Arnold Schultz, Professor Emeritus, University of California, Berkeley (1920-2013)

Professor Emeritus Arnold Schultz was a well-loved mentor of the College of Natural Resources (CNR) and one of the founding fathers of conservation and resource studies at UC Berkeley. His early research career focused on prescribed brushland and forest burning, quantitative ecology methods, as well as tundra and desert ecology. Later he developed innovative undergraduate courses in systems ecology and plant community ecology and a graduate seminar in agroforestry. At the heart of his courses was a view of the environment and resource management issues from an integrated perspective, blending hard sciences, social sciences, business, philosophy and culture.

Arnold was best known for his thought-provoking and innovative course in Ecosystemology. The course exposed students to concepts in ecology, systems thinking and the pure pursuit of knowledge through essays, parables, games, art, humor and a pilgrimage to the pygmy forest in Mendocino County. Through the Ecosystemology course, Arnold's students learned the importance of interconnectedness. He encouraged them to think about whole ecosystems and inspired them to be fervent environmental educators. His Ecosystemology course reader (which evolved over the years he taught the course) contained his introductions to each topic (reproduced here) as well as collected writings by well known authors.

The Conservation and Resource Studies program drew Arnold Schultz' greatest devotion. The program reflected Arnold's core belief that an interdisciplinary approach to environmental problems delivers the best solutions for nature and humanity. And for more than 25 years, his CRS students developed striking solutions to environmental problems by studying the interactions among natural resources, population, energy, technology, social institutions and cultural values.
Arnold always took a personal interest in his students and passionately believes in their potential to change the world for the better. He imbued his students with an eternal optimism about the possibility of protecting the environment. And many of his former students have done just that. A good example is Norman Myers, author of *The Sinking Ark* and 11 other environmental books, and a leader in international efforts to protect tropical habitats. Another example is Stuart Loren Cole whose doctoral dissertation under Arnold was titled "Implementation aspects of an ecosystems approach: the conservation of natural resources program, University of California, Berkeley: 1969-1972" (1975). Other students have formed their own environmental organizations, serve as conservation biologists and resource managers, provide consulting services to nonprofits, engage in environmental education and lead governmental agencies. Arnold's students acknowledge the impact that Arnold has made in the way they think and the way they approach complex problems. Arnold received the CNR Teaching Award in 1991 and the University Teaching Award in 1992. In August 1999, he celebrated his 50th year of service to UC Berkeley. Arnold moved to Phoenix Arizona and then to Boulder, Colorado where he lived with his son Tom Schultz and daughters Virginia Schultz and Sally Hofmockel and his beloved dog Quincy. In 2010 he celebrated his 90th birthday. He passed away on May 25, at the age of 92.

By Arnold Schultz
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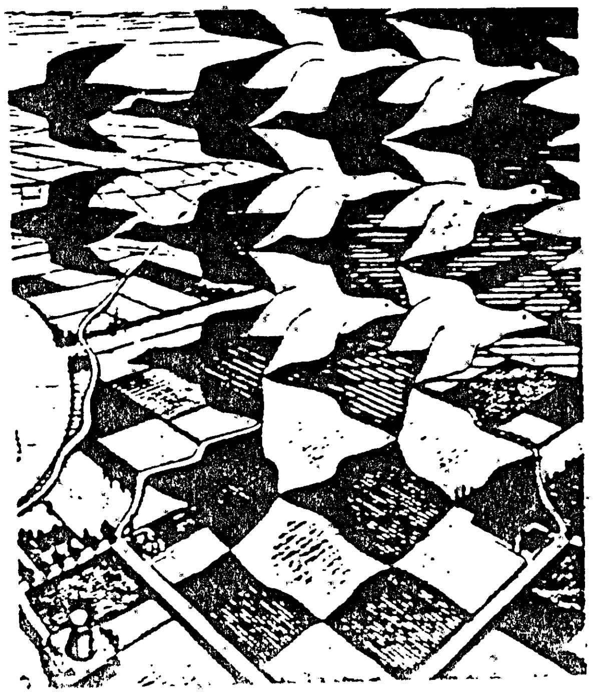
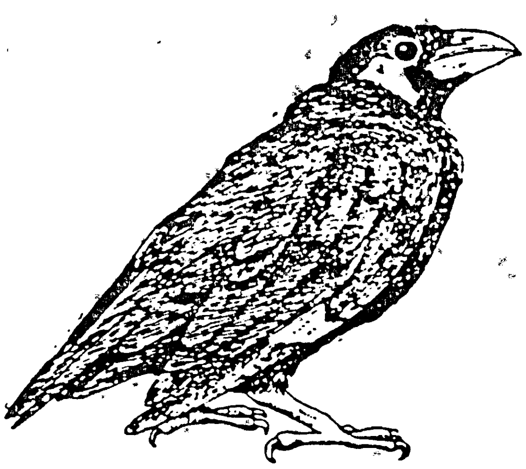
The ad hoc Interdisciplinary Ph.D. Program/Loren Cole/Inquiring Systems Incorp.
Futurism/Creating Alternative Futures/The Politics of the Solar Age/Wm. Thompson
Magorah Maruyama/The Second Cybernetics/General Systems Yearbook/George B. Leonard
Diversity/Resilience/Change/Vertical Thinking/Poor Polly/Tagliacozzo/Tree of Culture
Thought for the Day/Einstein's Brain/Robert Ornstein/Idries Shah/Left and Right Brains
This vase-and-faces figure was designed specifically for the new Ecosystemology Reader

PREFACE





A word is dead
When it is said,
Some say.

I say it just
Begins to live
That day.

- Emily Dickinson
1872

Ecosystemology has been offered on the Berkeley campus since 1974. Several versions of readers have now been written and used during these 16 years. They reflect the continuous evolution of the course.

The first edition was titled: "Readings in Ecosystemology--An inquiry into concepts and perceptions." There was no preface; students were dunked immediately into heavy stuff like The Meaning of General System Theory! It was a heavy beginning. Although every article and every excerpt included in it was dynamite, I found that students read only half of the material, so it became obvious that the dynamite had bad fuses. The lesson I learned that year had been well stated by Marshall McLuhan who said "No book will sell if it has over 20 per cent new material in it."

The second edition was a beauty and it became a collector's item the day it went on sale. The pages were of a different color for each major topic and deeper intensities of a color for the shades of profundity within each topic. Instead of making a commanding reading assignment, such as ".... for next Monday read pages 27 to 39 ...." all I needed to do was put a colored poster-board on the classroom wall, suggesting that pinkish sections would be the appropriate things to read next. The already passe Escherian logo gracing the cover of the earlier edition was replaced by a mynah quoting Emily Dickinson (see left-hand column).

The logo was changed again for the third edition. It showed young Isaac Newton sitting under a light-bulb tree, getting a delicious idea--possibly the notion of the Apple computer with which much of this reader has been prepared. The title of this (third) reader remained the same as the previous version: ECOSYSTEMORABILIA, to indicate that it is a collection of memorable ideas about "ecosystem thinking." The rainbow colors remained but, unfortunately, the wave-lengths got randomized by the printer and the colors no longer had any classificatory significance.

Up to this time the reader had been meant to be supplementary to the Ecosystemology lectures; however, for many students connections between the pertinent literature of the field and the content/process interaction that was supposed to be happening in the lecture room and discussion sections were not made explicit enough. This was a shame because many of the selected works were little educational institutions in themselves. However I took the students' critiques seriously, so the format for the 3rd and 4th editions was drastically changed--and continued here in this 5th edition. The fourth edition with its symbolic vase/faces frontispiece, featured original text -- written by me-- which parallels the lectures. This same format occurs here in this latest reader.....but expanded two ways.

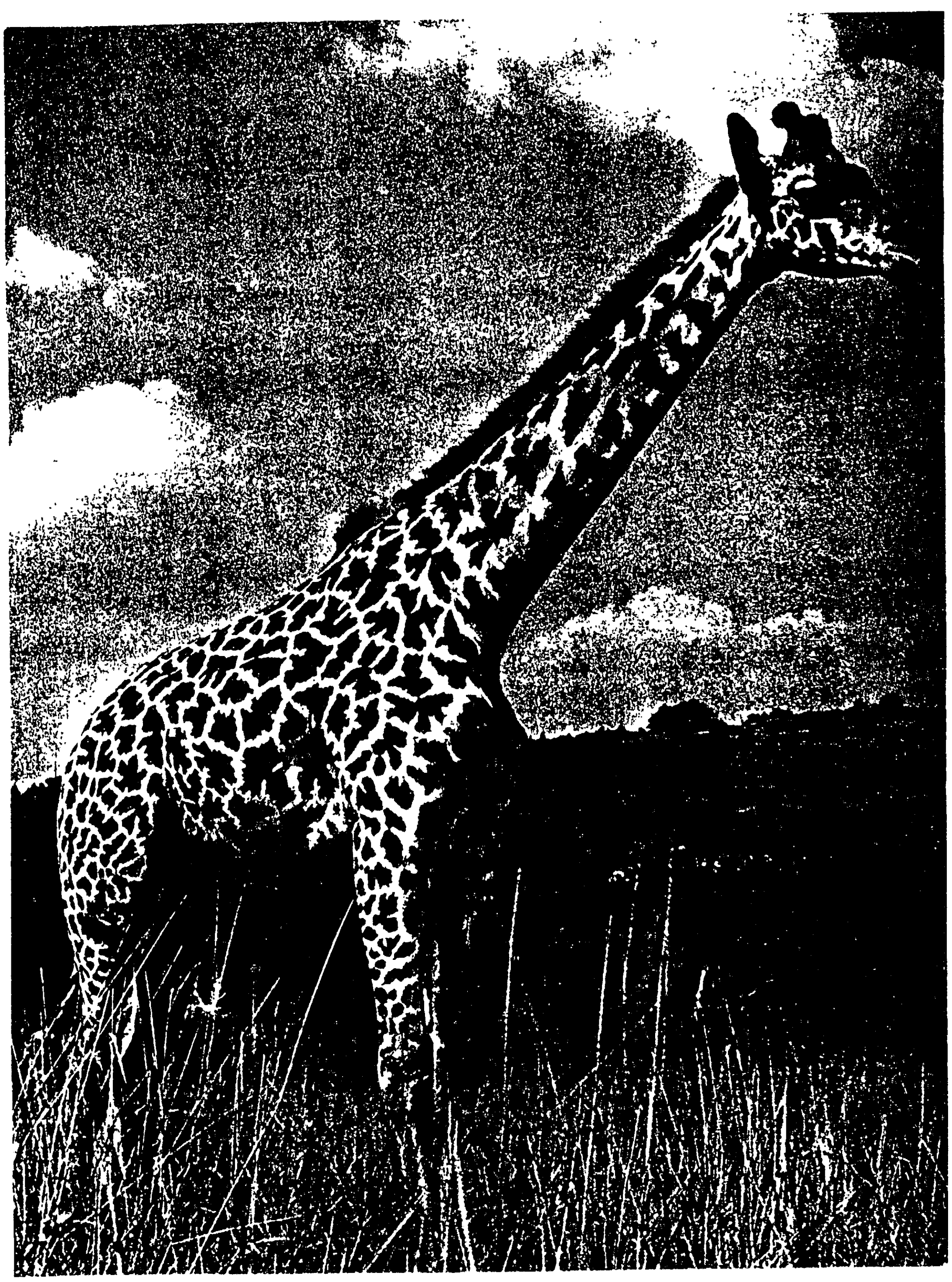
Why is it on 11x14 size paper? Most class readers are made to fit upright on a shelf after the course is over or even while the course is in progress. This reader should never be filed away on a bookshelf: When not being read, it should lie flat on your coffee table, kitchen table, or on the floor next to your bed. It should always be in view, handy, and serve as a conservation conversation piece. With the large 11x14 size you can't misplace it.

The text is only on white pages. It consists of original writing and is organized very much like my lectures and topics for discussion. Note that the text appears in the wide col- umns on the outer side of each page. The adjacent narrow inner column contains a variety of illustrative material, short excerpts, quotations, cartoons, poems, puzzles, and doodles. The "gap" between the two columns on paper is 11/16 inches wide but in thought it is much narrower. It is the students' job to make the connections.

The readings are on colored pages. They may be excerpts from book chapters, entire journal articles, or the like, always pertinent to the topics in the corresponding wide-column text. There are only a few colors available in the large folio size paper: blue, green, pink, canary, goldenrod and ivory. The colored pages do not have page numbers. The white (text) pages are numbered consecutively, beginning on the first page of chapter one through the last page of chapter twelve. After each chapter there will be up to four readings, each printed on a different color of paper. Interspersed here and there you will find some supplementary materials (always on ivory); these may be questions for discussion, problem sets, recommended reading lists, puzzles and games, and items too big to put into the narrow columns on the white pages.

Finally, there are fillers. Wherever the text or a reading comes to an end without filling the page, a space-filler is included. Remember the credo: EVERYTHING IS CONNECTED! So even the fillers will have a connection to everything else in the Reader.

This is a filler:



This is not a filler. It's very important stuff. See the connections? Read about tessalations in Chapter 9,

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SYSTEMS THINKING FOR THE EARTH'S FUTURE

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To my Ecosytemology students,

Past, Present, and Future

ECOSYSTEMOLOGY:
SYSTEMS THINKING FOR THE EARTH'S FUTURE
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INTRODUCTION

BY FRITJOF CAPRA

"Systems thinking" means thinking in terms of relationships, patterns, and context. This is the thinking Professor Arnold Schultz taught for a quarter of a century at the University of California, Berkeley, to thousands of students, who know him affectionately as "Arnold." In the late fifties, around the time I graduated from high school, Arnold coined the term "ecosystemology" to convey the essence of his teaching. The first two parts of this term form the word "ecosystem," followed by "-ology," which is derived from the Greek *logos* ("word," "thought," or "discourse") and is commonly used in the sense of "the science of." So ecosystemology is the science of ecosystems, which Arnold understands in a very broad sense, always including human beings and their ideas, values, and cultures. "Ecosystemology," he writes, "is designed to study ecosystem in all its complexity."

The last two parts of this term, "systemology," could be interpreted as "the science of systems"; and if you combine the first and last part, you get "ecology," interspersed by "system," which I interpret as the study of ecology with special emphasis on systems thinking. All these meanings resonate in Arnold's evocative term "ecosystemology."

In my own work, I use systemic thinking and some of the key concepts of complexity theory to develop a conceptual framework that integrates three dimensions of life: the biological, the cognitive, and the social dimension. I extend the systems approach to the social and cultural domain and apply it to some of the major issues of our time. This is very much in the spirit of Arnold's work. As he put it: "Along with the human beings come ideas, policies, theories, rules and regulations, management practices, etc. These also are components of the ecosystem. You can't leave them out."

What we need is an operational definition of ecological sustainability. The key to such an operational definition is the realization that we do not need to invent sustainable human communities from scratch but can model them after nature's ecosystems, which *are* sustainable communities of plants, animals, and microorganisms. Since the outstanding characteristic of the biosphere is its inherent ability to sustain life, a sustainable human community must be designed in such a manner that its ways of life, businesses, economy, physical structures, and technologies *do not interfere with nature's inherent ability to sustain life*.

This definition implies that the first step in our endeavor to build sustainable communities must be to become "ecologically literate," i.e., to understand the principles of organization that ecosystems have evolved to sustain the web of life. In the coming decades the survival of humanity will depend on our ecological literacy — our ability to understand the basic principles of ecology and to live accordingly. This means that ecoliteracy must become a critical skill for politicians, business leaders, and professionals in all spheres, and should be the most important part of education at all levels — from primary and secondary schools to colleges, universities, and the continuing education and training of professionals.

At the Center for Ecoliteracy, here in Berkeley, my colleagues and I are developing a system of education for sustainable living, based on ecological literacy, at the primary and secondary school levels. This involves a pedagogy that puts the understanding of life at its very center, and an experience of learning in the real world — for example, by growing food, exploring a watershed, or restoring a wetland.

Our aim is to foster not only the understanding of ecology, but also an experience of the natural world that overcomes our alienation from nature and rekindles a sense of place. This endeavor is fully consistent with the teachings of Arnold Schultz. "I am convinced," Arnold writes, "that teaching ecological principles, fortified by countless facts and figures, won't cut it. We have to develop empathy, love and loyalty to all life and to the land… We must learn with our hearts as well as with our brains."

At the Center for Ecoliteracy, we are developing a curriculum that teaches our children the fundamental facts of life — that one species' waste is another species' food; that matter cycles continually through the web of life; that the energy driving the ecological cycles flows from the sun; that diversity assures resilience; that life, from its beginning more than three billion years ago, did not take over the planet by combat but by networking.

This new knowledge, which is also ancient wisdom, is now being taught within a growing network of schools in California, and is beginning to spread to other parts of the world. Similar efforts are under way in higher education and in many new institutions of learning throughout the global civil society.

Ecoliteracy is the first step on the road to sustainability. The second step is to move from ecoliteracy to ecodesign. We need to apply our ecological knowledge to the fundamental redesign of our technologies and social institutions, so as to bridge the current gap between human design and the ecologically sustainable systems of nature.

Design, in the broadest sense, consists in shaping flows of energy and matter for human purposes. Ecodesign is a process in which our human purposes are carefully meshed with the larger patterns and flows of the natural world. Ecodesign principles reflect the principles of organization that nature has evolved to sustain the web of life. To practice industrial design in such a context requires a fundamental shift in our attitude toward nature, a shift from finding out what we can *extract* from nature, to what we can *learn* from her.

In recent years, there has been a dramatic rise in ecologically oriented design practices and projects, all of which are now well documented. They include a worldwide renaissance in organic farming; the organization of different industries into ecological clusters, in which the waste of any one organization is a resource for another; the shift from a product-oriented economy to a "service-and-flow" economy, in which industrial raw materials and technical components cycle continually between manufacturers and users; hybrid-electric cars achieving fuel efficiencies of 80mpg and more, while also being safer and more comfortable than standard cars; and finally, the development of efficient hydrogen fuel cells that promise to inaugurate a new era in energy production — the “hydrogen economy.” A fuel cell is an electrochemical device that combines hydrogen with oxygen to produce electricity and water — and nothing else! This makes hydrogen the ultimate clean fuel.

As the transition to the hydrogen economy progresses, its energy efficiency will become so superior to oil that even cheap oil will be uncompetitive and thus no longer worth extracting. As the ecodesigners like to point out, the Stone Age did not end because people ran out of stones. Similarly, the Petroleum Age will not end because we will run out of petroleum. It will end because we have developed superior technologies.

The ecodesign technologies and projects I have mentioned all incorporate the basic principles of ecology and therefore have some key characteristics in common. They tend to be small-scale projects with plenty of diversity, energy efficient, non-polluting, community oriented, and labor intensive creating plenty of jobs.

The technologies available now provide compelling evidence that the transition to a sustainable future is no longer a technical nor a conceptual problem. It is a problem of values and political will. Ecosystemology teaches us that security, energy, environment, climate, and economy are not separate issues but merely different facets of one global system. It leads us to understand that the root causes of our vulnerability are both social and technological, and that both kinds are consequences of our resource-extractive, wasteful, and consumption-oriented economic system.

A shift of energy policy from the current heavy emphasis on fossil fuels to renewable energy sources and conservation is not only imperative for moving toward ecological sustainability, but must also be seen as vital to our security. More generally, we need to broaden the concept of security to include not only energy security but also food security, the security of a healthy environment, social justice, and cultural integrity. Systemic thinking implies a shift of emphasis from security through protection by police force and military power to security by design. A community designed to be secure is also one that is ecologically and socially sustainable.

To Arnold's students the fundamental link between security and sustainability is not surprising, because sustainability means long-term survival. Over more than three billion years of evolution, nature’s ecosystems developed “technologies” and “design principles” that are sustainable in the long run and hence resilient and inherently secure. Natural selection has seen to it that the vulnerable systems are no longer around. Designing a secure society, therefore, means designing it with ecology in mind.

