toys, games, puzzles, Erector sets and other leisure diversions can also be found here for the bored geniuses who are likely to frequent the place.

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Chaos Cafe

This space, along with the Rower’s Market, is an architectural strange attractor. It gives people, who might not otherwise be attracted to Chaos or Complexity theory, a reason to make the trip. It will be a social gathering spot where patrons can rub elbows with a diverse cross-section of the Boston/Cambridge population. It possesses a lively atmosphere designed to promote and facilitate chance discussions.

Patrons watch as fruits, vegetables, meat, and fish make their way from the Rower’s market to a salad/sushi/wok show kitchen in the Cafe. Imported coffees, teas, and other beverages, from around the world are served. Live entertainment occurs periodically.

Patrons sit at networked Smart Tables which feature digital Sketch Napkins. Smart Tables are networked locally as well as globally through Internet. Digital Sketch Napkins with pen and voice recognition systems complement Electronic Placemats, which can be used as interactive menus, bank card machines, computer displays, electronic newspapers, dating services, CD-ROM, TV, and other media displays. Private electronic mail, research, banking, and other on-line computing may be done from the Smart Table with network lockout security. All Smart Tables have a simple learning mode for non-technical patrons. They can be ignored completely and will shut down automatically without interaction. A wall-sized multi-media screen shows what the majority wants (Monday Night Football, the Chaos Gallery, news, movies, etc.) and periodically displays all unlocked table screens to facilitate interaction among patrons.

Adjacent water features mask conversation and a jungle of plants help absorb noise reverberating from the atrium skin.

Chaos Gallery

The purpose of the Chaos Gallery is to teach the general public and the academic community the applications of Chaos and Complexity theories, to encourage further exploration of the rest of the Institute and increase dynamic association among Chaos theoreticians and others outside of their immediate realm. The prime focal point of the Gallery is the window into the Control Room display terminals and the 40’ by 60’ HDTV screen in the Auditorium beyond the Control Room. In addition, interactive teaching and display stations, which appear as flat-panel wall-hung monitors, are fed from the Control Room and allow Gallery Patrons to play and discover. It is a children’s museum for adults who have never grown up.

Classrooms

These are group meeting places to lecture, compare notes, and discuss research with other lab groups. They feature moveable desks with built-in terminals. A six-by-eight-foot HDTV monitor is networked to all desk terminals and the Control Room. The decor is soft and comfortable, conducive to relaxed brainstorming.

Control Room

This is the brain of the beast. This computerized communications center controls HVAC, security, and lighting systems and translates communications among various computer platforms, formats, and human languages. In addition, it has artificial intelligence programs which allow it to facilitate brainstorming and cross-linking among varied research activities taking place on the network at any time. It can also facilitate research with custom Knowbots (Knowledge Robots), specialized software couriers which go out into the networks and search for relevant articles and deliver
The Chaos Institute

them to the proper researcher. Much of
the activity of the Control Room is visi-
ble on a large bank of 40 monitors,
which become a major feature of the
adjacent Chaos Gallery.

Kitchen

The kitchen is actually a performance
space. It serves to visually and function-
ally connect the Rower's Market and the
Chaos Cafe and serves as a strange
attractor for both spaces, providing spe-
tacle for strangers to strike up conver-
sations about. The most beautiful produce,
fresh fish, and fruit of the day are ammu-
nition for slightly crazed chefs as they
prepare salads, soups, sushi, sandwiches,
and shish kabobs right before the eyes of
patrons, who can watch their orders move
from the market floor to their plate. The
best coffees in Cambridge are brewed
here and the aroma is irresistible. Open
24 hours a day, as is most of the Institute.

Laundry

Many highly-motivated people are
more able to relax and interact infor-
mally with others if they feel like they are
accomplishing something at the same
time. The laundry space, located adja-
cent to the Chaos Cafe, allows them to do
wash and network at the same time.
Wash can be viewed from adjacent tables
and used in discussions of nonlinear
dynamic behavior. WASHERS and dryer
drums are transient and backlit, cele-
brating the chaotic movements of the
clothes and making them entrancing
points of interest. Colorful, dynamic
lighting from them is relaxing and ro-
manic. This is laundry as a hypnotic
form of entertainment and social rite.