The choice is clear. If we continue to favor an economic system dependent on fossil fuels, centralized technologies, and vulnerable supply lines, we need to protect it by a huge worldwide police force at enormous expense and risks to civil liberties. If, on the other hand, we shift to a decentralized world economy, based on renewable energy sources, sustainable agriculture, and regional food systems, we can create communities that no terrorist can threaten and that threaten no other nation. We have the necessary technologies to do so; what we need is political will and leadership.

The two developments that will have decisive impacts on our well-being and future ways of life are the rise of global capitalism, and the creation of sustainable communities based on the practice of ecodesign. These two scenarios — each involving complex networks and special advanced technologies — are currently on a collision course. Whereas every member of a living network is included and contributes to the sustainability of the whole, global capitalism is based on the principle that money-making should take precedence over all other values, which creates great armies of the excluded, and an economic, social, and cultural environment that is not life enhancing but life degrading.

However, human values can change; they are not natural laws. The critical issue is not technology, but politics and leadership. The great challenge of the twenty-first century will be to change the value system underlying the global economy, so as to make it compatible with the demands of human dignity and ecological sustainability.

Indeed, this process of reshaping globalization has already begun. Its conceptual and ethical foundations were built in no small part by Arnold Schultz during many decades of selfless and inspired teaching.

From the Inaugural Arnold Schultz Lecture, University of California, Berkeley, September 29, 2002. Fritjof Capra, Ph.D., physicist and systems theorist, is a founding director of the Center for Ecoliteracy in Berkeley. He is the author of several international bestsellers, including *The Tao of Physics* and *The Web of Life*. This introduction is based on his most recent book *The Hidden Connections: A Science for Sustainable Living*.
www.fritjofcapra.net

CHAPTER 1 : WHAT IS ECOSYSTEMOLOGY?

Ecosystemology should not be thought of as a book, or a book based on a college course; it is an experience. Don't be surprised at anything you read here. Whatever you see, be assured that it relates directly to Ecosystemology.

In a moment I will tell you how my course (and this book) came to be called "Ecosystemology," and what is meant by the term *ecosystemology*. In learning ecosystemology, we concentrate on how to think; more specifically, we learn to think a certain way. If you object to this, and tell me that this is coercive and can lead to fascism and cultism, I will answer: at least from second grade on to where you are now in life, your education has probably subjected you to a one-way-only way to think and a one-and-only-one way to look at the world. You have not had any choice. I repeat: you have not had any choice. Ecosystemology gives you a choice.

Consider the fact that you have probably had at least 15 years of Western education, of preparation for rigorous specialization, of seeing the world only analytically. It hardly seems fair to pit those years of constant drumming against a single book. In order to even it out you will all be expected to participate fully as a reader of this book: make connections between the different ideas in these chapters, make connections with these ideas and your own life, really think about what you read. Without full participation you will not have a good basis for making the choice mentioned in the paragraph above.

You won't find the word "ecosystemology" in any dictionary. While the term may have been coined independently by others unbeknownst to me, *ecosystemology* and its meaning originated with me somewhere around 1958, as I contemplated the failure in the scholarly development and teaching of ecology. Indeed, it would be inappropriate, in my sense of the term, for "ecosystemology" ever to appear in a dictionary because no adequate definition could be squeezed into the space which dictionaries usually allot to meanings. I feel that a sufficient definition of ecosystemology is not even expressed in the entirety of this book nor in the totality of my lectures. As the book comes to its end, I hope that the reader will realize that a holistic, transdisciplinary study of nature and society will have just begun. Thus, in a way, the entire book is an introduction – not just this chapter.

This first chapter goes deeply into the origin and *raison d'être* of Ecosystemology. Concepts tend to be more meaningful when one learns how and why they originated.

ORIGINS OF ECOSYSTEMOLOGY

In ecology there was an era I like to call B.C. Ecology. Most university-educated ecologists might say, "Of course, B.C. must mean 'Before Clements.' Frederic Clements was, after all, the Father of American Ecology. Before him there was very little ecology." Or if you happened to belong to the Chicago school you might substitute Henry Cowles, another prominent academic ecologist, for Clements, and it would still come out B.C. For me, however, the new era for ecology began with Rachel Carson and her book *Silent Spring* (1962). This was a book read by hundreds of thousands of non-university-educated "ecologists." Before her, there was Ecology, to be sure, but it was well protected from people; the only times it got out from the hallowed halls of academe and the esoteric pages of scientific journals was when civil servants found ecology useful for land or water resource management decisions. "After Carson" an entirely different kind of ecology was needed. Unfortunately, many institutions in the business of training ecologists do not recognize this, even today, more than 40 years After Carson.

Some academics have said that the new brand of "ecologists" were not ecologists at all – they had no *logos*, they were emotional activists, not rational scholars and researchers content to add to our already great fount of knowledge about nature. And that, precisely, was (and still is) the difference between the grass-roots activists and the purer academic ecologists. (Ecologists, like other scientists, must publish or perish.) The "silent springers" were not so silent; in fact, they were very vocal. They were not waiting to get more data; they sprang to action as soon as they became aware of an imminent danger. Their motto was a credo expressed somewhat later by Jacques Costeau: "Act first, measure after." After all, it could take ten years to get all the relevant data to solve an ecological problem while a bulldozer could eliminate the problem in ten minutes. For this new brand of ecologists, traditional ecology was constrained by the *logos* – the requirement of logic and reason, of statistics and scientific method, and especially the requirement of objectivity. Traditional ecology was devoid of *pathos*. I remember seeing a beautiful bumper sticker in the late '60s that said TAKE CARE OF YOUR LOCAL ECOSYSTEM. Here were people who never had heard of Arthur Tansley (who coined the term "ecosystem"), Raymond Lindeman (who did the first empirical research using the ecosystem concept), or Eugene Odum (who wrote the first popular ecology textbook with an ecosystem approach), but they knew that their home, their city, their countryside needed to be cared for, simply because they loved it, and because succeeding generations would love it too if we handled it tenderly today.

Just think how radical such an approach in thinking about ecology and ecosystems seems, compared to one where the main motivations are getting proper credit for one's discovery, getting prestige and status in one's particular field of study, and maintaining loyalty to one's discipline rather than to the natural objects that discipline is about. I do not imply that all conventional ecologists are motivated by self-interest, but most are forced into such tracks simply by the nature of academic life.

During the 1960's and early 70's, I was "inside" (inside the academic structure), looking out at the new approach that was happening. And I wondered how this "radical" approach could be brought inside, so that college students could get "the best of both worlds." The phenomenon, sometimes called the Environmental Crisis or the Environmental Movement (and once called the Big Ecological Binge), which was working country-wide and even world-wide in the wake of *Silent Spring*, was a major factor in my developing thoughts about Ecosystemology. However, many other experiences contributed to it, too. Perhaps the best way to explain how I perceived the kind of education needed is to give a short biography – using my own personal experiences to illustrate the before and after, not only of my education in ecology, but of my generalist education.

AUTHOR'S BACKGROUND

My students often wonder how I came to be a generalist and why I endured being a maverick among the large prestigious (and branded!) faculty at my university. (By the way, a maverick is a stray calf or unbranded steer that jumps all fences. It's a term that comes from the U.S. wild West.) The answer to the second question is easy: the potential security of conforming to a reductionist, monodisciplinary approach to problem solving could not dissuade me from my convictions that a holistic, transdisciplinary approach is essential – for me and the planet. In other words, I did not want to prostitute myself to normal science (to use Kuhn's terminology – more on that in Chapter 3) for the sake of getting easy rewards. But such an answer still begs the question of the deep-down "why" which brings us back to the first question: how I came to be a generalist in the first place, in order to acquire these convictions. This again points directly to education.

In one of his many books, Buckminster Fuller explains how he came to be a holistic thinker. As a child he was severely cross-eyed. All close-up things were blurred, so he focused and concentrated only on grand views in the distance. This became so habitual with young Bucky that even after his affliction was corrected with proper glasses, he looked only at the far-off views – the big pictures. This habit that developed with his visual perception carried over to his other senses and to his thinking as well.

Arthur Koestler, another noted generalist, had quite a different experience – and rather a sudden one. At the age of 21 Koestler was a physics student in Vienna. One day, lying on a grassy knoll near his home in Budapest, and looking at the blue sky above him, he pondered one of the few questions physicists of that day had not yet answered: the infinity of the universe. In thinking about the futility of the question, and its sheer irrelevance to the many pressing problems of the world around him, right then and there he decided to drop out of the university, to leave physics and all science. He threw away all of his notes and books, and embarked on the rich, diverse life of the Arthur Koestler that we now know. He did come back to science, but in a much broader context than that of the physics he had studied in 1926. For examples, read *The Ghost in the Machine* (1967) and *The Act of Creation* (1964).

As a child I was neither repulsed nor awed by the infinity of the universe, nor was I fortunate enough to be cross-eyed. I grew up on a farm in southeastern Minnesota – a sparsely populated community. My elementary education happened in a one-room schoolhouse. There was one teacher for all eight grades. First to eighth grade pupils sat in deliberately random distribution (for disciplinary reasons, where "discipline" meant punishment, not field of study). When a class recited a lesson, say Geography or spelling, they went to the front of the room where the teacher sat. Those in a different grade, or not taking Geography, meanwhile remained in their seats to study, and were admonished by the teacher to keep their noses in their books! I did not always obey. I got into the habit of listening to the recitation while studying other subjects, and consequently got the subjects thoroughly mixed – no, integrated – in my mind. For me there were no clear dividing lines between disciplines (which here has the second meaning). My habit of excessive daydreaming helped to keep the distinctions fuzzy. Furthermore, the teacher had gone through the same system. She too went to a one-room schoolhouse, then to a small high school, and had only two years of "normal school" (teacher's college) which was not enough to infuse the separateness of disciplines or to clear the fuzziness of boundaries from her mind. The one-room schoolhouse was a great institution; it is sad that no one is trying to bring it back.

In college I changed my major several times. Such ambivalence and non-directedness was castigated by deans and some professors. But wouldn't one expect the stray calf to jump from one field to another when it sees no fences between them? Late in my junior year I stumbled accidentally into an ecology class. I had no idea what ecology was. The class fit into an open slot in my schedule, so I took it. It turned out to be a happy accident. Ecology was the right field for me – even though it was what I would later call B.C. Ecology.

Pardon my name-dropping, but I want to give evidence that I have had the most high-powered ecology education in America. At the University of Minnesota I studied under Raymond Lindeman who did the classical work on trophic levels in ecosystems. I did a Master's degree with Professor William Skinner Cooper who was a student of Henry Cowles at Chicago. After World War II, I went to the University of Nebraska for a Ph.D. under Professor John E. Weaver, who was a student of Frederic Clements. Cooper and Weaver were then the two top plant ecologists in the country, representing the famous Chicago and Nebraska schools of ecology, respectively. There were two other famous schools of ecology: the so-called "individualistic" school of Henry Allan Gleason (represented by Professor Herbert Mason at Berkeley) and the Josias Braun-Blanquet school in Zurich and Montpelier, where Hans Jenny did his earliest work. After coming to Berkeley in 1949, I had much contact with both Mason and Jenny, although not formally a student.

So much for my “establishment” credentials. So why have I not been a good disciple? Why did I begin teaching this heretical course called Ecosystemology?

As you may suspect by now, the Ecosystemology class is not an ecology course per se; nevertheless, there are some historical aspects and some principles of ecology that are necessary background to an understanding of why a course like Ecosystemology needed to happen. Let me briefly review some of these.

In 1869 Ernst Haeckel, the German biologist and philosopher, coined and defined the word *Oecologie*. It was “the study of the relationship between organisms and their environment.” That definition has withstood the test of time, and even today it is the standard textbook definition of ecology. Notice that neither the organisms nor the environment are specified. Taken literally, the definition implies that the study should be an interdisciplinary one. In fact, it is this very interdisciplinariness of ecology that has kept ecology from developing into a respectable discipline at some institutions. For example, the University of California at Berkeley, between 1920 and 1940, enforced a policy set by Dean Lipman of the Graduate Division that no ecology course was to be taught on the campus. Dr. Mason got around it by calling his course Plant Geography. During the same period at Johns Hopkins University, Burton Livingston (a plant physiologist who today would be called a physiological ecologist) threatened expulsion to any student using the word ecology or mentioned ecological concepts in his classes. At institutions where ecology was allowed to exist, it was harassed in other ways, especially by the molecular biologists who considered ecology to be nonscience or even nonsense. Chafing under such derision, many ecologists responded by "joining them," that is, they succumbed to the normalcy of the reductionist paradigm. In one school an attempt was made to explain plant succession entirely at the wee molecular level. Several so-called "invisible schools" of ecology go no higher than the interbreeding population level for achieving ultimate understanding of the complexities of nature. A second kind of response was for ecologists to become quantitative and mathematical. They felt that the high degree of subjectivity and obsession with qualitative "data" that marked ecological studies in the past was the reason for the field's low stature among the natural sciences. "Nature study" had low predictive value, hence it was not a science; many considered ecology to be nothing more than nature study at the university level.

So that was the situation in Ecology, at least in America, as I entered, first as an undergraduate and later as a somewhat better-directed graduate student. I was weaned on a textbook with the plain title *Plant Ecology* by Weaver and Clements; this was the only textbook available until 1950. Then three new books appeared, with almost the same titles: *Fundamentals of Ecology* (Odum, 1953), *Principles of General Ecology* (Woodbury, 1954), and *Elements of Ecology* (Clarke, 1954). Although these new textbooks professed to get down to the basics, the basics still consisted of the ecological dogma or paradigm that had been established during the earlier years, namely, the nature of the community, plant succession, and competition. I learned it thoroughly, as did all the other ecology students of that time. It was all laid out there in the books.

There were three or four ecologists who were thinking differently than the rest, and I enjoyed reading their papers, even though I didn't agree with what they said. One was Henry Gleason to whom ecologists referred as "primarily a taxonomist." Gleason had not jumped on the plant community/succession-to-climax bandwagon, and he was ostracized from the Ecological Society of America for his individualistic ideas. Another was Frank Egler, who had studied at Minnesota with Cooper, but felt compelled to criticize his mentors and all the contemporary ecological beliefs. In 1949 after I had finished my degree at Nebraska and went to Berkeley, there was Herbert Mason, teaching his own brand of ecology in the Botany Department. And in the Soils Department, there was Hans Jenny who had developed the ecosystem concept independently from the ecologists. While these iconoclasts were interesting for me to read and contemplate, I soon realized that their greatest value was in forcing me to think, not in their being any more "right" than Clements or Cowles, Weaver or Cooper. Also, they made me realize that I had a lot of un-learning to do.

In 1935 A. G. Tansley coined the word *ecosystem* and discussed the concept with more clarity than had any of the several earlier synonymous terms been explained. This will be treated in detail in the chapter on Ecosystems, but I bring it up now because, as you might suspect, it is crucial to my conception of Ecosystemology. During my college and postgraduate days, only Raymond Lindeman, then an instructor in Animal Ecology at Minnesota, was enthused about the ecosystem concept; no one else thought it would ever supersede "community" as the logical organizational level for ecological study. After all, the community was real; the ecosystem, abstract. Today, of course, the ecosystem has become real to most ecologists and is a legitimate object of study at most institutions where Ecology is taught. Yet, as you will see later on, few ecologists actually see the ecosystem as an object itself; most think of it as a convenient container.

One of the few who saw the ecosystem as an entity with its own properties was Hans Jenny. Jenny (b. 1899, d. 1993) was a Professor (later Emeritus) of Soil Science at UC-Berkeley. I became acquainted with him soon after I arrived in California in 1949. We worked on several ecosystem research projects together, and one such project is still ongoing at present. (My Ecosystemology students all saw the site of this project when the class went on the weekend-long field trip to Mendocino.) Our style of research was not to gather voluminous data to make statistics look good; rather, it is to verify hypotheses with thought experiments, much discussion, laboratory-field reiteration, lateral thinking, and careful observation. I have learned more about ecosystems from Hans Jenny than in all my formal training. Before coming to America from Switzerland, Jenny had studied with Braun-Blanquet at Zurich. He is best known for his work in soil chemistry and soil formation, but after retirement he put most of his efforts into preservation of natural areas in California. I said to him once that I thought of him more as an ecologist than as a soil scientist. “No, no,” he said, “I know very little about ecology, but about ecosystems I know a lot.” That statement re-emphasized for me that ecosystems study and ecology were two quite different things.

In extensive reading – outside of “my field” – I learned that the term “ecosystem” was being used by anthropologists, sociologists, economists, and psychologists, not in the original biological sense of a natural system, but as holistic units into which these social scientists put their own prime objects and attributes of study, along with the biological components (or sometimes without them). Some of my ecologist colleagues were aghast at this liberal use (and abuse!) of their very own ecological term. I am reminded that they had not yet gotten over the provoking uses of the older word "ecology" in such titles as *Steps to an Ecology of Mind*, *The Ecology of Politics*, and *The Ecology of Commerce*. My feeling is that simply because a term was invented by one group, say the (biological) ecologists, they cannot preempt it if it proves useful elsewhere. The biologist's bias in such an all-embracing concept as *ecosystem* is too confining. And finally, should we not be most interested in those systems in which humans are important components and in which social concerns are paramount? Can you think of any prominent ecosystem in which people are not interacting components?

The kind of reading I did which contributed most significantly to the development of Ecosystemology dealt with systems – not ecosystems specifically, but systems in general. A vast literature can be found in this area, started by the Austrian biologist, Ludwig von Bertalanffy. Bertalanffy developed General Systems Theory and it soon caught many followers. I subscribed to *The Yearbook of General Systems Research*, which was a journal published once a year, and I found it to be the most relevant of all the scientific journals that I read. Concurrent with General Systems Theory and its research side was the development of five new "disciplines," all with the common purpose of integrating and cutting across existing disciplines. The first three were cybernetics by Norbert Wiener, information theory by Claude Shannon, and game theory by John von Neumann. Somewhat later came catastrophe theory by René Thom and the theory of non-equilibrium dynamics by llya Prigogine. Many of these "disciplines" (I use quotation marks because they really are a-disciplinary, and some are subject to periodic revamping of basic terminology, yet they are fields that can be studied as disciplines themselves) will be discussed later as integrating concepts.

In 1958 I offered a semester-long seminar for graduate students in the School of Forestry at Berkeley, in which I tried to show how information theory, cybernetics, and general systems theory could contribute to range management, forestry, and general ecology. These ideas were brand-new at that time and my own understanding of them was not very deep. From the students' standpoint the course was a complete flop, but for me it was a great learning experience. The most important thing I learned was that in trying to teach new, revolutionary concepts, students had to first be asked to unlearn some of the old ones. This experience set me to thinking about the ideal course I would like to teach, which I would call Ecosystemology. Frank Egler (the iconoclast I mentioned above) jumped the gun and publicized this desire of mine in an article he wrote for *BioScience*, and students from all over the country wrote to me about it. The opportunity to organize and teach such a course finally came in 1964. It was sponsored by the Chancellor's Committee on Natural Resources, an interdepartmental committee which had as one of its goals the promotion of interdisciplinary research and teaching on the Berkeley campus. The course was given in the Forestry Department and listed in the catalogue as FOR 224, *Natural Resource Ecosystems*. I subtitled it *Ecosystemology*.

READER'S FOREGROUND

The decade of the 1960's is remembered not only for its Environmental Movement. More importantly, it was a period of crisis in education. The middle of the decade saw student discontent at many academic institutions, with serious riots breaking out, first at Berkeley, then San Francisco State, Michigan, Kent State in Ohio, and elsewhere. Some of the rioting was incited by non-student agitators with political motives; however, most of the students who participated or sympathized with the protests did so because they felt that their education was not relevant to the times – the world outside was changing rapidly and the sluggish university was not adapting to these changes, nor was it listening to the students' complaints about this refusal to adapt. Thus, the educational crisis and the Environmental Crisis were much the same, and I am inclined to say that the latter was imbedded in the larger (educational) issue.

Student unrest in the '60s was by no means confined to the Berkeley campus of the University of California. There was upwelling in many places around the country, spontaneous and independent from what was happening where I was. However, Berkeley seems to be identified most closely with the protests, since it seemed to get into the more spectacular bits of news. Since I know the situation best there, I shall describe the symptoms and causes as they pertain to Berkeley; the reader may generalize to other schools or places if he or she wishes.

Many of the laurels on which the University of California at Berkeley rested after World War II came from its work in nuclear physics and its part in winning the war with its atomic bomb. With its "subsidiary campus" at the Lawrence Livermore Lab, the University remains closely connected to U.S. Defense Department activities. Neither the Regents, nor the Administration, nor the majority of the faculty repudiated this involvement in weaponry development. We must remember that also during the time period under discussion, there was an extremely unpopular war being waged by the U.S. in Viet Nam. Civil rights, women's rights, and students' rights issues were prominent all over the country, and the last two of these were not satisfactorily dealt with by the University administration, and only lip service and tokenism offered by departmental faculties. But of all the sources of complaint, the deepest and most general feeling stemmed from failure of the University to shift from the outdated paradigms fixed in curricular structure. There was one feeble attempt made to reform the system; the Muscatine Committee was given the charge to study and recommend educational reforms. In their final report entitled *Education at Berkeley* (1966), the committee took cognizance of my efforts to teach an interdisciplinary course, namely the graduate level "Natural Resource Ecosystems" course alluded to earlier. Thereafter, a separate committee established the ad hoc Interdisciplinary Ph.D Program, to be administered directly by the Graduate Division, not by any department. I then had the honor of being the major professor for the first Ph.D candidate to be enrolled in the program, Dr. Norman Myers. This ad hoc program was the most significant step taken by the University towards education for environmental problem solving. The Graduate Division dropped the ad hoc program in 1994.

The demand for interdisciplinary courses and interdisciplinary research became greater as time went on. As evidence of this crying need I shall again refer to my graduate Ecosystemology course. On its first offering in 1964 it attracted fifty students – Master's and doctoral candidates – an unheard of number for a graduate seminar in the Forestry Department. And during the first three years the class was attended by graduate students from 44 different campus departments. I think it was the first interdisciplinary course in which the subject of interdisciplinarity itself was a major issue. In subsequent years the number of students and the diversity of majors diminished because some of the other departments began to develop their own interdisciplinary courses. That this would happen, sooner or later, was inevitable. In one way it was good; in another way, not. To have loci of interdisciplinarity spreading widely is certainly desirable, to make it available to more students and bringing a greater variety of faculty into the teaching. On the other hand, it promotes the tendency to cluster around ever narrower emphases, that is, to become more (mono)disciplinary – the very reductionist problem we are trying to get away from in the first place.

The old saw, “you can’t teach an old dog new tricks,” seems to apply to this graduate course experience. While most students in every class found the alternative ways of thinking to be refreshing and interesting, very few actually adopted them into their normal academic activities. Those who had already embarked on a research project for their Master’s or Ph.D thesis did not make a significant change in direction, either in conceptualization or in methodology. The main reason was security, not lack of desire to make the shift in thinking. By security I mean this: all dissertations must be approved by a committee of faculty members; if the committee “knows,” *a priori*, the “right” way for the research to be carried out or the “right” concepts for the student to use, then it may be unlikely that they would sanction an alternative or revolutionary approach. My experience with the 1958 seminar on cybernetics and information theory is a case in point. It was attended by several faculty members who, much sooner than the students, decided that it was worthless material, which suggests that the faculty are “older dogs” than students, and they are usually setters, not pointers. On the Berkeley campus at least one graduate program did not present such a threat of thesis disapproval: the ad hoc Interdisciplinary Ph.D. program described above. Here the student preselected his or her committee on the basis of its being favorable to interdisciplinary and/or alternative approaches to resolving problems. As one might suspect, the choices for faculty membership on such sponsoring committees were not overwhelmingly large. In fact, there were just two faculty members who were on the bulk of the ad hoc dissertation committees: I was one of them, and the other one was C. West Churchman, a systems philosopher and maverick (and now Professor Emeritus) in the School of Business Administration.

Ecosystemology became an undergraduate course easily and very quickly. So why have I devoted so much space to talking about graduate education? Just this: the reluctance that graduate students had regarding changing their directions of study in mid-stream meant that the message of ecosystemology came too late in their life. It should be offered at the undergraduate level, and preferably at lower division to be open to first and second year students. For this reason, I took the first opportunity to teach the course at an undergraduate level.

WHY CALL IT ECOSYSTEMOLOGY?

Why is a course and a book like Ecosystemology needed? And why call this topic *Ecosystemology*? During the decade of the 1960's a number of books were written which might have been called ecological horror stories. One of the earliest of these –

and by far the best known – was Rachel Carson's *Silent Spring*. The stories that were told were all somewhat different: the site, the criminals, the victims, and the weapons. But one victim was always the same: Nature, the earth, the ecosystems; and one criminal was always the same: a mentality which allowed the resource managers, engineers, and architects to measure the success of their actions only by whether their original purpose was achieved – never by the direct or indirect consequences of their work. This kind of mentality is deeply ingrained in our culture. It is endorsed by our education system and perpetuated by a society not willing to look very far ahead.

The horror stories were published by a concerned and vociferous group. Alarmists, they were called. Thus began the era of the Environmental Crisis. In its wake we got the EPA (Environmental Protection Agency), CEQA (California Environmental Quality Act), EIRs (Environmental Impact Reports), UNEP (United Nations Environment Program) and many other institutional arrangements for controlling development and managerial practices that had the potential for environmental damage. I, for one, had high hopes that environmental study programs, courses and curricula which became established in many colleges around the world, along with the monitoring and enforcing functions of agencies, local to international, would slowly turn things around. I predicted that the incidence of atrocities would gradually diminish in number and in magnitude as the awareness of environmental problems became more generally known.

I'm sorry to say that I have never before been so wrong, or so badly influenced by my hopes that human beings would learn from their mistakes. The truth is that we have not yet learned how to learn from our mistakes. This is why we need courses and books like

Ecosystemology, curricula like Conservation & Resource Studies and Environmental Science, and transdisciplinary institutions that integrate the physical, biological, social, economic and cultural aspects of this integrated world we live in. We are losing ground! Ecologists, conservationists, environmentalists – they all are falling behind the developers, explorers, extractors, and destroyers. Today's environmental problems are bigger, more serious, and more insidious than ever before. They are increasing exponentially while our ability to teach effectively how to solve or control them is improving not even linearly. *Ecosystemology* has been my attempt to improve the teaching and enhance the learning about environmental problems.

I am convinced that teaching ecological principles, fortified by countless facts and figures, won't cut it. We have to develop empathy, love and loyalty to all life and to the land. We have to relearn those things we learned in kindergarten, and appreciate them more than we do calculus, balance of trade, stock markets, and things that the universities know how to teach very well. We have to teach the importance of hope. If hope is important in our lives, then the universities, just like the kindergartens, should endorse it. We have to learn, and learn how to teach, the importance of perceptual and conceptual blocks to learning, because these blocks hamper the way we manage our resources and work with our fellow human beings. We must try to find ways to study and manage whole ecosystems without taking them apart.

We must learn with our hearts as well as with our brains. We must teach to the heart, not only to the brain.

And why should such learning and teachings be called *Ecosystemology*?

What is the most all-encompassing term you can think of – short of the universe? There are a number of candidates, but I think "ecosystem" is the best. The way I define *ecosystem* in this book is not the way that most ecologists or resource managers would. The ecosystem, as Tansley first discussed it in 1935, incorporated the physical components – soil, air, water – with the living organisms, in a space/time unit. Tansley, being an ecologist, admitted to having a biological bias, which meant that the organisms were central to the concept, but in any rational study the abiotic components had to be considered as well. His more serious bias was leaving out people. Even back in 1935 there were exceedingly few ecosystems in the world that had no human components. Along with the human beings come ideas, policies, theories, rules and regulations, management practices, etcetera. These also are components of the ecosystem. You cannot leave them out.

In school you can learn about social systems, economic systems, political systems, biogeochemical systems, and others. In nature these are not separate systems, as much as we would like to think they are. The *ecosystem* concept embraces them all. Ecosystemology was designed to study *ecosystem* in all its complexity. We must begin to think that way.

CHAPTER 2 : ECOSYSTEM PROBLEMS

Why is the title of this chapter "ecosystem problems" instead of "environmental problems," as most people would call them? In Ecosystemology we consider that the term "environment" deals with everything that exists and happens *outside* of the system, and the term "system" deals with things and events which we are trying to manage or control. Thus, if you mess it up (that is, mismanage the system), the environment will be affected, to be sure, but the problem lies within the system, and any possible solution must also be sought within the system. By definition, we have no control and no management opportunities outside of our system. This notion will be expanded, illustrated, and thoroughly discussed in Chapter 4, System and Environment.

Having understood, or perhaps accepted, the rationale for sticking problems to systems, not to environments, we must face the fact that we are still saddled with such popular phrases as environmental crises, environmental impacts, environmental science and even the oxymoronic term environmental system. Never once did I consider calling my course "Environmentology!" But since we are saddled with those terms, we might as well continue to use them; they are now firmly established in our vernacular.

EXAMPLES OF ENVIRONMENTAL DISASTERS

1980	Acid rain found to be killing many trees in the Black Forest of Germany, as well as in Czechoslovakia and Hungary; effects also noticed in the United States
1981	Effects of selenium poisoning discovered in the Kesterson Wildlife Refuge in central California – waterfowl chicks were deformed when hatched
1984	Union Carbide's Bhopal, India pesticide plant spewed out poisonous gas, killing 2,500 people in the first few days, 1,000 more over the next two years. India settles for $470 million in compensation
1986	Nuclear power plant explosion at Chernobyl, Ukraine (60 miles from Kiev): radiation killed many immediately; 135,000 were evacuated; tens of thousands of cancer deaths expected over the next several decades; affected crops and livestock in many countries in Europe
1988	Scientists discovered big holes in the ozone layer developing annually in the Arctic as well as the Antarctic; the EPA belatedly called for worldwide freeze of use of methyl chloroform and of production of other chemicals; Australians need to wear lots of sunblock even today
1988	Oil spill from the Exxon tanker Valdez destroyed marine life in much of Prince William Sound, Alaska; this was the biggest oil spill so far: 10,000,000 gallons
1991	Southern Pacific freight train overturned near Dunsmuir, California, spilling toxic chemicals into the upper Sacramento river and killing all fish and vegetation
1993	The oil tanker Braer grounded off the Shetland Islands, spilling 26,000,000 gallons
1995	At the Omai gold mine in Guyana, a tailings dam failed, gushing roughly 1,000,000,000 gallons of cyanide-laced effluent into two nearby rivers
1998	The UN Food & Agriculture Organization reported that 60-70% of the world's marine fish stocks are fully exploited or overfished due to large-scale commercial fishing practices
2001	The U.S. government found that about 724 miles of streams in Appalachia had been buried by valley fill from mountaintop mining since 1985
2001	A looming global warming disaster?... the Intergovernmental Panel on Climate Change reported that ecosystems at risk for significant irreversible damage due to global climate change include glaciers, coral reefs, mangroves, forests, polar and alpine ecosystems, prarie wetlands, and native grasslands; glacier and iceberg melting are occuring already.

CAUSES OF THE ENVIRONMENTAL CRISIS, CIRCA 1970's

Barry Commoner's book *The Closing Circle,* published in 1971 (the year after the first Earth Day), opens with a number of quotations which blame a wide variety of singular causes (culprits) for the environmental crisis. In the late 1960's and early 1970's (the middle of the Environmental Movement), many books were published that blamed one or another of these culprits, although keep in mind that if ten such books were written all blaming the same culprit, the last nine published might not have very sold well.

Below is a list of reported causes along with one of the more vocal “spokespersons.” The first seven are topics of separate chapters in this book. The rest will be discussed briefly in this chapter.

1. Paradigms	Thomas Kuhn
2. Thinking	Edward de Bono
3. Perception	R. L. Gregory
4. Learning	Gregory Bateson
5. Complexity	Gerald Weinberg
6. Disciplinarity	Erich Jantsch
7. Reductionism	Richard Levin
8. Non-connectedness	Barry Commoner
9. Specialization	Buckminster Fuller
10. Fragmentation	David Bohm
11. Human greed	Gregory Bateson
12. Education system	Arnold Schultz
13. Technology	Theodore Roszak
14. Industrial revolution	Alvin Toffler
15. Agricultural revolution	Wes Jackson
16. Politics	Charles Reich
17. Religion	Lynn White, Jr.
18. Human population	Paul Ehrlich
19. Science	Fritjof Capra

20. Man-dominated Earth	Man-dominated Earth
21. Economics	E. F. Schumacher
22. Us	Pogo

Non-Connectedness

Barry Commoner's book gives the Four Laws of Ecology. The first law says, "Everything is connected to everything else." And, of course, like Newton's law of gravitational attraction and the first and second laws of thermodynamics, the first law of ecology, as stated, is meant to be universal. This means that it works not only in Berkeley or Boulder, but in all of California and Colorado, all of North America, on the entire Earth, our solar system, and in the universe.

Who believes it? This question will be raised again and again in this book. It will be discussed quite fully in Chapter 10**,** Holism and Reductionism. For now, it seems that most of our environmental problems (sic) will remain unsolvable until we "believe" the first law of ecology and start looking for connections. The tobacco industry insisted there was no connection between smoking and throat and lung cancer. In spite of the surgeon general's belief that there was, the strong tobacco lobby appeared to force us into using stricter statistics to prove the connection, stricter than are needed for proving relationships when there is no lobby. Similarly, the National Rifle Association sees no connection between ownership of handguns and homicides. In still another case, the Atomic Energy Commission long insisted that radiation is good for us. In our culture, we take as “given” that things are independent of each other. The onus of proof is on showing that they are connected.

Specialization

In the good old Medieval times, a scholar at the Universities of Bologna or Uppsala took a curriculum of medicine, law, theology and philosophy. Today such a person would be a jobless pedant. We are now in the age of specialization. The general catalogs for most big universities are about 3/4 inch thick and list around 7,000 courses. The bulk of these courses are in science, but even within medicine, law, and theology there are many finely divided subdisciplines. In the real world, jobs are also finely classified and divided. Education has become more and more a matter of matching curriculum specialization with employment specializations.

A fuller story of this trend is told in Chapter 11, Disciplines. And Buckminster Fuller has some choice words about faults with specialization:[1]

> “Of course, our failures [to resolve our common dilemmas] are a consequence of many factors, but possibly one of the most important is the fact that society operates on the theory that specialization is the key to success, not realizing that specialization generally precludes comprehensive thinking…. One of humanity’s prime drives is to understand and be understood. All other living creatures are designed for highly specialized tasks. Man seems unique as the comprehensive comprehender and coordinator of local universe affairs. If the total scheme of nature required man to be a specialist she would have made him so by having him born with one eye and a microscope attached to it.”

[1] *Operating Manual for Spaceship Earth*. Carbondale: Southern Illinois University Press, 1969.

Fragmentation is the same as specialization. In the book *Wholeness and the Implicate Order* (1980), David Bohm tells how fragmentation, not only in the academy but throughout society, "creates an endless series of problems and interferes with our clarity of perception so seriously that it prevents us from being able to solve most of them."

Human Greed

I remember well the time at UC-Berkeley when students' emphasis on jobs was minimal. This was in the late 1960's, early 1970's when the environmental movement was going full blast. It was fun to teach then. As I insinuated in Chapter 1, the cohorts of students of that period were interested in a good education (which they perceived as necessary for keeping the world from going to pot). They were willing to take into their own hands whatever it took to get such an education. After that short period of time, gradually, the hippies began to be outnumbered by the yuppies. The Haas School of Business, not Dwinelle (humanities), not the Valley Life Sciences Building, not Giannini (study of natural resources), became the focal point of the campus, the locus for the "how to make money" curriculum.

The University's Board of Regents, most of whose members had been appointed by Governor Reagan and represented the Industrial Establishment, had gotten tired of environmental talk – you save the world with sound, profitable business, they said. One of the regents, Gregory Bateson, was different. Bateson, who was then a professor at the UC-Santa Cruz campus, was appointed regent by more radical Governor Jerry Brown.

He was not afraid to criticize the University and his fellow board members. In his last book, *Mind and Nature: A Necessary Unity* (1979), Bateson cites a sharp rebuke he gave to the Regents' Committee on Educational Policy in 1978. He accused the University of being best at teaching greed. The remark also applies to our education system as a cause for the environmental crisis.

Can altruism be taught? Do we have to wait for the collapse of the economic system, and for the failure of a completely materialistic world to provide the things that really make life worth living, before we learn that teaching to fill the pocket-book is short-sighted for us as individuals and for us as a species?

Technology

Arnold was born in 1920. To him it doesn't seem very long ago. The automobile had been invented and his dad owned a Model-T Ford. On the Minnesota farmland, tractors were a rarity. Electricity and indoor plumbing were unheard of on the farm. Plowing was done with horses, cows were milked by hand, and houses were heated with firewood chopped on the farm woodlot. Farming was not easy. (Arnold decided to become a teacher.) There's more to come about farming, later.

If a time chart were drawn to show the rate at which technology changed in Arnold's lifetime it would be sharply exponential, zooming up through rapid computers, fast planes, and instantaneous communication. Yes, the biggest changes are in transportation and communications. The scariest are in genetic engineering. And the acceleration will accelerate (perhaps like Bateson's Motion III in his theory of learning – see Chapter 8, Perception and Learning).

Perhaps the most important question to ask is not what these new technologies will be, but "will they be good for us?" A number of authors feel that technology has been the leading cause of our environmental crisis; if that is already true, what is to happen as the rate accelerates?

The strongest statement I know of at this point was written by Jeremy Rifkin in *Declaration of a Heretic*.[2] Concerning the two greatest scientific discoveries of this century – the split atom and the double helix – Rifkin admits that:

> "…on balance, the world is better off, in two respects, for their having been discovered. First, it has brought us closer to understanding the basic truths of our existence. Second, they have given birth to a new generation of tools that have made our lives more secure and the future more hopeful. This constitutes the wisdom of our time."

But then he goes on to say,

> "So convinced are we of the righteousness of our point of view on this matter… that not even the faintest murmur of protest has been recorded that might imply disapproval of the discoveries themselves or the mentality underlying them…. not the slightest hint of a suggestion that perhaps we ought not to make use of them at all, under any circumstances… to cast these discoveries aside, to let languish the concepts that gave rise to them, to abandon the line of intellectual thought that inspired them, for the true believers, the staunch upholders of the existing orthodoxy, such thoughts qualify as heresy."

And so it is… sheer heresy. Such heresy happened right here in California, in reaction to a discovery in Berkeley. Remember ice-minus, the bacterium that would make it possible for potatoes, tomatoes, strawberries, and many other frost-sensitive crops to

[2] Boston: Routledge & K. Paul, 1985.

withstand freezing temperatures. The discovery was made relatively safely in the laboratory of plant pathologist Steven Lindow on the Berkeley campus. But to make sure that it would work under field conditions, a field test would have to be carried out. Such a test was designed and planned for a potato field in Modoc County. That is when the “damn environmentalists,” including Jeremy Rifkin, stepped in and stopped the demonstration cold. Was it right to do this? In a field test the bacteria could escape and infect other plants. Conceivably, it could change the range of many native as well as cultivated species, extending their territories northward. Bananas in Alaska? So what happens to the disadvantaged plants that do not happen to be affected by these modified bacteria? These are just a few of many arguments that were used successfully to stop the field tests.

Richard Levins is another person who thinks that the role technology is playing today is harmful to society. In a book written with Richard Lewontin, *The Dialectical Biologist* (1985), especially in a chapter called “The Pesticide System,” Levins hammers away on a technology that has become far more serious than what Rachel Carson told about in *Silent Spring*. Levins has led the legal case against the federal Agricultural Experiment Stations in their role in mechanizing and dehumanizing agriculture in the United States, and for this he has been likened to a Luddite.