Library/Reading Room

A place to browse the latest maga-
zines, journals, and books on chaos
theory. An extensive collection of CD-
ROM discs is also available. If you know

the secret passageway, it is a place to
retire from the cyberworld and sink into
a comfortable club chair with a classic
leather-bound book and prop your feet in
front of the fireplace. It is a paradoxical
combination of the old order hidden
within the new order.

Metal Shop/Wood Shop

Chaosicians tend to be gadget freaks
and their experimental apparatus is often
custom made by their own hands. For
this reason, their is a fully-equipped
metal shop and a separate wood shop.
Both are putterer's paradises.

Multi-faculty Offices

Space where faculty can easily make
cross-disciplinary connections with fel-
low faculty of different disciplines in a
communal, comfortable, high-touch at-
mosphere.

Multi-functional Labs

Highly flexible lab spaces capable of
facilitating electronic, biological, chemi-
cal, and mechanical experimentation and
cross-disciplinary teamwork.

Apartments

Chaos Fellows receive full room and
board plus a stipend to conduct research
under the direction of the world's fore-
most authorities on Chaos and Complex-
ity. Each apartment is close to the action,
should there be a sudden nonlinear, dy-
namic thought in the middle of the night.
Apartments are arranged in suites of four
units around a common living room to
facilitate interaction.

Rower's Market

By dropping the G from the existing
market's name, this farmer's market
pays homage to the rowing crews who
are ever-present features of the Charles
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River. Along with the Chaos Cafe, this market serves as a strange attractor. It gives people, who might not otherwise be attracted to Chaos or Complexity theory, a reason to make the trip. This is the primary atnum space of the whole complex.

Farmers, fishermen, nursemannen, florists, artists, and other producers bring their latest here to sell to the public. Deeply discounted rates keep the booths active at odd hours for the area’s large night owl population. The booths are mobile, allowing for ever-changing, emergent order among the chaos of the marketplace. Canopies, functionally similar to those on Smart Tables, have active, translucent amorphous photo voltaic panels.
Figure 3
The Lorenz Attractor
This image revealed the fine structure hidden within a disorderly stream of data. Traditionally, the changing values of any one variable could be displayed in a so-called time series (top). To show the changing relationships among three variables required a different technique. At any instant in time, the three variables fix the location of a point in three-dimensional space; as the system changes, the motion of the point represents the continuously changing variables.
Illustration 1: Overhead of Initial Design Model

Illustration 2: Elevation of Initial Design Model
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Design Process

INITIAL DESIGN

The initial design process for the Chaos Institute began with an exploration of “zones of influence” of the surrounding context of the site. Four zones, residential, educational, recreational, and industrial were identified and arbitrarily symbolized with overlapping circles. (see Figure 1) The existing buildings within each zone are aligned uniformly, but the buildings in one zone are not aligned with the buildings in any other zone. This seemed an obvious metaphor for classical, disconnected scientific inquiry, that is, uniformity within each specialized area with isolation from diversity.

Extruding the combination of alignment lines and circles of influence drawn on the site map vertically produced a complex pattern of spaces with architectural possibilities. After several runs through this process, with pieces added and taken away, a plausible site plan could be drawn. (see Figure 2) To explore how this might take shape in 3D, a model was constructed. A mixture of straight vertical walls and non-linear arcing elements was used in the initial model. Vertical walled elements were meant to resonate with the adjacent structures whose alignment they mimicked. Nonlinear elements were patterned after the fractal geometry of a Lorenz Attractor which loops in three dimensions around a strange attractor. (see Figure 3) These nonlinear elements were used to connect off site elements to the site. For example, one such element loops over Memorial Drive and back as a pedestrian bridge to the river pedestrian path. Another links the Institute with the residence hall tower. (see Illustrations 1 & 2)

An apartment tower was added to focus the composition. Structural members of the atrium radiated from this tower in a spiral manner similar to patterns in a Mandelbrot set fractal image. The height of the apartment tower was meant to fill the gap between the residential tower to the north of the site and the stacks of the power plant to the south of the site.

The result of this early experimentation was a complex which would certainly catch the eye of anyone in the general vicinity. It resembled a watch whose spring had been wound too tight to the point it popped out of its case. It had looseness and diversity of spaces which was appealing. It lacked subtlety and sophistication, however. More importantly, it lacked self-similar scaling, a critical characteristic of fractal geometry and natural forms.

FURTHER EXPLORATION

After the initial design, this project benefited from computer-aided-design. A 486/66 computer, equipped with Datadvice and Intergraph Microstation was used to model the project the rest of the way.

This process seemed fitting for a number of reasons. First, Chaos theory was dependent on the invention of computers. Before the advent of computers, the math required was beyond manual calculation and the fractal images could be generated in another way. Computers also play an important role in the function of the Institute, so it is appropriate that they be used in its design. CAD makes frequent iterations of design possible. Certain computer commands, difficult to duplicate manually, were important to the design process. For example, using the computer, it is easy to copy and rescale elements — a technique used often here to explore self-similar scaling of elements.

After the site was digitized in three dimensions, including adjacent buildings, these elements were manipulated. This time, instead of arbitrarily marking zones of influence on the site, off-site elements were pulled onto the site along their lines of influence. The result was an array of forms which appeared to have crashed into each other in an interesting
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manner. Using the computer to edit this collection produced some useful arrangement of space which, with further editing, could facilitate the program. The pieces pulled onto the site became a kit of parts which could be moved, turned, rescaled and edited.

Through dozens of iterations three distinct voids developed which indicated atrium spaces. For these forms, evolution of emergent order in complex systems was revisited. Growth was considered as a model for the three atrium structures that resulted from this exploration. (see Illustration 3) The smallest atrium to the south is the simplest. As the progression continues the atriums grow larger and more complex. The result is a complex composition of dissimilar forms crashing into each other balanced and anchored by a progression of regular forms holding things together. Emergent order at the edge of chaos.

While the overall form for these structures was being explored, there was a concurrent exploration of form for the actual structural system holding them up. For this structure, the fractal geometry of simple plants was used — bifurcation. The columns holding up the roof structure diverge from their base and split four ways. Each of the four pieces diverges again, and again, getting proportionally smaller with each bifurcation, until the uppermost members form a light, lacy canopy. (see Illustration 4) Here the computer was useful, as it would have been nearly impossible to visualize such a complex structure in the time allotted with traditional modeling methods.

This same bifurcating column was used in various ways throughout the project including the structure of the Bridge of Trees for pedestrian access to the river path. (see Illustrations 5 & 6) It is not difficult to see the similarity between this column structure and the natural form of the trees it supports.

The design process for this project was itself nonlinear. Small elements were designed concurrently with large elements and each informed the other.

Of the small elements, the Smart Tables perhaps define the atmosphere of the Institute more than any other feature. (see Figure 5) As described in the program, these tables are networked computer stations with translucent solar arrays as canopies. Further research indicated that an amorphous type photo voltaic cell could be made up of sandwiches of spitter-coated glass which one could see through. The Smart Tables use this type of see-through photo voltaic panel for the cover of the Smart Placemat and Sketch Napkin, the seat surface, and the table surface. In fact, the whole smart table is made of square photo voltaic panels, some (or all) of which are also backed by computer displays.

This inspired a design which is capable of changing form. The tables can transform themselves into solar tracking arrays. If all the panels are backed by displays, each table could also transform itself into a giant display screen, and tables could be grouped together for even larger screen arrays. Taken a step further, all the south-facing glass of the atriums could be made of this type of energy-producing glass, or become a huge electronic billboard.