Leading the assault on nature, chemical companies have created thousands of new compounds which nature “never thought of making and apparently hasn’t needed.” Many of these have been marketed without adequate prior testing. Along with aggressive marketing by the companies and consumer ignorance of the potential dangers, many species, plants, animals, and bacteria, have been eliminated in ecosystems by a vast array of pesticides, herbicides, and fungicides.

The Agricultual Revolution

The Agricultural Revolution is said to have been more devastating to the Earth and its resources than the Industrial Revolution has been. What is the basis for this claim, made by Wes Jackson of the Land Institute in Salina, Kansas?

According to most anthropologists, hunter-gatherers had little effect in controlling the abundance of plants and most animals (maybe not the mammoth). Only when people settled down and started to grow crops did a major change occur. Humans found that cereal grains (wheat, rye, oats, barley, rice, and maize), when selected and bred as annual grasses, produced higher seed crops than the perennial ancestors of these same species. However, the annual cereals had to be planted every year, unlike the perennial forebears. Also, in order to get the highest yields and provide the longest possible favorable growing season, the fields had to be kept clean of competing vegetation and a good seedbed had to be prepared. For this purpose the plow was invented, and according to Jackson, it was the plow and repeated tillage year after year that has led to soil erosion. Soil erosion is considered to be the number one problem in America and many other places in the world today. Not only has the erosion of top soils lowered crop yields year by year, it has forced an accelerating use of chemical fertilizers and pesticides to compensate for the lowering of fertility.

A solution to the problem is to try to get back to the use of perennial plants for providing our staple foods; only one-fourth as much plowing would be needed. This is one of many ideas being championed by advocates of *sustainable agriculture*, a movement that has been sweeping the country in the last 25 years.

Politics and Form of Government

To blame politics for the environmental crises is easy, and almost every author that speaks about them also refers to their political aspects. Books such as *The Politics of Conservation* (1966) by Frank Smith, *The Politics of Ecology* (1970) by James Ridgeway, *The Unsettling of America* (1980) by Wendell Berry, and *The Politics of the Solar Age* (1981) by Hazel Henderson gave varied opinions and often proposed solutions on the political situation at the time.

One of the earlier writers to attribute political causes to environmental problems was Lynton Caldwell. Caldwell found it difficult to explain how and why government organizations failed to serve the environmental necessities to people, and speculated on what changes are necessary to fix this and how are the changes to be implemented. The machinery of government, he asserted, was intended to assist in the exploitation of discrete resources with little regard to the full range of environmental relationships. And in its sluggish way, government has not caught up to the threats imposed on the environment.

Richard Nixon became president in 1969. He decided that for his Interior Secretary he would appoint a man from a western state who would naturally favor exploitation of natural resources. He thought that Walter Hickel from Alaska would be the ideal person for the position. Hickel, however, fooled Nixon because right from the start he tried to get the government to pay more attention to people and less to politics. Nixon got rid of this humanist in a hurry and replaced him with Rogers Morton from Maryland, who had the "correct" conservative (not conservationist!) philosophy. Hickel then wrote *Who Owns America,* a revealing book whose first section is entitled "How to become an endangered species." Although this book was written in 1971, it is still worth reading. I wonder how many presidents have understood the word *ecology*. Al Gore, Vice-President for eight years and very nearly President in the 2000 election, wrote *The Earth in Balance* (1992). That seems somewhat promising.

Many writers have blamed our hopeless (?) environmental situation on the capitalistic system and we all can find a plethora of evidence for why this idea is true. However, there is also evidence *against* the idea that environmental problems are less severe in socialist or communist countries because of the kind of government they have. A case in point was made by comparing the effects of development of Lake Tahoe in the USA with Lake Baikal in the USSR, the two deepest lakes in the world. The development (non)-plans for both lakes were sheer disaster.

Religion

One of the most often reprinted articles (along with Garrett Hardin's "The Tragedy of the Commons"*)* during early years of the environmental movement was Lynn White, Jr's "The Historical Roots of Our Ideological Crisis," published in *Science* in 1967.

White says that the roots of our environmental troubles stem largely from religions, that the attitudes and actions of modern man (sic) contradict the reality that man is part of nature, not the rightful master over nature. He goes on to point his finger directly to the Judeo-Christian tradition, but includes Islam and Marxism as part of that tradition. In contrast, White says, that the East Asian religions, for example, Zen Buddhism, revered nature and handled it better.

Quickly thereafter (in 1968 and again in 1970) Yi-Fu Tuan wrote rebuttals to White's contention. Tuan argues that the inconsistency and paradox between the human treatment of the environment is a characteristic of all cultures, not only of the Western world. The high-minded *ideals* of the eastern cultures are actually not practiced. But this, too, can be contested. In the Ecosystemology course, students see the video "Ancient Futures," and hear about Ladakh, a high-altitude arid land west of Tibet. The story shows how following the Buddhist religion has helped the Ladakhis keep a simple but stable ecosystem intact for centuries, and in turn how the climate, the paucity of resources, in other words, the entire environment, has developed their Buddhist religious system.

Population

Paul Ehrlich wrote *The Population Bomb* in 1968. The book itself was like a bomb. It has been said that Ehrlich has done more than anyone since Malthus to make the general public aware of the population crisis. In that book, and subsequently in other writings, Ehrlich pins the blame for the environmental crisis directly on the world's exponential population increase. He had good ammunition for his argument. At the time the book was written, the world's population stood at 3.6 billion. The growth rate was 2% per year, which means a doubling every 35-40 years. Every year, 70 million more people were being added to the planet. (The estimated world population in 1997 was actually higher than Ehrlich's projection: 5.8 billion.) The critics said, "Hold on. What's the problem? There's plenty space. There's plenty food and we know how to produce more. The problem is its distribution." The Population culprit continues to engender debate and study as new growth figures are published and factors related to human fertility, mortality, and migration change dramatically over time.

Economics

One of the classics of the period is E.F. Schumacher's *Small is Beautiful*, published in 1973. Its important subtitle, *Economics as if People Mattered*, suggests that the way the "dismal science" is structured, it may well share some of the blame for the environmental crises that prevail. Schumacher had the deliberate purpose of subverting the science of economics by calling into question every one of its assumptions, right down to its psychological and metaphysical foundations.

Another book to consider, already mentioned under the section on politics, is Hazel Henderson's *The Politics of the Solar Age* with the subtitle *Alternatives to Economics*. Henderson makes no pretensions to "objectivity," which she says is a fraudulent concept in an age of industrialized and politicized science in which intellectual mercenaries too often serve forces of power and greed, the ambitions of competing nation-states, or the requirements of commerce. There are, in fact, very few economists who write as if the environment comes first. One of these is Herman Daly, whose books on steady-state economics should be read by all, especially would-be economists. Another is Kenneth Lux, an economic theorist and clinical psychologist, who wrote *Adam Smith's Mistake: How a moral philosopher invented economics and ended morality* (1990). A quote from the jacket:

> "Adam Smith, the Father of Economics and author of *The Wealth of Nations* (1776), saw self-interest as the driving motivation of human affairs. *Adam Smith's Mistake* traces the failure of societies based on self-interest, from the misery of Charles Dickens' England, through the Great Depression in the United States, to the culture of narcissism of the past decade. Lux shows how Smith, and the economists who followed him, made a fundamental mistake: self-interest by itself leads to social strife, ecological damage, and the abuse of power. Yet another principle does exist to modify self-interest: that of benevolence. By recognizing Smith's mistake, we as a society can move forward to a time when benevolence rather than greed becomes the economic motivation of our society."

Patriarchy

In *The Turning Point*, systems thinker Fritjof Capra speaks of several cultural transitions that happen to coincide today. He claims that they are shaking "the very foundation of our lives and deeply affect our social, economic, and political system. Perhaps the most profound of these transitions is due to the slow and reluctant but inevitable decline of patriarchy." Quoting further:[3]

> "The power of patriarchy has been extremely difficult to understand because it is all-pervasive. It has influenced our most basic ideas about human nature and about our relation to the universe – "man's" nature and "his" relation to the universe, in patriarchal language. It is the one system which, until recently, had never in recorded history been openly challenged, and whose doctrines

[3] New York: Simon & Schuster, 1982.

> were so universally accepted that they seemed to be laws of nature; indeed, they were usually presented as such. Today, however, the disintegration of patriarchy is in sight. The feminist movement is one of the strongest cultural currents of our time and will have a profound effect on our further evolution."

Two books that are classics in the field are *Woman and Nature* (1978) by Susan Griffin and *The Death of Nature* (1980) by Carolyn Merchant.

The Educational System

In my past Ecosystemology classes I asked the students which of the culprits presented the "worst" or "hardest to solve" problems in our society. Every one of the twenty-two listed were picked by at least one student. Human greed, non-connectedness, and reductionism ranked third, fourth, and fifth respectively. Second was the education system and first was *us* or "all of the above." However, the majority of the students suggested that a more important question should be asked: Who or what should be blamed for causing the culprits in the first place? When that was asked, almost all of the students agreed that our education system must take most of the blame.

Gregory Bateson said it well when he castigated the Regents of the University (see earlier section on Human Greed). His remarks were directed to the college level. But the high schools and the late elementary grades can also be criticized for educational obsolescence. And who is to blame for that? Our television programs, their commercials, the newspapers and magazines… oh, where does blaming stop?

WICKED PROBLEMS

There are some ecosystem problems, and social problems, too, which are impossible to solve. They have been called “wicked problems.” This term was given by Horst Rittel and Mel Webber of the College of Environmental Design at UC-Berkeley, in a paper entitled “Dilemmas in a General Theory of Planning.” The name applies to problems that are so complex and dynamic that they defy solution. Because they are everchanging, if for a short period of time a solution could be found, at a subsequent period the problem has changed so that the “solution” is no longer valid. Not only that, but the solution in that next period of time becomes a part of a new problem. Often it becomes a whole new problem! Thus, because problems change from time to time, they must be solved over and over – that is, resolved. For this reason it is better to use the term *problem resolution* rather than *problem solution*.

In a study entitled “Systems Modeling for Environmental Planning in the Lake Tahoe Basin, California” by Wei-Ning Xiang (1989), a set of six well-known characteristics of wicked problems was discussed: diversity, uniqueness, dynamics, nonlinearity, irreversibility, and cumulativity. These are defined below.

Diversity. This refers to the number and different kinds of relationships between the physical, biological, social, political, economic, and psychological components of impacted systems. The characteristic could also be called *complexity*. An example would be a large metropolis like New York City – its problems are changing day to day. Or the tropical rainforest in Brazil: here, not only the great diversity of organisms, their importance outside of the tropics, and the problems of the indigenous peoples, but our growing awareness of the relationships are becoming overwhelming in terms of the range of relationships to consider.

Uniqueness. A useful model is one in which an ecosystem is seen as determined by a constellation of state factors such as climate, species pool, topography, parent substrate, and duration of time. (This is called the “CLORPT” model which you will read about in Chapter 6, Ecosystems.) Since there are literally millions of variations in climate, geological formations, angles of slope, species combinations, and time-lengths, it follows that every ecosystem is unique. Problems arising within one-of-a-kind systems will therefore have characteristics unique to each of those systems. For example, the Arctic tundra ecosystem in the immediate vicinity of Point Barrow, Alaska is different from one fifty miles on either side or ten miles inland.

Dynamics. In nature there are no stable systems, even though ecologists often use static models for studying them or land managers may not have changed management procedures for decades. Not all compartments of an ecosystem change at the same rate. Without human intervention some ecosystems appear to be extremely stable. Much of the older ecological and floristic literature remarks how completely unchanging the tropical rainforest is and how unstable the arctic tundra is. Today, after wholesale perturbation by humans, many ecosystems are changing so rapidly that they keep ahead of all attempts to stabilize them. A case in point: pesticide resistance buildup and rapid evolution in insect populations.

Nonlinearity. Most ecosystem problems exhibit nonlinear characteristics. Rates of change accelerate through time. Effects often become stronger in exponential fashion. Indirect effects can be more powerful than direct effects. Often effects are unnoticed until a threshold is reached, after which the visible change accelerates rapidly.

Irreversibility. Species that have become extinct cannot be brought back. (That statement may no longer be true, perhaps, if DNA experiments with the frozen mammoth work out.) Endangered species that reach a certain minimum population level will not come back. Wilderness, once defiled, is lost as wilderness. Many ecosystem changes are irreversible, such as changes wrought by agriculture, industrialization, urbanization, irrigation, strip mining, drainage, and others. There are no good technological solutions. The key word now is mitigation.

Cumulativity. Many ecosystem changes (global problems) stem from the accumulation, both in space and time, of individually small or trivial changes (local problems) in or adjacent to the system we are dealing with. Cumulativity has two aspects, displacement and accumulation. First a problem shows displacement, so that through space and time there are lots of seemingly separate small problems. Second, there is an accumulation of problems at the same space/time level that then generates a big problem. The essential feature of accumulation is *interaction.* For example, a type of regional problem which individually may be trivial, recurs over and over, close enough together in time so that the instances interact in series. A case may be small discharges of nitrates into a lake every week for a year. For another example, take automobile exhaust emissions and fumes from a number of industrial point sources, each by themselves negligible but happening simultaneously on a sufficient spatial scale to interact with one another to erupt into a big smog problem.

The nature and magnitude of the interactions is not generally known or even measurable. The interactions fall into these three categories:

1. Synergistic/non-linear (1 + 1 > 2), meaning the overall action (result of the interaction) is more serious than the sum of the individual actions.

2. Additive/linear (1 + 1 = 2), meaning the overall action equals the sum of the individual actions.

3. Antagonistic/non-linear (1 + 1 < 2), where some of the actions negate others, or compensate, so that the overall action is less severe than the sum of the individual actions.

An example of the antagonistic/non-linear case would be where two otherwise toxic chemicals neutralize each other. Planners and land managers would consider such to be a favorable outcome. Unfortunately, we rarely notice this type of effect. The synergistic/non-linear type of interaction is the more common problem.

Of the six primary characteristics of wicked problems, *Cumulativity* is perhaps the more serious, insidious, and hardest to cope with in a society where “rugged individualism” runs rampant. All six are serious and, in fact, can make a problem intractable when there are uncertainties about the impacts of these characteristics.

ENVIRONMENTAL PROBLEMS, CIRCA 1980 TO 2000

There is no argument about whether or not those environmental disasters listed on the first page of this chapter actually happened. The power plant accident at Chernobyl was real; many people experienced the first explosion and many more are still experiencing the consequences. Likewise, the Union Carbide disaster at Bhopal, India and the oil spill from the Exxon tanker Valdez. Those and many others were so obvious that their occurrence could not be denied by their perpetrators. However, in the last thirty years or so, a number of other disastrous events started to happen, with gradually increasing impact on the entire planet: acid rain, ozone depletion, global climate change. The effects cannot be felt by individuals, or even in local communities. They are truly global problems but unlike Chernobyl, there are still many people who do not believe that they are happening – this includes industrialists, politicians, and even some scientists who are in denial. Proof that the earth is getting warmer is hard to get. For example, there is evidence that the Antarctic continent is gradually cooling. The best evidence of warming is indirect – the carbon dioxide content of the earth's atmosphere is steadily rising. People living in Southern California are not yet worried that the Arctic ice caps may be melting, causing coastal Los Angeles to be flooded.

What would happen if all the chemical and physical processes that separately result in acid rain, ozone depletion, global warming, and unusual weather phenomena accumulate to some threshold and begin to interact synergistically?

In the last twenty years something much more sinister than ozone depletion has been sneaking up on us. It is called *economic globalization*. Starting with the worldwide shenanigans of the World Bank and the fast spread of large transnational corporations, economic globalization is now abetted by the governments of most of the developed and developing nations of the world. Its potential effects are not only environmental in scope but detrimental to the lives of millions of people in developing countries. To explain what globalization may mean to us, let me quote Jerry Mander, one of globalization's staunchest antagonists.[4]

> "Economic globalization involves arguably the most fundamental redesign of the planet's political and economic arrangements since at least the Industrial Revolution. Yet the profound implications of these fundamental changcs have barely been exposed to serious public scrutiny or debate. Despite the scale of the global reordering, neither our elected officials nor our educational institutions nor the mass media have made a credible effort to describe what is being formulated or to explain its root philosophies.
>
> "The occasional descriptions or predictions about the global economy that *are* found in the media usually come from the leading advocates and beneficiaries of this new order: corporate leaders, their allies in government, and a newly powerful centralized global trade bureaucracy. The visions they offer us are unfailingly positive, even Utopian: Globalization will be a panacea for our ills.
>
> "Shockingly enough, the euphoria they express is based on their freedom to deploy, at a global level – through the new global free trade rules, and through deregulation and economic restructuring regimes – large-scale versions of the economic theories, strategies, and policies that have proven spectacularly unsuccessful over the past several decades wherever they've been applied. In fact, these are the very ideas that have brought us to the grim situation of the moment: the spreading disintegration of the social order and the increase of poverty, landlessness, homelessness, violence, alienation, and, deep within the hearts of many people, extreme anxiety about the future. Equally important, these are the practices that have led us to the near breakdown of the natural world, as evidenced by such symptoms as global climate change, ozone depletion, massive species loss, and near maximum levels of air, soil, and water pollution.
>
> "We are now being asked to believe that the development processes that have further impoverished people and devastated the planet will lead to diametrically different and highly beneficial outcomes, if only they can be accelerated and applied everywhere, freely, without restriction; that is, when they are *globalized.*"

Mander concludes his statement with a promise of hope, saying that as a wicked problem, globalization may be reversible. He thinks it is not too late to stop all this from happening. And one day, as I rewrote the last "white page" of Chapter 2 in my Ecosystemology class reader, I got a most encouraging (but badly interpreted by the media) bit of good news in that direction. At the Seattle meeting of the World Trade Organization (WTO) in November 1999, environmentalists (including a strong contingent of past and present Ecosystemology students), labor union workers, and

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[4] From his introductory essay in *The Case against the Global Economy and for a Turn towards Localization*, ed. Edward Goldsmith and J. Mander. London: Earthscan, 2001.

farmers brought the trade talks to an abrupt halt, and sent the delegates from 135 member nations home empty-handed.

From as early as the beginning of the Agricultural Revolution, problems were perpetrated by the "ecosystem" managers. Perennial grasses were converted to annual grains, with the consequences of accelerating soil erosion. Irrigation in the fertile valleys of Mesopotamia (now Iraq) caused soil salinization, laying waste to much productive land. In Attica, Greece, ancient shipbuilders started deforestation. Mining operations in recent times similarly led to devastation of land and landscapes. In the last fifty years, almost universal use of herbicides have taken a toll on plant and animal life. Technology, ostensibly advanced to make life easier for people, also became more prone to accidents, often resulting in massive loss of human lives and destruction of natural resources.

Who are the most powerful ecosystem decision-makers today? It would be easy to say the World Trade Organization members and its supporting governments. That may seem to be true today, but tentatively. The real culprits still are us, and the institution that we must improve and nourish is education. Imagine a school for presidential candidates, for congressmen and CEOs, with a curriculum that teaches altruism, compassion, friendship, and above all, love for the Earth. The school would teach a new approach, a new way to see the world – in short, a new *paradigm*, and that brings us to the next chapter.

CHAPTER 3 : PARADIGMS & PARADIGM SHIFTS

The buzzword for today is *paradigm*. One of its meanings is *worldview*. We ecosystemologists want to develop the good habit of holisitic thinking – and to cultivate an ecosystem-oriented paradigm. First, let us set the stage, discussing paradigms in general. It is an important concept for us, although the term is overused.

In our framework for thinking about ecosystems and environmental crises, it is as important to appreciate the gradual evolution of the world views, as recorded by the disciplines of philosophy and history, as it is to understand the empirical facts and laws of the universe as developed by quantitative science. One reinforces the other. Among the *parameters* of the human being (things that constrain our acts and thoughts) are the existing sets of ethical principles, as well as our time-invariant sets of physical laws. The ethics are, of course, man-made, but the making started long ago.

When an early human looked out from the mouth of hir (**hir**: a genderless pronoun, a combination of *her*, *him*, and *his*) cave to sense the world around hir, what were hir thoughts about the nature s/he apprehended? We might wonder if s/he said, “This is earth, and that, water; here is air, and there, fire. The world seems to be made out of different kind of stuff.”

Conversely, did s/he divide the world into big spatial chunks? Did a part of the world seem more immediate, a part that s/he could isolate for control and better understanding? This would have been the origin of the notion of *system and environment*: for practical purposes, two separate parts of hir universe. The system would be hir close-in world: hirself, hir home, and the surroundings that s/he could manipulate, hir ecosystem. Outside of this would be the "wilderness," an unknown and largely unknowable environment that affected hir only when elements like lightning and tigers sprang from it into hir home. Human survival depended on how well s/he could control hir ecosystem and how impregnable its boundaries were to outside forces.

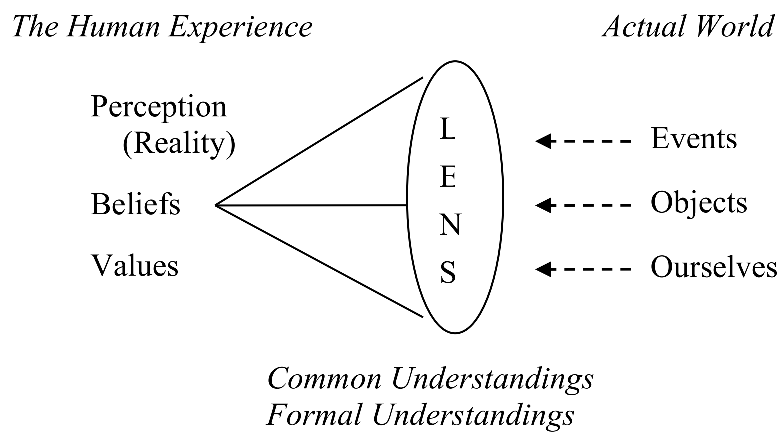
On the other hand, did the world appear to the early human as a vast undifferentiated environment, hopelessly chaotic, and too complex to control or understand? With this view, s/he would, in time, note an experience gradient sloping away from hir skin in all directions. Immediately around hir body, the zone with which s/he was best acquainted, s/he was in complete control; further out, less so. S/he also noted an experience gradient from hir soul up to heaven. This gradient would provide no boundaries and would not help to solve the problem of complexity. Heaven could move down closer to hir, for instance coming to dwell on mountain tops; gods could become explanations for the unknowable. The importance of the question of survival could be played down in deference to another life – the hereafter.

The history of how humans divided up their universe, and the effects on themselves of the subdivisions they invented, can be traced to the present day. It is essentially a story of the thinking of philosophers on three kinds of conceptions: (1) the universe in terms of space, time, and causality; (2) nature, in relation to God and man; and (3) the system of inquiry used to investigate or consider the first two. We usually think of the latter as belonging only to the rational system of science, but magic, myth, religion, and art also do the job.

Since the time of written history, three entirely different modes of thought, or world views, based on concepts of space, time, and causality, have arisen. We must attribute the views to creative people – thinkers and writers – who first gave clear expression to the formal thoughts. Only much later did they seep into the thinking of the masses. These modes of thought did not simply supercede each other: all three exist and are viable today. They show a prominence approximately proportional to their length of existence. These three modes of thought have been named (1) the Euclidean or common-sense world view, (2) the non-Euclidean or uncommon-sense world view and (3) the organismic-transactional world view. The latter is often called the *holistic* view.

PARADIGMS

Paradigm is not a new word in the general lexicon, but it came to much use (and some abuse) after Thomas Kuhn published his classic *Structure of Scientific Revolutions* (1962). It largely replaced the term *world views*. Instead of giving a Kuhnsian definition of paradigm, let's try something else. Below is a diagram showing a lens:



From the right side, representing the actual world, objects and events filter through the lens and converge on the left side as the total human experience, including our values, our beliefs, and our perceptions, in other words, our reality. This "lens" is analogous to our common understanding about the world, e.g. space, time, relations, causality, "I" and "it," and all of our other "common-sense" ways of looking at the world. Also, it is analogous to our formal understandings which come to us by way of our learned disciplines: physics, chemistry, astronomy, biology, psychology, etc.

We, that is, our culture, has been using the same lens for a long time. It comes with your registration packet when you go to college. You keep it, like a credit card, after you graduate. It does the same for you as rose-tinted glasses that give you a different view of the world around you. It determines your reality, your perception, and it determines your values and beliefs.

The fact is, this one lens is mass-produced today and we are not told that we actually have a frame, into which one can insert interchangeable lenses. The part of our culture most responsible for the filtering power of this lens is our education system, through its nurturing of the formal disciplines as well as through the perpetuation of the "common" understandings.

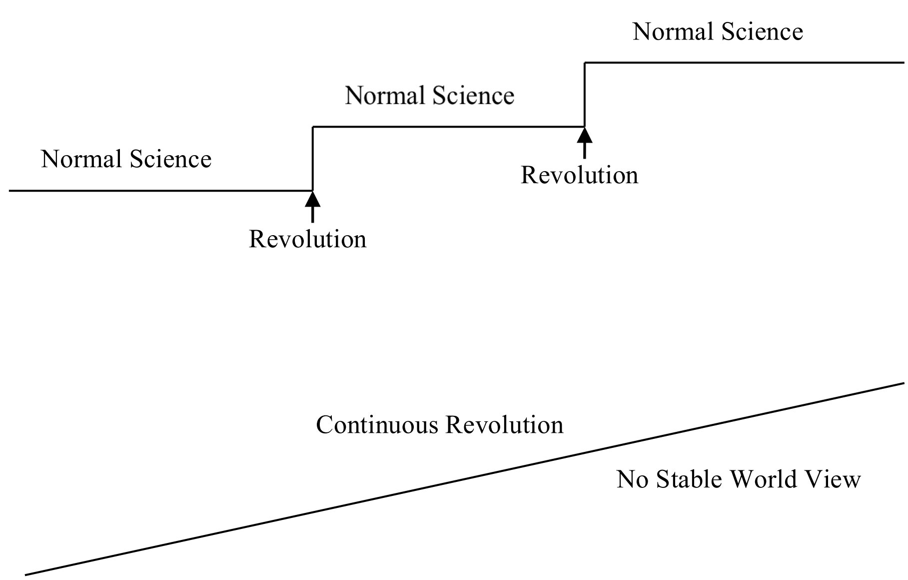
This metaphoric "lens" might best be called a world view or paradigm. As you will have surmised when reading the introductory chapter, in Ecosystemology one learns to change the lens. Other names for paradigm that you will come across are world view, Weltanschauung, Zeitgist, Episteme, and sometimes, story. Going back to the diagram, the paradigm focuses on or organizes the events of the actual world into our reality, and into our belief and value systems. The focusing or organizing is largely a *thinking* process. The Euclidean, common-sense view of the world induces us to think linearly and in terms of three-dimensional things or objects. These objects become for us the real parts of the universe. Thereafter it becomes difficult for us to think in terms of wholes.

PARADIGM SHIFTS

Throughout the long history of civilization, the same lens has not always been in place. Replacement of the lens is a *paradigm shift*. Notable paradigm shifts are what Kuhn calls scientific revolutions. The best example is the Copernican revolution. Before Copernicus, the common understanding was that the earth was the center of the universe. The sun, the planets, and the stars revolved around the earth. Although it was difficult for the church and for common-sense people, who noted the sun rising in the

East every day, to believe otherwise – and some astronomers literally lost their heads over it – the revolution finally succeeded. Today few people still ascribe to the old Ptolemaic world view. Another example is the shape of the earth. Common sense tells us it is flat. Mariners who noted ships bobbing over the horizon became suspicious. Yet it took a long time for any popular textbook to come out pronouncing the world (earth) to be round.

One notion is that a particular paradigm holds for a long time while the subsequent revolution which overturns it is of short duration; the new paradigm then endures for another long time, until the next revolution comes along. It seems that "paradigm durations" are getting shorter and shorter and revolutions are becoming more frequent. Japanese systems philosopher Magoroh Murayama has suggested that the graph of paradigm shifts which used to look like this (top part of diagram):



now, (bottom part of diagram) is just a gradual incline in which shifts are going on continuously and the tenure of a particular world view is too short to recognize as such. This idea itself is revolutionary. Think of the consequences. Textbooks kept on disks, no longer printed. Disciplines in constant flux. University departments abolished? What else?

I think what we have today is somewhere in between. Indeed, there are some recognizable trends occurring today in nearly all fields. Without remarking on each shift in any detail, on the next page is a list of current changes taking place.

AREA	FROM	TOWARD
Physics	Atomistic, Mechanical, Absolute Space and Time, Universality, Objective, Newtonian	Quantum Mechanical, Holographic, Relativistic, Complementarity, Indeterminacy, Heisenbergian
Chemistry	Equilibrium, Reductionist, Entropy Increasing	Non-Equilibrium, Morphogenetic, Order Increasing
Mathematics	Continuous Functions, Quantitative Change	Mapping Discontinuities, Qualitative Change
Philosophy	Universal Truth, Eternal Essence	Relationships of Resemblence, Historical Existence
Linguistics	Atomistic	Structural
Politics	Centralized Hierarchy, Authority, Necessity	Pluralism, Legitimacy, Voluntary and Incentive-Based
Evolution	"Random" Mutation, Survival and Conquest	Diversity, Co-evolution
Ecology	Competition and Self-Interest, Ideal: Stability, Closed Systems	Collaboration and Altruism, Resilience, Open Systems
Psychology	Identity, Individual	Harmony, Transactional
Religion	Monotheistic, Transcendence	Polytheistic, Immanence
Consciousness	Hierarchical (Relational)	Heterarchical
Learning	Mono- and Multidisciplinarity	Transdisciplinary
Arts	Representational, Stable	Abstract, Fluid

PARADIGM SHIFTS IN ECOLOGY

You have been reading about the big time paradigm shifters: Copernicus, Newton, Darwin, and Einstein. In Thomas Kuhn's terms they were the igniters of four great scientific revolutions. In terms of the science that developed after their revolutions, they are the "Great Men" or the *eponyms* behind, respectively, the Copernican heliocentric theory, Newtonian mechanics, Darwinian theory of evolution, and the Einsteinian theories of relativity. But we know that none of them did it alone. Within a period of less than one hundred years, several other astronomers, each from different countries (Johann Kepler from Germany, Tycho Brahe from Denmark, and Galileo from Italy), developed heliocentric theories independent of that of the Polish astronomer Copernicus. Newton's mechanistic world view was also proposed by René Descartes and Thomas Hobbes, all working (but not together) within a hundred year span of time. It is said that Alfred Russell Wallace actually beat Darwin to the punch with the evolutionary theory, but apparently he didn't publish soon enough so he didn't get the credit. Einstein's theories came along in the presence of other brilliant physicists, notably Max Planck, Werner Heisenberg, Erwin Schrödinger, and the much younger Niels Bohr.

During the period from 1938 (when I took my first ecology course in college as a junior) to 2000, I became aware that ecology, too, had its own distinct paradigms (called "schools"), paradigm shifts, and even its own Great Men. I shall now give a brief history of ecology from this point of view. During my lifetime of learning, reading, teaching, and writing, I lived through and experienced much of this history myself. The paradigm shifts and their "Great Men" are listed below, along with approximate dates or periods.

OLD PARADIGM	NEW PARADIGM	"GREAT MEN"	DATE
Biology considered to be only an intra-organism study	Biology to include external relations of organisms	Ernst Haeckel	1869
Ecology of individual organisms (autecology)	Ecology of biotic communities (synecology)	Frederic Clements	1900
Community Ecology	Ecosystem study	A. G. Tansley	1935
Ecology as a closed academic subject	Ecology open to everybody	Rachel Carson	1962
Classical and production-oriented ecology	Deep ecology	Arne Naess	1972
Ecology literature written primarily by men	There are prominent women in ecology, too	Carolyn Merchant	1980
Ecology as a biological subject	Ecology as the study of relations	Gregory Bateson	1972

Now let me tell the stories of how the paradigm shifts occurred.

Ernst Haeckel, a German zoologist, coined the word *oecologie* (anglicized to *ecology*) in 1869 or thereabouts. There have been no prior citations of the term. Haeckel's definition – "the study of the relations between organisms and their environment" – has stood the test of time, largely unchanged throughout these 130 years. In my mind, Haeckel's contribution to the entire field of Biology is second only to Darwin's.

Academically, Biology has a number of important and well-developed subfields which have been taught at universities in Europe and America through most of the 19th and all of the 20th centuries. These include morphology, anatomy, histology, cytology, physiology, genetics, and molecular biology – studies of the interior structures and functions of organisms. In all that time, studying the external relationships of organisms has not necessarily been considered Biology, and sometimes had not even been considered science. Throughout much of its history as a field, Ecology was belittled and often literally despised at many universities in America and deprecated as "high-school level nature study," as I outlined in Chapter 1. When I came to Berkeley in 1949 I found a botany department with a faculty predominantly anti-ecology, and I wondered why. I found no good reason why ecology should be derided and loathed, except that they could not overthrow that old paradigm which restricted Biology to the internal functions of organisms. As you know, it took a long time for Ecology to be widely accepted as an academic field.

Within Biology, the organism-centered view – that the part of the animal or plant that needed to be studied was only the part inside its skin – was as strongly held as geocentrism had been before Copernicus. Even with the newborn field of Ecology, Haeckel's definition limited ecological study to the individual organism – this came to be called *autecology*. The textbook for the first ecology class I took at the University of Minnesota was the *Chicago Textbook of Botany* by Coulter, Barnes, and Cowles. Henry Chandler Cowles wrote Part 3, "Autecology." A major shift in Ecology had taken place around the turn of the century, from focus on autecology to *synecology*. There was no change in Haeckel's definition, except that the concept of "organism" had changed. The English philosopher, Herbert Spencer, used "organism" in the broader sense of an organization, that is, a *community*. Thus synecology (*syn*- meaning "together") became the study of biotic communities in relation to their environment.

Ecology students in the first half of the century were all acquainted with Clementsian succession theories. Frederic Clements was born and raised in Lincoln, Nebraska, the exact center of the true prairie. He formulated his “succession to climax” theory as early as 1898; he published profusely and his writings were read, at least known about, by most ecologists at the schools that taught ecology. In many places, especially in the Midwest, Clements was called the Father of (plant) Ecology. Clements and his only graduate student, John E. Weaver, wrote the only plant ecology textbook that existed up to 1950, which means that all plant ecology students in the country were weaned on Weaver & Clements’ Clementsianism. Animal ecologists, of course, also learned it because animal communities were distributed more or less like the plant communities (i.e. bison in the true prairie, prairie dogs in the short grass prairie).

I used the Weaver & Clements text as an undergraduate at Minnesota and also as a Ph.D student at Nebraska. When I came to Berkeley, my colleagues immediately branded me as a Clementsian, even though I was not a disciple. Clements was not the only community ecologist of the time. Henry Cowles from Chicago, who was mentioned earlier, in 1889 made the first comprehensive study of plant succession on the sand dunes of Lake Michigan – in the deciduous forest biome. But like the case of Darwin over Wallace, Clements, not Cowles, was awarded the eponym. There’s no better PR than having the corner on the textbook market.

Another paradigm shift was occurring in the first half of the century: from community to ecosystem. Soon you will be reading a whole chapter on the ecosystem concept, so I will not describe it here. Here I want to talk only about the circumstance of the shift itself. In 1899 the Russian soil scientist, Vasiliy V. Dokuchaev, coined the word *biogeocoenose* to indicate that in order to understand nature, the appropriate unit to be studied should contain both the biotic components *and* the geologic components, that is, the soil and its parent materials. In 1913, R. I. Abolin had the same idea; he named it *epigen*. In 1941, Hans Jenny added three more factors to biota and parent material: climate, topography, and time. All five factors ("CLORPT") define Jenny's *larger system*. Arthur Tansley, in 1935, called it *ecosystem*. Is this a better name? Why is it the only one that stuck?

Between 1920 and 1950, the teaching of ecology was concentrated in a few large universities, all in the Midwest. The Nebraska school and the Chicago school were the main centers. The University of Minnesota also had a large, active ecology graduate program. My major professor (for my Master's degree) was William Cooper, a student of Cowles at Chicago. I would guess that during this period at least 80 percent of Ph.D's in ecology came out of the Clements and Cowles dynasties. Later (after 1950) other universities took up ecology with faculties independent of these "doctrines," such as Georgia under Eugene Odum and Wisconsin under John Curtis. For a long time most Ph.D's in ecology became teachers of ecology; others got jobs in the U.S. Forest Service or the Soil Conservation Service. All in all, ecology was a "closed shop," hidden in the academic closet. The public never heard of it; the media didn't care about it. Until…

Silent Spring was published in 1962. Ecology turned a new page with Rachel Carson's book. I don't know if this event should be called a paradigm shift. I think it is more like the invention of the printing press. All of a sudden, ecology was for everybody. For details, reread the first several pages of Chapter 1.

During most of the period (up to 1970) ecology was anthropocentric. It was taught in forestry schools, agriculture curricula, and conservation programs to learn how to grow trees, how to produce more crops to feed the hungry world, and the need to save the bald eagle from extinction so that future generations could enjoy it. Arne Naess called it “shallow ecology.” I taught what I thought to be a very good ecology course in our Forestry department at UC-Berkeley, but except for a few emotional lectures, it was shallow ecology. By now you know what the opposite, deep ecology, is.

In my very good ecology course I gave lists of required reading, recommended reading, and worthless reading. All were written by men, including some of the “Great Men” mentioned above. Thanks to Carolyn Merchant for telling us that there are women ecologists, too.

Finally, let me return to Haeckel’s definition of ecology: the study of the relationship between organisms and their environment. Through time, the term *organism* has been broadened to mean the community and the ecosystem. The environment has been enveloped in a great movement. And now relationships are getting top billing. Today ecology is the study of relationships, period; it has escaped its biological confines. (Witness such book titles as *Steps to the Ecology of Mind*, *The Ecology of Politics*, *The Ecology of Commerce*, and *The Ecology of Fear*.) We can use Haeckel’s definition as a launching point for the next chapter by considering *systems* instead of *organisms*.

CHAPTER 4 : SYSTEM & ENVIRONMENT

Prominent within the word *ecosystemology* is the well-known term *system*. Very closely associated with *system* is the equally well-known term *environment*. In this chapter we shall look at both the popular and the technical meanings of these two terms.

SYSTEM

System is already such a ubiquitous word in our language, and it is used in so many different ways, that you shouldn't be surprised to find many definitions. All definitions, however, will have a common logic core, though the associative frameworks that we hook on may be different from one discipline to the next, from one class to the next, and from one student to the next.

For our purposes we shall consider three definitions of *system*. We shall discuss them to enhance understanding of ecology and other sciences, to help us in managing our natural resources, and to appreciate the beauty that exists in our lives. The three definitions are taken from (1) an analytical point of view, (2) a managerial viewpoint, and (3) how the poet would look at it.

ANALYTICAL VIEW OF SYSTEM

Definition (1): A system is a set of objects together with relationships between the objects and between their attributes.

Thus, a system has three essential components:

OBJECTS ATTRIBUTES RELATIONS

Set implies that the system has boundaries. The set may be finite and completely describable by hypothesis; or it may be less discrete and defined only by the limits of the conceiver's interests. *Set* also implies that we can use set theory and its symbols in handling systems, such as by putting brackets around the three components, like this: {objects, attributes, relationships}.