One of the characteristics of complex adaptive systems is the ability to respond to outside stimuli. What if the tables could transform themselves into full-scale tracking solar arrays when not in use as tables? What if they could also migrate to designated grid nodes in the floor to help power the Institute? This created an image of an architectural space which is alive, active, dynamic, unpredictable, connected to the “system of outsides.” It is not difficult to imagine the appeal of watching tables seek the sun when not in use, creating an ever-changing landscape.

Booths in the market, while equipped with solar arrays, do not move on their own. (see Figure 6) However, some exploration was made into the ability of
using the vendors as the engines of response to environment. In this case the environment would consist of systems of human interchange, commerce, economy. The movement and alliances among the vendors for maximum economic advantage could become the basis for experiments in Complexity — emergent order in complex adaptive systems.

Another issue which was explored was how to design circulation in such a way as to encourage chance meetings of people who would exchange information and encourage their individual creativity. One variation on this theme was to make certain essential circulation elements variable. Stairs were made to slowly undulate and migrate to the point where regular users would be forced to alter their path on a daily basis. The possibility of such changes occurring in a fashion as to constitute a gigantic cosmic clock was studied at length. (The north stairs are in the corner, it must be the Vernal Equinox!) Again, a possible answer to the issue, of connecting to the system of outsides and make the architecture live was addressed.

Finally, there was much research into Internet, the self-organizing global communications network, and how it might be used to facilitate associative brainstorming, positive feedback loops, and a new synthetic, holistic, dynamic scientific method. Conclusion: the virtual Chaos Institute already exists on Internet — at 30 million users and growing geometrically.
THE CHAOS INSTITUTE
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Figure 8: Site Plan / Main Floor
Illustration 5: Bridge of Trees, Structural Model

Illustration 6: Bridge of Trees, Structural Model, End View
Reflection

I believe there is something very important just below this tip of the iceberg I have scratched so gently. One of the most difficult problems I faced with this project was also the most gratifying. That problem was one of focus. I kept trying to focus my efforts on a particular narrow scope so that I might get finished, come to a conclusion, or final succinct product. Instead, every time I turned a page in my research, I was led in a thousand different, equally fascinating directions. As a result, my thesis has the look of a work in progress rather than a final product.

While at first I found this disturbing, on further reflection I realized that this is the essence of the nonlinear dynamic process — ever-changing, evolving, growing more complex with each iteration. I discovered that such a process is not well suited to arriving at a simple, reductive conclusion. Progress is measured instead in gradual accretion of complexity and cross-associative discovery — the mental equivalent of a coral reef. Perhaps that is the “new paradigm of the Third Millennium” — accretion rather than conclusion.

The more different paths I walked concurrently, the more associations among those paths I found. The result, to this date is a growing sense that I am onto something, but it’s form yet eludes me. Along the lines of Prigogine’s *Le Monde*, I am prepared to make some value judgments. The following is a list of continua or opposites which become each other at some point. From my studies this year, I have concluded that the ones on the right have higher evolutionary value. The ones on the left, are, for the most part, rather recent human inventions.

- Reductionist vs. Holistic
- Rational vs. Intuitive
- Segregated vs. Integrated
- Monoculture vs. Diversity
- Secrecy vs. Communication
- Closed vs. Open
- Linear vs. Nonlinear
- Single purpose vs. Multipurpose
- Simple vs. Complex
- Disconnected vs. Connected
- Redundant vs. Unique
- Static vs. Dynamic

While I am convinced that self-similar scaling, and other characteristics of fractal geometry are powerful tools for generating architectural form, I am even more excited about the potential for emergent order in complex dynamic systems. I haven’t a clue, yet, how to translate this into a construction process, i.e., how to grow a building. (I am exploring molecular engineering and nanotechnology, for the possible answer.) But, I can safely say this past year has been the most intellectually stimulating of my life, and I intend to pursue this thesis for many years to come.
Bibliography

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Complexity and Evolution: Toward a Living Architecture