OBJECTS are the basic entities (parts) of the system which are either directly perceived or logically inferred. The objects may be systems themselves, but for now we are not to be concerned with that possibility (see *holon* later in the chapter). In concrete or "real" systems the objects are physical units such as:

mesons stars wheels flowers arms nuts atoms wires switches frogs molecules springs

In conceptual or abstract systems the objects are abstract entities, like:

values concepts equations processes species laws numbers communities societies cultures etceteras

ATTRIBUTES are expressed as measures or qualities of the objects. For example, atoms have weights, stars have temperatures, springs have tensions, switches have positions, and flowers have odors. When the scientist studies systems, the data she records are always the attributes of the objects, not the objects themselves. Thus, in systems thinking, the attributes are more important than the objects that "carry" them. For instance, in a thermostatic control system, it is not the air (object) in the room about which we are concerned, but rather the temperature (attribute) of the air; it is not the hardware of the switch that is important to us, rather its position, off or on; nor is it the iron furnace that affects us, but whether it is burning high or low.

Objects will have more than one attribute. When a number of attributes of an object are considered together at an instant of time, we refer to its *state*. *State* is best reserved for its higher level meaning, that is, as the quality of the whole system when the attributes of its various objects are taken together. For example, think of economic systems where we can say that the state may be either "boom" or "bust."

RELATIONS, the third member of the set of system components, in systems thinking are even more important than the attributes. Without relationships we wouldn't need to conceive systems at all. Relations (or relationships, your choice) tie together the system's parts. In a system every pair of objects are somehow related, perhaps only passively or trivially, at least by a distance or a direction. In practice, however, we are interested only in relationships that are measurable. Now remember, the definition refers to relations between the objects <u>and also between the attributes</u>. Let me illustrate this point with two examples from a research project you'll be hearing about during Chapter 6: the Arctic tundra study. Lemmings (prey animals) are eaten by weasels and owls (predators). The predator-prey relationship (object vs. object) can be seen, and photographed, but not measured. What the researcher is interested in and sets out to measure is how many lemmings the weasel eats per day, how many calories the lemming provides, how many individuals there are of both lemmings and weasels, and so forth. These are attribute relationships. This is why scientists take some statistics courses and learn about correlation coefficients, regression equations, analysis of variance, and other tricks.

MANAGERIAL VIEW OF SYSTEM

Definition (2): <u>A system is an organization for control</u>.

It is implied by this definition that by organizing various entities and attributes into a bounded set or system, the outcomes can be controlled. In other words, we can manage, manipulate, or achieve control only within the limits of our system; whatever is outside of our system is also outside of our control, and therefore must be treated as "given." Thus, this means that we must conceive our systems (always for the purposes of management or understanding) so as to include all that <u>but only that</u> which we have the competence, the interest, or the need to manage or study.

This definition also emphasizes that systems are really only conceptions. They do not exist until we conceive them. They are not real, tangible, perceivable entities like a tree, for everyone to observe in the same manner. Every conceiver of a system is likely to have a different interest or purpose and also to have a different background of knowledge. There are some systems theorists who would put PURPOSE along with objects, attributes, and relations as essential components of systems. The managerial view of systems will be easier to comprehend when we get to discussing ecosystems.

AESTHETIC VIEW OF SYSTEM

Definition (3): Poets, artists, musicians, and dancers know that a system is a good way to look at the world.

It is much more natural for an artist or poet to think of a system as a point of view than for a scientist. Two scientists working in similar fields, when looking at a scene such as Old Faithful geyser, would see essentially the same thing and make it out to be a determinate machine. They have been trained, or conditioned, to interpret the repeatability of the phenomena in similar ways. But now take two poets, say Longfellow and William Blake; if they were looking at the same scene together, we would expect each to describe it in quite different words.

The poet is concerned not only about what she sees, but how she feels about what she sees. *System* is a truly beautiful concept because it can accommodate feelings as well as the cold measurements, and because it permits personal, individual appreciation. Artists also appreciate its flexibility: it can be moved around, expanded or contracted. Again, this will be shown when we come to ecosystems.

Below are two systems. What do you see? What do you feel?

A Complementarity

A sweet disorder in the dress
Kindles in clothes a wantonness;
A lawn about the shoulders thrown
Into a fine distraction.
An erring lace, which here and there
Enthralls the crimson stomacher.
A cuff neglectful, and thereby
Ribbands to flow confusedly,
A winning wave (deserving note)
In the tempestuous petticoat,
A careless shoe-string, in whose tie
I see a wild civility,
Do more bewitch me, than when art
Is too precise in every part.

Robert Herrick, 1648

What do these three viewpoints of system have in common? Well, at least this – that a system is a set of interrelated parts. This simple definition re-emphasizes what was said before about relations: if it were not for the relational aspect, then indeed systems would not need to be conceived at all.

Based on the definitions given, can you think of anything that is not a system? A term that has been invented is *heap*. A heap is a non-system. How would you define *heap*? What can we do about parts that seem to be inside a system but obviously are not related to any of the other parts? Give some examples.

What is outside of a system?

ENVIRONMENT

Definition: For a given system, the environment is the set of all objects a change in whose attributes affects the system and also those objects whose attributes are changed by the behavior of the system.

This formal definition of environment uses the same terminology that was used in the analytical definition of system. The definition says three things: (l) that an environment is specific for a single particular system; (2) the environment can affect the system and the system can affect the environment; and (3) a constant environment will not change the system nor will a stable system change the environment. What this definition does not tell us is when an object belongs to the system and when to the environment. In order to answer this question we must go to intuition.

> "Where Can I Find a Heap?"
>
> Systems, systems, everywhere
> Where can I find a non-system?
> I look under the rug where stuff has been swept.
> I see dust-balls intertwined with tiny dog hairs,
> And under the microscope if I looked
> I would see trillions of teeny microbes,
> Interacting with the dust balls and dog hair
> As a system.
>
> I look in the vacant lot junk yard
> Where old car batteries were haphazardly thrown
> No connecting wires to the plus or minus poles
> Still oozing juice and energy to rot the rat filth
> More connections now than ever in the car.
> The weeds, the rats, the termites are in seminar
> Discussing the systems approach together
> As a system.
>
> I look upward to the sky where there's plenty space
> To possibly find a non-system
> However the poet had told me
> About a faint, ever-so-faint but nonetheless present
> Dotted line that connects Sirius, the Dog Star
> With the little dog hairs that wiggle when I lift the rug
> And the positive pole on the decomposing battery.
> And that's a system too.
>
> I go to the wilderness for solitude.
> Ah! There are no people other than just me.
> Silence! Absence of Society! Ecstatic bliss!
> What is the first thing I see: a colony of ants
> And next a swarm of wild bees.
> In a systematic Vee formation, a flock of geese
> All working as systems.
> I give up. Where can I find a heap?
>
> – AMS

Our intuitive concept of environment is quite similar to the formal one, except that it is sloppy in two respects. First, we tend to slur over the important point that environments belong to systems. If it is understood that the specific environment refers to you or me as its system, there is no problem. We should note that everything outside of my skin, my underwear, my home – everything to the outer extremity of the universe constitutes my environment. It also includes you in it. Your environment is a little different than mine because it has me in it. This interpretation of environment, however, points out *Homo sapiens*' egocentricity and therein lies most of the "environmental crisis" that we have heard so much about. The concept of *environment* I am trying to explain relates to systems in general, not only to you and me.

The second sloppy point is the extent of the environment. Referring again to the intuitive concept of a human's environment (yours or mine), it starts outward from the surface of the skin. There is no place out there where one can say, "At this point it ceases to be environment," because everything beyond that point would still be environment. But the outer edge is not as important a question as the inner edge, i.e. the transition between system and environment.

In ordinary everyday conversation the all-inclusiveness of the concept *environment* causes no difficulty. After all, smog is smog whether at your doorstep or in the next county. But when we want to do something about it, such as control it, that's when we run into difficulty. No corporation in the world, no foundation, no government has enough resources on hand to control a "total environment." Up to now neither the U.N. nor NATO have controlled earthquakes, tornadoes, or torrential floods. We have to pull in our horns and think in terms of an "immediate environment." No matter what degree of technological prowess humans achieve, there will always be a gradient of controllability, running from the fingertips, where it is maximum, to far outer spaces where it approaches zero. Somewhere along this gradient there is a point (more accurately, a sphere) beyond which we cannot, wish not to, or should not manage nor manipulate. If there is such a sphere, such a concept, it ought to have a name. What should we call it?

Well, it already has a good name: it's the *system/environmental boundary*. Unfortunately, the popular notion of *environment* has taken a somewhat different drift. Remember in Chapter 2, Ecosystem Problems, the point was made that only within the system do we have control, not in the environment, and only within the system do manageable problems exist, not in the environment of the system. In order to emphasize this distinction, I refrained from naming the chapter "Environmental Problems," which they are conventionally called today.

To illustrate further how the managerial viewpoint of system (Definition 2) might apply to a system's environment, let me present this scenario. A farmer in the low-altitude foothills of the Sierras in California raises alfalfa to feed his cattle. For all intents and purposes his system (which is also an ecosystem) consists of his farm. He expects seasonal average rainfall to maintain good production of alfalfa (a constant environment will not change the system). But along comes a lengthy period of drought and the alfalfa crop is about to fail. Drought is an environmental phenomenon, outside of the farmer's ability to control it. (Can this be called an environmental problem rather than an ecosystem problem?) However, a meteorologist tells the farmer that by cloud seeding he can make rain. So he shoots some silver nitrate up into the reluctant clouds, it rains, and the alfalfa crop is salvaged. Has the farmer overcome the "rule" that you can't manipulate the environment? No, he has simply enlarged his system to include the clouds and the cloud seeding operation. And now where is the new system/environment boundary? What if there are no clouds? No problem, says the farmer. All that I have to do is find a way to drag some moisture bearing clouds down from Canada, which means I have to expand my system out to the whole atmosphere.

Maybe the example is facetious but the "moral" is not. The beautiful thing about systems is that they are concepts and depend on the conceiver's purposes. A city's mayor, if he or she is ambitious, may increase hir scope of influence to the state or to the nation. S/he just makes hir system bigger.

Back to the question of how to tell whether an object is in the system or in its environment. Really now, does it matter? If an object that we would ordinarily call *environmental* interacts so readily with a system as our formal definition implies, why shouldn't that object be part of the system? Well, it depends entirely on the conceiver. She will bound her system simply by the limits of her interests and by her purpose. Academically, one may be interested in the entire universe, pragmatically only in the accessible and measurable. Thus, the system of one conceiver excludes or neglects

> We in America belong to what has been called a "thing" culture. It's not about our materialism. It's about our language, the words we use. Every day we overuse the words *something*, *anything*, *everything*, and *nothing* in totally abstract ways. We often use expressions like "the thing is to have fun" or "I have a thing about ice cream," where *thing* is an abstract entity and not really a thing at all.
> The word *system* derives from the Latin *sistere*, which means <u>to stand out from</u>. This should help us to understand how a system "stands out from" its environment, or is separate from it, even though there may be no sharp boundary.
> One reason why holism is rejected by the scientific community, and interdisciplinarity has been slow to catch on in academia, is because within these paradigms nothing clearly stands out. Everything is related. Even systems are invisible because it's all environment! It's all background. Think about it.

certain attributes which another conceiver’s system includes. A bacteriologist would include microbial forms which a mammologist might leave out. An anthropologist would include the native medicine man which the public health officer or the A.M.A. physician might not. Mapped on paper, such inclusives would look like a flock of Venn diagrams.

What should we do about those individuals who happen to be equally interested in the system and its environment? Aha! There is a name for that larger conception: UNIVERSE, or more specifically, *universe of discourse*. The series of diagrams below will show the relation between system, environment, universe of discourse and two other terms: *operational environment* and *potential environment*.

(1) [System S] Environment E E’ E’’ E’’’ E’’’’ … E^n

(2) Universe of Discourse:

[[System S] Environment E --- E’’’’’---]

(3) [[System S] Operational Environment E] Potential Environment E’

(4) [[System S] [System E^1] [System E^2] [System E^3]]

These diagrams show a capital “S” (for System) in a box. Environment, however, being unbounded on its "outer" edge, does not have to be in a box unless it is construed to be another system (as in 4).

In diagram (1) the system is surrounded by an environment which to a manager would appear to be a graded series with diminishing opportunity for control. The system is the unit of primary concern, while the environment(s) are "givens" which influence the system, and in turn are affected if the system changes. Diagram (2) applies to the scientist (or any interested observer) who is equally interested in measuring the processes which s/he can control within hir system and those s/he cannot "control" among the givens. Many physical scientists are interested in the "universe of discourse" or even in the entire universe even thought their measurements "out there" are weak. On the other hand, poets are not hindered by the great distances to Environment E'''''' and beyond.

Diagram (3) suggests that right at the outer boundary of the conceived system is where an effective environmental input can be measured. Put the rain gauge at the top of the tree layer; count the immigrants at the portals; measure your food inputs at your mouth. This defines the *operational environment*. The groceries you have stored in your pantry are in the *potential environment*.

> *He drew a circle that shut me out –*
> *Heretic, rebel, a thing to flout.*
> *But Love and I had the wit to win:*
> *We drew a circle that took him in!*
>
> "Outwitted" by Edwin Markham, 1901
> (or, how a systems analyst can use Venn diagrams)

The next step in the progression, diagram (4), shows that we can, in fact, make measurements or estimates of the potential environment. That is, we can separate E' from E’’ from E’’’ and so on. But as soon as we put these environments into boxes, we have “converted” them to systems. By adding appropriate arrows between the boxes, we will have constructed a framework by which we can study the universe of discourse through the method known as *systems analysis*. It’s cheaper than the method known as NASA, where people actually go toward the edge of the universe to collect samples – with a minimum of discourse.

SYSTEMS THEORY

In all the systems-related literature that I have encountered while writing this chapter, there were four distinct subtopics which I felt had to be dealt with. Two have already been mentioned: Churchman’s *systems approach* and the other, the common approach that is usually taught in engineering and business schools, *systems analysis*. The third subtopic for us to look into is *systems theory*.

> What’s a theory?
>
> Imaginative contemplation of reality
>
> A belief, policy, or procedure proposed or followed as a basis of action
>
> The body of generalizations and principles developed in association with practice in a field of activity and forming its content as an intellectual discipline
>
> A hypothetical entity or structure explaining an observed set of facts
>
> Something taken for granted especially on trivial or inadequate grounds
>
> “It is certainly not the least charm of a theory that it is refutable.” – Nietzsche

Systems theory began with Ludwig von Bertalanffy around the mid-twentieth century. Bertalanffy was a biologist who was interested in how biological forms were organized so that they could sustain themselves within their environment. Then he found that similar generalized theories prevailed in many fields besides biology, for example, the pioneering work in mathematical ecology of Alfred Lotka and Vito Volterra on the dynamics of predator and prey populations, and theories in quantitative economics and econometrics. Bertalanffy came to realize he was dealing with open systems, that is, systems exchanging matter and energy with their environment:[1]

> "Thus, there exist models, principles, and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relations or 'forces' between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general."

This is how Bertalanffy postulated the new discipline he called *General Systems Theory*, the subject matter of which is the formulation and derivation of those principles that are valid for systems in general. A general theory of systems gives us models that can be used in, and transferred to, different fields and provides safeguards from the vague analogies that have often inhibited progress in those fields.

General Systems Theory will be revisited when we come to Chapter 9, Complexity and Science, in connection with theories of organized and unorganized complexity. Classical physics has depended primarily on the latter; unorganized complexity is rooted in the laws of probability and chance and in the second law of thermodynamics. But today, not only physics but many other fields deal with problems of organized complexity: concepts of order, wholeness, differentiation, teleology, and information. Such concepts have appeared in widely different fields, often independently and based on totally different sets of facts. There are instances where identical principles were

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[1] From Bertalanffy, *General System Theory: Foundations, Development, Applications*. New York: Braziller, 1968.

discovered because workers in one field were unaware that the theoretical structure required had already been well developed in some other field.

Three principle aims of General Systems Theory that are especially relevant to Ecosystemology are:

(1) To point toward a general science of "wholeness" which had previously been considered to be a vague, hazy, semi-metaphysical concept.

(2) To recognize the general tendency toward integration within the various sciences, both natural and social, and between them.

(3) To recognize the unifying principles running "vertically" through the universe of individual sciences.

(4) To provide a rational basis for most of the "new disciplines" that have developed since 1950. These are briefly described in Chapter 5.

Now let us examine the foundational "system sciences" that have been important to the development of Ecosystemology.

CHAPTER 5 : SYSTEMS SCIENCES

Each of the sciences listed below will be described for general utility to learners of Ecosystemology. I will mostly focus on the original ideas of each field; many of these sciences have undergone metamorphosis over time. Towards the end of the chapter I will then discuss the trends of these metamorphoses and the state of the systems sciences today, and conclude with remarks on the import of systems thinking.

- Information theory
- Cybernetics
- Feedback theory
- Hierarchy theory
- Theory of Dissipative Structures
- Game theory
- Catastrophe theory
- Chaos theory
- Complexity theory
- Ecosystem theory

INFORMATION THEORY

Information has two meanings. One is the everyday meaning which is defined in most dictionaries as knowledge communicated or received concerning a particular fact or circumstance, that is, <u>news</u>. The second meaning is technical. It is not radically different but is much more precise. The everyday meaning of information is something that we get from reading, listening, or observing what is around us. Any statement or observation is informative if it tells us something that we did not already know. This means that we gain information only about things in which we are ignorant or uncertain. Thus, we can define *information* as that which removes or reduces uncertainty. What is neat about this definition is that once we are able to measure uncertainty, then we can measure information in the same terms. This, then, is the technical meaning of *information*. Note that the meaning of the message sent may not be involved.

Suppose I am looking for my keys. If I know that they are in my pants pocket I will find them in a hurry. If misplaced somewhere in my house, it will take longer – the uncertainty is greater. If I misplaced them somewhere on the university campus, then the uncertainty is very great. So how can we measure this uncertainty? We can get the answer by playing a series of six games. Each successive game will involve greater uncertainty. As the respondent in each game you must answer one or more "yes" or "no" questions.

Game No. 1: The Warden's Game (see box below). How many times can the prisoner's wife sneak a message past the crafty warden?

Game No. 2: Coin toss. How many yes-or-no questions must be asked in order to identify whether a fair coin lands heads or tails?

Game No. 3: Cast of a regular six-sided die. What's the minimum number of yes-or-no questions that must be asked to identify with certainty how the die lands?

Game No. 4: Deck of cards. How many yes-or-no questions will answer which card has been pulled out of a 52-card deck?

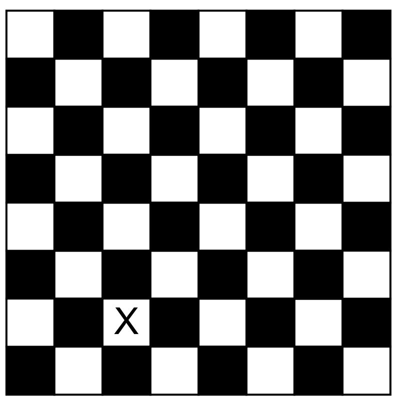
> Game No. 1: The Warden's Game
>
> A Prisoner is to be visited by his wife who is not to be allowed to send him any message, however simple. It is understood that they may have agreed, before his capture, on some simple code. At her visit, she asks to be allowed to send him a cup of coffee. Assuming that the coffee is not forbidden, how is the warden to insure that no coded message is transmitted by it? He knows that she is anxious to let her husband know whether or not a confederate has yet been caught.
>
> The warden will cogitate with reasonings that go somewhat as follows: "She might have arranged to let him know by whether the coffee goes in to the cell sweetened or not – I can stop that by adding lots of sugar and then telling him that I have done so. She might have arranged to let him know by whether she sends a spoon – I can stop it by taking away any spoon and telling him that prison regulations forbid spoons anyway. She might do it by sending tea instead of coffee – no, that's stopped because, as they know, the canteen will only supply coffee at this time of day." So the warden's cogitations go on, and what is noteworthy is that at each possibility he intuitively tries to stop the communication by forcing a reduction of the possibilities to one – always sweetened, never a spoon, coffee only, and so on. As the possibilities (alternatives) shrink to one, communication is blocked, and the beverage robbed of its power of transmitting information.
>
> Another prisoner story: Two soldiers are taken prisoner by two enemy countries A and B, one by each; and their wives each later receive the brief message "I am well." It is known, however, that country A allows the POWs a choice from: "I am well" or "I am slightly ill" or "I am seriously ill," while country B allows only one message: "I am well," meaning "I am alive." The wives will certainly be aware that though each has received the same phrase, the informations that they received are by no means identical.
>
> These two stories indicate that the transmission of information is essentially related to the existence of a set of possibilities and the information carried by a particular message depends on the set it comes from. *The information conveyed is not an intrinsic property of the individual message.*
>
> From W. Ross Ashby, *An Introduction to Cybernetics*. New York: Wiley, 1961.

Game No. 5: Checkerboard. A checker is secretly placed on one of the 64 squares of a checkerboard. How many questions must be asked to find the spot?

Game No. 6: Animal-vegetable-mineral, also called Twenty Questions. My audience knows that I know at least 1,048,576 different kinds of animals or plants or minerals. But now I am thinking of only one. How many guesses are required to find out what I am thinking of?

Let's pretend that we have played all six games and have put the conditions and results in the form of a concise table. For each game we have tabulated the number of possibilities and the number of yes-or-no questions needed to specify (with certainty) the right answer.

The Game	No. of Possibilities	No. of Questions	**H** = bits of uncertainty
No. 1	1	0	0
No. 2	2	1	1
No. 3	6	2-3	2.58
No. 4	52	5-6	5.7
No. 5	64	6	6
No. 6	1,048,576	20	20



We can use the checkerboard game (No. 5) to illustrate the process used to get these figures. The checkerboard above has an X placed in the square near the lower left corner, as you see. Questions are always asked the same way: Q1: is the X located on the left half of the board? A: Yes. Q2: is the X on the top half? A: No. Q3: is it on the left half of the remainder (southwest quarter)? A: No. Q4: is it on the top half of that remainder? A: No. Q5: on the left half? A: Yes. Q6: on the top half of what's left? A:

Yeah, there it is. So the X has been located with complete certainty with six questions. Of course, it could also have been located with one question (with a lucky guess) or with 62 questions, but never with certainty until question number 63. Each of the 6 questions cut the alternatives exactly in half – getting a "yes" or a "no" was equiprobable.

If you have time to play another game, let's play No. 6. I'm thinking of some animal, plant, or chunk of the earth. My adversary starts off with, is it organic? From there it progresses as on the right. In this game you will note that it is unlikely to be able to cut the alternatives exactly in half. The bread-box may not be the median size of all things I can think of.

Game No. 6: Twenty Questions

1. Organic? Yes
   (so it's not mineral)
2. Vegetable? No
   (it has to be animal)
3. Terrestrial? Yes
   (ah, a land animal)
4. Bigger than a bread box? Yes
   (maybe a dog or bigger)
5. Bigger than a horse? No
   (maybe a cow or smaller)
6. Warm-blooded? Yes
   (vertebrate, not a reptile)
7. Four-legged? No
   (bird or primate)
8. Mammal? Yes
   (good, that makes it easier)
9. Native (to America)? Yes
   (not much help)
10. Fur-bearing? No
11. Primate? Yes
12. Homo sapiens? Yes
    (millions in the U.S.A.)
13. Living? Yes
14. Female? No
    (man alive)
15. In sports? No
16. In politics? No
17. In education? Yes
18. Over forty? Yes, Yes
    (Oh, oh, getting warm)
19. Over weight? Yes, Yes, Yes
    (I think I've got it)
20. Arnold? None other

Now we should generalize the principles learned from playing these games. A series of yes-or-no answers are a sequence of binary digits (or *bits*) such as 1 0 0 0 1 1 (for the checkerboard game) where 1 means a yes answer and 0 means a no. The *bit* is a unit of measure for information and uncertainty. We can say that the uncertainty involved in the question, "on which square of the checkerboard is the X?" is equal to six bits. If you remember your high school math, the number of bits is the power to which 2 must be raised to equal the number of alternatives or possibilities. The small italic letter *m* is used to designate the number of equiprobable alternatives from which a choice is made. The capital H (which happens to be named after Hartley) is the amount of uncertainty expressed in bits. In the equation, m = 2, the number of bits equals the logarithm (to the base 2) of the number of alternatives. It can also be expressed as

$$H = \log_2 m \quad .$$

Information theory was developed by Claude Shannon for the Bell Telephone Company prior to World War II, but his research was suppressed by the U.S. government because it would be useful to Army Intelligence in communications, especially for coding and decoding messages. After the war ended, the work was released and for awhile it was thought to be the top idea of the century. Even ecologists put it to use in estimating the information (measured in bits) in very complex ecosystems. That fad quickly faded. Imagine asking and answering 100,000 or more yes-or-no questions about the arctic tundra! We’ll hear more about Claude Shannon in Chapter 10, Organized Complexity.

CYBERNETICS

Cybernetics originated with Norbert Wiener. Before World War II, Wiener was a participant in a monthly discussion group at the Harvard Medical School. Other participants were physicists, mathematicians, and, of course, physicians. Usually the group’s main focus was on scientific method. Frequently the topic was the then-neglected area of science, the no-man’s-land between the well-established disciplines;

science had been increasingly the task of specialists in fields growing progressively narrower. Projects undertaken by the group involved missiles. Wiener concluded that what was needed was what control engineers called feedback. At the time there was no common terminology and not a single name for the field in which they were tinkering.

The group decided to call their field “of control and communications whether in machines or living organisms” by the name *cybernetics*. It is derived from the Greek, *kubernete*, or steersman. It is also the root word for *governor*.

A much more accessible explanation of cybernetics than Wiener’s is given by British psychiatrist W. Ross Ashby. Ashby uses an entirely different approach to the field. Nevertheless, it still comes out looking only at the deterministic aspect of systems, i.e. those system functions that are repeated or only stochastic in some regulated way, or in other words, portraying natural systems as machines.

The main themes of cybernetics, especially for biologists, are coordination, regulation, and control. Cybernetics is also a “theory of machines,” but with this difference: it treats the machine not as a thing, but as a way of behaving. It asks the question, “What does this machine do?” not “What is it?” and thus is entirely functional and behavioristic. Cybernetics deals with all forms of behavior,

The Law of Requisite Variety

“Only variety can destroy variety.”

As we have seen in Chapter 2, the kinds of perturbations that can occur in ecosystems and the variety of causes of these perturbations are many. And, of course, there are many different kinds of ecosystems, so that the kinds of perturbations and kinds of causes aggregrate to a great variety of problems.

How do we go about training our problem solvers or our resource managers? Too often our schools and colleges have fixed curricula. They turn out entire cohorts of students who have only one tool or one strategy for problem solving.

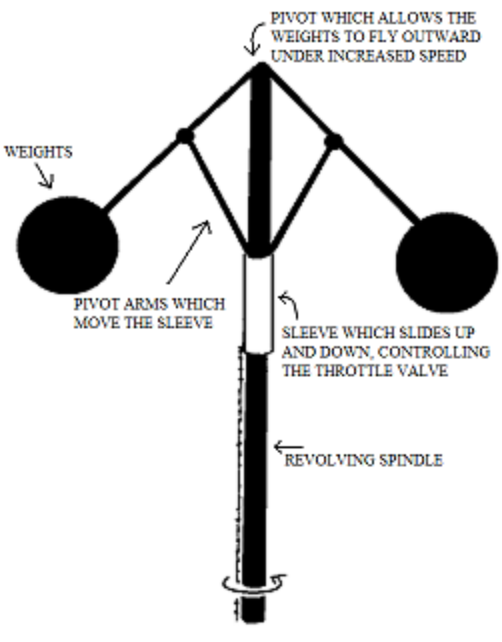
The law of requisite variety states that to be successful, the variety of methods, tools, or strategies must be at least as great as the variety of problems to be solved.

as long as they are regular, deterministic, and reproducible. Cybernetics offers a single vocabulary for representing the most diverse types of systems. Think of it: a way to handle systems as diverse as radio sets, VCRs, the human brain, hydraulic brakes, or ecosystems! A second virtue peculiar to cybernetics is that it offers a method for the scientific treatment of very complex systems, where complexity is too important to be ignored, which again applies to ecosystems. In simpler systems the methods of cybernetics may have no obvious advantages over older methods.

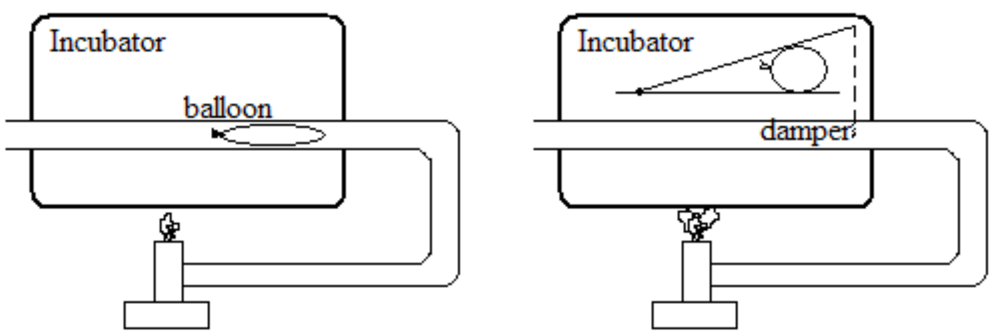
FEEDBACK THEORY

The notion of feedback is often attributed to James Watt, the Scottish engineer who modified the steam engine, making it a more efficient machine. His governor was the single most important invention to bring on the Industrial Revolution in England in the eighteenth century. Watt's governor is one of the earliest and best examples of feedback in mechanical systems. So that you become entirely familiar with the concept of feedback, we should look at several other examples, mechanical, physiological, social, and, of course, ecosystemological! But first let's look at the governor (below).

The revolving spindle is connected to a wheel of the train; the faster the train is going, the faster the central spindle revolves, and the iron ball weights fly outward. As the weights fly out, the sleeve slides up, reducing the conveyance of steam through the throttle valve and slowing down the train. As the train slows, the weights fall down, opening the throttle valve to increase the conveyance of steam again. This process automatically regulates the train’s speed to stay within a certain range.



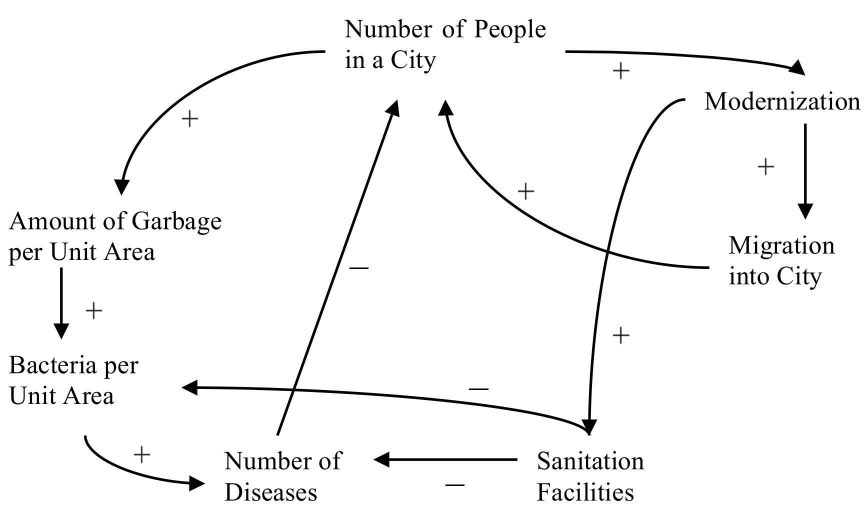
James Watt's Governer



Negative Feedback   Positive Feedback

A thermostat affords one very simple case of feedback in everyday use. When the temperature in a room rises too high, the extra heat activates a switch which cuts off the source of heat, which in turn reduces the temperature. Illustrated above is a simplified mechanical model of a thermostat with negative feedback. As the incubator warms up, the balloon in the gas pipe expands to reduce the flow of fuel; then when the incubator cools, the balloon deflates and lets more fuel to go to the burner. The second model is rigged so as the incubator gets warmer, the damper opens even wider, the incubator gets hotter, and kaboom! This is an example of positive feedback. Like a bad governor going wild with power!

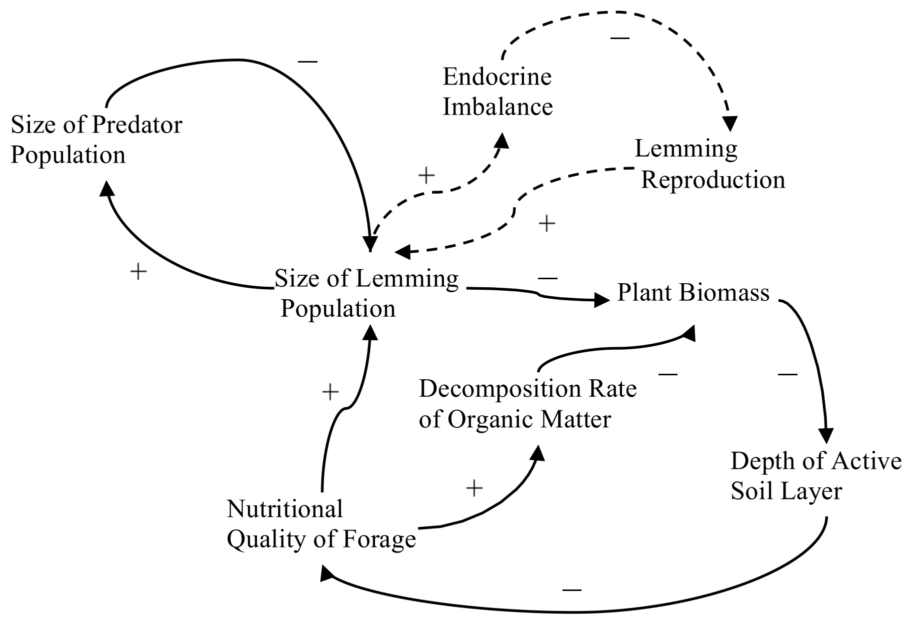
I can think of an example of feedback control of teaching quality which might work like this: A professor gradually improves his teaching ability and consequently enrollment in his class begins to increase. However, very large classes tend to degrade the quality of instruction. So enrollment declines as students realize the professor's courses are not so good after all. When classes again reach an optimum (or at least, smaller) size, teaching quality again improves.



Elsewhere in this book you will find other examples of feedback, both negative and positive. Let me discuss a case described by the Japanese systems scientist Magoroh

Maruyama in his article “The Second Cybernetics.”[1] Maruyama presents a diagram of a hypothetical city as it grows. I have reproduced it above. It shows a whole system with parts or subsystems that can assume a variety of states. More than one transformation or way of behaving can be identified. These are shown as “loops” marked with one or more + or – signs. Starting with the city’s population at initial time one, upon modernization (+), more people will want to migrate in (+), so the city grows (+). Any loop that has only + signs or an even number of – signs designates positive feedback. But, of course, as a city gets bigger (e.g., Calcutta) other problems develop, like garbage (e.g., New York in 1980). As garbage piles up (+), bacteria increase (+) as does the number and incidence of disease. Now, if enough people get sick and die, the population of the city will decrease (–). What a way to stabilize city growth! Better to improve sanitation facilities (–).

[1] Magoroh Maruyama, “The Second Cybernetics: Deviation-Amplifying Mutual Causal Processes,” *American Scientist* 51:2: pp. 164-179, 1963.



In my research on the Arctic tundra I found the ecosystem to be replete with feedback processes, some negative and some positive. The model above shows three different ways that the ecosystem may behave. Moreover, it implies that through time, in order to ensure system survival, ecosystems may evolve many feedback mechanisms. I'll tell you all about it in the next chapter.

HIERARCHY THEORY

You will have noticed that, except for cybernetics, all of these new system sciences are called theories. Are we not yet bold enough to call them sciences? One of my colleagues, a pedologist, used to say that any field that included "science" as a suffix, like social science, computer science, etc., was not a science at all, and should admit it.

Now we come to *hierarchy* and some will say it isn't even a theory.

In Chapter 10 (Organized Complexity) you will hear Herbert Simon say that we do have a theory showing why the world is structured hierarchically. So in spite of what Nobel Laureate Simon says, I raise the question of whether the real world is organized hierarchically or is hierarchy nothing but an invention of the human mind, which uses it as a pattern or grid to overlay whatever it perceives so that the perceptions appear to be hierarchical.

In another paper by Maruyama, "Metaorganization of Information" (1965), we find a good description of one of several categories of hierarchy, the hierarchy of classification. Maruyama describes the classification universe. It consists of substances, which may be material, spiritual, or otherwise. The substances have two main characteristics: they persist in time and they obey the laws of identity and of mutual exclusiveness. They are classifiable into mutually exclusive categories, divided into subcategories, and combined into supercategories. There exists the largest category which is called the universe and the smallest which used to be called the atom. Methinks all this dates back to Aristotle.

Another kind of hierarchy is the hierarchy of control. It takes the form of nested structures or levels in which the lower level units provide specialized services or materials which the upper levels require to exist and the upper levels constrain, direct, or control the activities of the lower. Entities at each level have a dual nature, being at the same time part of the level above and whole to the level below. Arthur Koestler, in *The Ghost in the Machine* (1976), gave the name *holon* to this two-faced Janis-like entity. ‘Hol’ comes from *whole* or *holistic* and ‘on’ implies *part*, as in electron, proton, or neuron.

Can hierarchical arrangements be linear? Like a book? Although the contents of this book are organized into chapters, sections, paragraphs, sentences, words, and letters, they follow a page after page sequence. A common hierarchical form is the tree. Hierarchical trees usually hang upside down, trunk in the air, branches facing down. Still another common form is found in the nested Chinese boxes. Nested boxes invoke the notion of inclusiveness in a volumetric sense. Each member of the hierarchy has three-dimensional volume and is included in the next larger container. It is with this view that the ecologist J. Stan Rowe argues for excluding the community and the population from the levels-of-organization charts usually found in textbooks. Neither the community nor the population have volume in the sense that we bequeath to the individual organism and to the ecosystem.

The question posed at the beginning of this section which can be rephrased as, “Was the world hierarchically organized before the human mind evolved?” or “Did God think hierarchically?” has not been answered satisfactorily, I’m sure. Are there any complex systems anywhere that cannot be structured hierarchically? Is this kind of structure so universal, like feedback, that it may be nothing more than a metaphor? Let’s take it up again in Chapter 10.

The six remaining system sciences will be treated briefly. Each will be defined and shown how it relates to Ecosystemology.

THEORY OF DISSIPATIVE STRUCTURES

Physics through the 19th and first half of the 20th centuries dealt exclusively with closed systems and systems in or near equilibrium. According to the second law of thermodynamics, order in closed or near-equilibrium systems cannot increase – it can only change toward greater disorder. Ilya Prigogine showed that open systems which are in a state of non-equilibrium try to maintain their ability to exchange energy with the environment by switching to a new dynamic regime whenever the production of entropy becomes stifled in the old regime. This principle is called *order through fluctuation*. It reverses the dynamic characteristics that apply to closed and near-equilibrium systems. These open, non-equilibrium systems are called *dissipative structures*. They are called that because they maintain a continuous production of entropy and dissipate the entropy that accrues.

CATASTROPHE THEORY

Catastrophe theory is about change. The very early stages of some sciences could not deal with change; they investigated static things only. Only later were the mathematics invented that could analyze change, but the kinds of change that these mathematical principles were prepared to handle were continuous and quantitative, predictable and smooth, like the regular elliptical orbits of planets or the constantly varying pressure of gasses when heated or cooled. Not until the advent of catastrophe theory was a way found to handle the abrupt, the sudden and discontinuous kinds of change. Catastrophe theory looks at all kinds of sudden change, catastrophic ones like earthquakes and gentler ones like affairs of love.

CHAOS THEORY

A quick but incomplete way to describe chaos theory is to explain the Butterfly Effect which underlies both the unpredictability and the constancy of weather, where tiny differences in input can become overwhelming differences in output. As with many of the other systems science, it cuts across the traditional disciplines. It deals with different kinds of irregularity in nature. Its mathematical origin is noted in several of its applications, the most exciting one being the concept of fractals in nature.

COMPLEXITY THEORY

All of these systems sciences seem to be very closely related, certainly closer than chemistry, physics, and biology. For example, complexity theory derives from chaos theory, or is it the other way around? Chapter 9 of the Ecosystemology book is titled “Complexity and Science” and Chapter 10 is “Organized Complexity.” The chapters deal only marginally with the theoretical and technical aspects of complexity theory. Complexity theory today continues to be a popular name for many types of system sciences dealing with nonlinear dynamics, self-adapting systems, information and computation, artificial life, and evolution.

ECOSYSTEM THEORY

Is there an ecosytem theory? I think there is and I'll explain it in the next chapter. Ecosystem theory is only partly based on the theories of ecologists Dokuchaev, Tansley, Jenny, and Odum. The theory is also derived from Wolfgang Kohler's gestalt theory, C. West Churchman's ideas on whole systems, and David Bohm's concept of wholeness. In addition, Erich Jantsch's ideas on design of social systems and Ludwig von Bertalanffy's General Systems Theory point to the concept of *ecosystem*.

GAME THEORY

The theory of games is more a branch of mathematics than it is one of the system sciences. It was developed as means to deal with competitive economic behavior and as such it traditionally has had more relevance to the fields of economics, psychology, and politics (including war) than to biology or ecology. Game theory was first established in 1928 by economist John von Neumann.

SYSTEMS SCIENCES TODAY

Over time there has been a broad trend in the evolution of the "general systems" concepts. They were primarily descriptive, big ideas about general and sometimes vaguely defined processes and structures. They were accessible to a wide variety of disciplines and to people who weren't scientists. But to mainstream science they were pretty "radical" or "not rigorous," even "silly." General Systems Theory wasn't taken very seriously by the scientific establishment once the novelty wore off; ideas in this vein nowadays may speak of "networks theory" but rarely "General Systems Theory." Nobody talks about "Catastrophe Theory" anymore, though there are other related terms such as "self-organized criticality," "bifurcation theory," and "adaptive dynamics."

However, not all system sciences have been completely remodeled. The ones that escaped this fate tended to have some mathematical inclinations: game theory; chaos, complexity, and dissipative structures theories; and information theory and cybernetics. These theories evolved into some highly technical and specialized branches of physics, mathematics, and molecular biology, such as machine learning, stochastic control theory and financial mathematics, bioinformatics, and of course game theory, which is taught even in some high schools today.

One popular tool of the new systems sciences is the *computer simulation*. Since the things people try to explain are very complicated to keep track of mentally, people program a computer with all the important feedbacks. They then have the computer "grow" a system over time out of those relationships. Sometimes it works (i.e. the simulation looks a lot like the real system), and sometimes it doesn't. If the system in the computer does not look like the system in the real world, the programmers rethink things and try new equations to see if that works better. If the simulated system has strong resemblances to the "real" system, then they might claim to have found a possible explanation for what is driving the system. The methodology relies a lot on the idea of *self-organization* – rather than looking for global behavior to explain what the system is doing, you can look at the simple rules that govern how the tiny parts interact with their neighbors and change step-by-step, and over time the complex global behavior will emerge from that (if you got the rules right). Then the system can be described in terms of those simple rules, which helps make things for precise for the analyst and may provide powerful tools for the manager.

That type of "computational research" is pretty far out of reach for most people who aren't interested in computer programming. What does it have to do with Ecosystemology? In fact, some of these newer branches of the systems sciences may give the aspiring ecosystemologist some useful concepts.

One new branch of game theory called *Evolutionary Game Theory* has been applied to the coexistence of different types of one species. This field, applied to evolutionary and population biology, extends the Darwinian concept of "survival of the fittest," noting that the "fittest" type of behavior may change or cycle over time within a dynamic "fitness landscape." Another part of the field investigates the evolution of social cooperation in conserving a public good (such as an ecosystem resource base), theorizing about the kinds of conditions in which such societies tend to arise and the types of institutions that keep the cooperation going strong. (Quite a departure from the economics of globalization we discussed in Chapter 2!) And then there are NETWORKS.

In systems thinker Fritjof Capra's latest book, *The Hidden Connections* (2002), he talks a lot about *networks*. They pervade scales of existence ranging from the molecular to the planetary. So what is a network? How is it different from a system? In short: it is not really different from a system, at least the analytical view of a system. Rather than considering objects separately from attributes, a network simplifies a system into a set of connected "nodes" or "vertices" (which you can let be anything you want: objects, different attributes of one object, types of objects...). A "graph" is a visual representation of a network: circles or dots show where the nodes are, and lines ("edges") connect the nodes to show that a relationship exists. Usually if there is some kind of feedback or flow pattern, you use *arrows* to show the direction of the exchange. The graph is called *directed* or *undirected* depending on whether you have arrows or not. Directed graphs are called "acyclic" or a "tree" if there is no circular flow anywhere, and "cyclic" if it has some kind of way that you can go in a circle. (Unfortunately for the study of ecosystems, directed acyclic graphs are much more studied and well-understood than the directed cyclic graphs that capture feedback.) You label or define both the nodes and the edges (relationships), and then the network graph speaks for itself. It looks pretty much the same as a system diagram, like the ones I used to explain Feedback Theory. A food web is a network. Many biogeochemical (nutrient) cycles can be represented as networks. The diagrams illustrating Feedback Theory earlier in this chapter are, in fact, networks. In a way, a network is a simpler way to represent a system, and networks can be very useful to examine flows and processes of systems over time.

In the beginning of this chapter I mentioned a trend in the evolution of the system sciences. It seems that many systems ideas have changed to be more and more specialized, technical, and reliant on mathematics, computers, and programming. However, we also have books like *The Hidden Connections* coming out, integrating many new systems-related ideas and making them accessible and relevant for all kinds of people, trying to create "sustainability sciences" out of the systems sciences.

SYSTEMS THINKING

This has been a long look at systems. Mention was made back in the introduction to Systems Theory at the end of Chapter 4 that there are four distinct subtopics about systems to be dealt with: the systems approach, systems analysis, and systems theory. In Ecosystemology we cannot leave out the fourth one: *systems thinking*. If you are serious about applying any of the ideas you have read so far, then you are already doing systems thinking.

Systems thinking involves the appreciation of the concept "system," with its emphasis on both of its referential concepts: wholeness and interrelatedness. Peter Senge defined systems thinking as a discipline for seeing wholes, and a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "single shots." It is also a set of specific tools and techniques. Systems thinking is a sensibility for the subtle interconnectedness that gives living systems their unique character. It is a discipline for seeing the "structures" that underlie complex situations. Moreover, systems thinking gives us a language that begins by restructuring how we think.

Ecosystemologists are expected to develop systems thinking as a habit! We definitely need to be well-acquainted with the idea of *system* before we can even begin to talk about the idea of *ecosystem* in detail. Now we are ready to finally discuss that which Ecosystemology is the study of, in the next chapter on *ecosystems*.

CHAPTER 6 : ECOSYSTEMS

Once upon a time – about 1972 – I was in the process of writing a book about ecosystems. A publishing house had invited me to do this because they had heard I knew something about ecosystems. My qualifications at that time were: I had completed one and was in the middle of another whole-ecosystem study of long duration; that for a number of years I had taught an upper-division systems ecology course at the University of California at Berkeley; and that two years earlier I had co-founded the Conservation of Natural Resources major based largely on holistic, systemic, and interdisciplinary principles. My principal disqualifier was that I had never written a book before, but the publisher didn't seem to care about that. I sent in my prospective, which was duly approved; a contract was signed; and an editor was assigned to me. This turned out to be a fatal problem – not to me, but to the book.

I sent the first two chapters of my manuscript to the editor. She wrote back to me, saying, "The title of your book says that it's about ecosystems. I read your first chapter and still do not know what an ecosystem is. What is an ecosystem? It must be defined on the first page – in the first paragraph – in the first sentence." I responded to this with what I thought was a very tactful and patient explanation.

I said, "If I start off with my definition of ecosystem, it will be a very short book – one page. My plan, as I had emphasized in my prospectus, was to develop the notion of ecosystem gradually, through background history and theory and through case studies based on my own research, ending up in the last chapter with a statement that could be construed as a definition – a textbookish definition. This approach I found to be very effective in teaching my Systems Ecology course. By beginning with the 'final' definition, the 'system' is closed. What more is there to say about it?"

The editor and I battled for several months. I won some of the battles but she won the war. The publisher cancelled the contract. The manuscript was put to rest in its folder. *Ecosystem*, as I thought of it, remained undefined in a formal, "An ecosystem is … " sort of way. But if you press me, I'll say that an ecosystem is what happens in an Ecosystemology class. This requires an explanation, of course.

HISTORY OF THE ECOSYSTEM CONCEPT

A British ecologist, Sir Arthur George Tansley, coined the term *ecosystem* in a paper entitled "The Use and Abuse of Vegetational Concepts and Terms" in 1935.[1] The concept, however, had been described earlier under different names. In 1899 the Russian ecologist, Dokuchaev, called it a *biogeocoenose*. Other terms are *epigen*, *biosystem*, *holocoen*, *ecotope*, and *larger system*. *Ecosystem* is the term that stuck. Fifty-five years is not very long in ecological terms – so the concept's best expression is quite recent. This is how Tansley explained it in his paper:

> "....the more fundamental conception is the whole system (in the sense of physics), including not

[1] Ecology 16, pp. 284-307.

> only the organism complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense. Though the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment with which they form one physical system.
>
> "It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth. Our natural human prejudices, especially those of the biologist, force us to consider the organisms as the most important part of these systems, but certainly the inorganic 'factors' are also parts – there could be no system without them. There is constant interchange of the most various kinds within each system, not only between the organisms but between the organic and inorganic.
>
> "These **ecosystems**, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom. The whole method of science is to isolate systems mentally for the purpose of study so that the series of isolates that we make become the actual objects of our study. Actually the systems we isolate mentally are not only included as parts of larger ones, but they also overlap, interlock and interact with one another. The isolation is partly artificial, but it is the only possible way in which we can proceed."

The first ecologist to use the ecosystem concept in a research project was Raymond Lindeman. He was the lab instructor in an animal ecology course I took at the University of Minnesota in 1938. Lindeman's paper, "The Trophic-Dynamic Aspect of Ecology"[2] is a classic in the field. This was the first explication of the energy flow model of an ecosystem, built on the notion of trophic levels. This is what Lindeman had to say:

> "The discrimination between living organisms as parts of the biotic community and dead organisms and inorganic nutritives as parts of 'environment' seems arbitrary and unnatural. The difficulty of drawing clear-cut lines between the living community and the nonliving environment is illustrated by the difficulty of determining the status of a slowly dying pondweed covered with periphytes, some of which are also continuously dying. In a lake, much of the non-living nascent ooze is rapidly reincorporated through dissolved nutrients back into the living

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[2] Ecology 23:4, pp. 399-418. 1942.

> 'biotic community.' This constant organic/inorganic cycle of nutritive substance is so completely integrated that to consider even such a unit as a lake primarily as a biotic community appears to force a 'biological' emphasis upon a more basic functional organization."

Lindeman then gives a formal definition of an ecosystem. This appears to be the first such in the ecological literature.

> "The ecosystem may be formally defined as the system composed of physical-chemical-biological processes active within a space-time unit of any magnitude, that is, the biotic community plus its abiotic environment."

Now let's look at these two explanations (definitions) of ecosystems. It is, first of all, important to understand that both Tansley and Lindeman were biologists: Tansley a botanist, Lindeman a limnologist. In his statement, Tansley admits to his biological bias. But merely confessing does not help very much. However, putting the soil, rocks, water and air on par with the organisms in their interlocked activities was a big step in understanding and appreciating all of Nature.

What is missing from Lindeman's physical-chemical-biological processes? Is it possible that Tansley has ever considered an ecosystem with people in it or seen one without people in it? Indeed, there was a time when ecologists would go to the farthest corners of the world to make their studies. In natural scientist and explorer Alexander von Humboldt's time (1769-1859), there were places that had had, for practical purposes, no human intervention. My professor at the University of Minnesota where I took my Master's degree, Dr. William S. Cooper, studied succession following a retreating glacier at Glacier Bay, Alaska. People were not involved – except Dr. Cooper. Other ecologists went to remote uninhabited islands for their research. But records show that even remote islands may have been "contaminated" by human activity, perhaps subtly and perhaps drastically, but now abandoned so we don't know what the real "primitive" condition was. Today, certainly there are no ecosystems that humans are interested in that do not have human elements, attributes, and relationships.

Thus, at very least, the ecosystem should be defined in terms of physical-chemical-biological-social-cultural processes. Even when this is conceded, ecologists display their "biological prejudices" in thinking only what people do to the biological components. Anthropologists now accept the full-blown ecosystem concept not only thinking of humans relating to the physical system but interacting amongst themselves economically, ethically, and so on.

Including people, of course, makes ecosystems very complex. In an unperturbed ecosystem, successional patterns are usually quite predictable. Superimpose management, mismanagement, and all other human activity, and prediction is impossible.

DEVELOPMENT OF THE ECOSYSTEM CONCEPT

Although other ecologists thought of it before Tansley (e.g. the Russian soil scientist Vasiliy V. Dokuchaev, who in 1899 called it *biogeocoenose*), and perhaps some non-ecologists did too, still *ecosystem* is a very recent idea both in theory and in practice here in America. One reason it was slow to catch on was because Ecology itself had slow going until about 1950. If the concept had been pushed by philosophy (as wholeness), by management (as ways to handle heterogeneity), or by methodology (as modeling), the ecosystem idea could have been adopted earlier. The ecological "seedbeds" for the concept of an ecosystem are not the only ones. This, essentially, is why ecosystemology is more than ecology.

ON STUDYING COMPLEX ECOSYSTEMS

Various models have been used in ecosystem studies. The pygmy forest and the marine terraces on the Mendocino Coast, visited on the Ecosystemology field trip, yield easily to the state-factor model "CLORPT." CLORPT is an acronym for the five factors which determine the ecosystemic state of a place: CLimate, Organisms, Relief (also known as topography), Parent material, and of course, Time. The idea of the Clorpt model is that given specific definitions of these five "inputs," there will be a unique "output." Consequentially, these five factors constitute all necessary information for describing an ecosystem.

In the case of the pygmy forest, we have a Mediterranean-type climate of mild seasonal variation, rainy winters, and coastal fog. The organisms come from a pool of tree, brush, insect, and animal species indigenous to the north and central California coast. The relief is a terrace structure caused by gradual tectonic movement of the ground upward and inland, punctuated by the interglacial periods when strong ocean waves cut flat levels into the cliff; additionally, the risers between terraces erode over time. The parent material is Graywacke sandstone laid down on the ocean floor during the

Jurassic period, rich in minerals like calcium, magnesium and potassium. The Mendocino landscape poses a wonderful CLORPT study because all these things remain relatively constant, and only the fifth factor, time, changes. Thus the progression of terraces is called a *chronosequence*. As you travel uphill from the beach in Mendocino, you pass from the youngest ecosystem to the oldest: grassland on the first terrace, young tall-trees forest on the second, older tall-trees forest on the third, tiny trees and “pgymy” forest on the fourth, and on the fifth, an even older (and stranger) pygmy forest.

Another model is called the *compartment model*. An example of an ecosystem study where the compartment model is useful is the arctic tundra. Here the ecosystem is divided into four compartments (which also can be called *trophic levels*), namely soil, plants, animals, and decomposers. Everything in the ecosystem has to be in one or the other of the compartments. One kind of compartment model, called the energy-flow model, was used by Raymond Lindeman in his classical study of Cedar Bog Lake.

In addition there are nutrient cycling models, cybernetic models, and others.

There are three basic methods for studying ecosystems. They can be classified and defined according to the kinds of problems that occur.

(a) The system does not yet exist; its structure is to be designed so that the realized design exhibits the prescribed behavior. This method of study is called **synthesis**.

(b) The system already exists (either physically or on paper) and its structure is known; its behavior is to be determined on the basis of the known structure. This method of study is called **analysis**.

(c) The system already exists (in reality) but nothing is known about it, and its structure cannot be determined directly. The problem consists in ascertaining the behavior of the system and with its aid, if possible, the structure deduced. This is known as the **black box method**.

THE BLACK BOX METHOD

The two basic properties which characterize systems are (1) behavior and (2) structure. *Behavior* means the action or function of the whole system without reference to the action of the parts individually. By *structure* we mean the spatial arrangement of the parts of the system. These two fundamental system properties are related as follows:

(a) A definite behavior corresponds uniquely to a certain structure.

(b) To a definite behavior there corresponds a class of structures defined by this behavior.

The Black Box concept. Suppose you wake up one morning and find that a black box has been placed next to your bed. Two different kinds of questions may arise. What is in the box? How does it work? What makes it tick? These are questions related to the structure of the box. Or you may ask: Why is this box here? What is the relation of this box to my dream? What is its purpose? These are questions related to the behavior of the box.

If the box is so constructed that you cannot find answers to the first set of questions, the structural questions, then it truly is a *black box*. So what can we do when we are faced with a *black box* – a box (or system) which for some reason we don't want to look inside, are not allowed to, or not able to? How does an investigator proceed when studying a black box?

Here are some examples of black boxes that we are all acquainted with:

1. The engineer's construct: its contents (mechanism) are inaccessible and must be investigated from the outside.

2. Christmas package under the tree. By convention it cannot be opened until December 25th.

3. Even if it were physically possible to open the box, the structure is too complex to be understood by the investigator. (E.g., looking under hood of car.)

4. There is no way to get inside. (The psychiatrist must investigate the patient by asking questions from the outside and getting responses from the "BB.")

5. It doesn't matter what is inside the box or how it works. (E.g., the farmer and his black cow; he doesn't care how the milk gets manufactured inside the cow.)

An investigator needs no special skills in the manipulation of inputs. A naive investigator may be as successful as a renowned researcher in studying a BB. Kicking the television set may make it work. Accidental inputs often get better results than carefully studied ones. That's why many of the greatest scientific discoveries are serendipitous ones. This does not mean, however, that a random assortment of inputs should be preferred to a well-planned series.

What really is inside a black box? To an investigator, a black box is a level of organization just beyond his comprehension or his competence to study with his traditional methods of analysis. So, if through some kind of enlightenment the investigator were able to "peel off" the outer opaque casing of the box, enabling him to "see inside," he would likely find another layer of perplexity (and complexity), that is, another black box, and so on ad infinitum until he has reached the "core" where no more peeling can be done!

So to answer the question, what's in a black box? – More black boxes.

Let us return to the example of the farmer and his black cow. Assuming that the farmer hasn't gone to college and is primarily interested in the profits of his dairy business, all he sees, measures, and is interested in is the input-output relations to and from the cow, that is, the hay-in/milk-out behavior of the system. To the farmer, everything between the cow's mouth and its teats is a black box. But the dairy physiologist, who not only went to college but teaches and does research there, studies how hay is ingested, digested, assimilated, turns into blood and plasma, and then into milk; this process can be studied at the tissue level. And depending on the level of advanced chemistry this dairy scientist may have had, sooner or later s/he comes down to a black box, which is the molecular or atomic substructure of milk and is not hir domain. S/he is not competent to investigate at this level. But in the physics building there is a nuclear physicist, who at lunch time may be wondering how many mesons there are in a drop of milk fat. S/he has the mental inquisitiveness, the theoretical models, and the laboratory apparatus to open the chemist's black box and dig in even deeper. But alas, even the nuclear physicist has hir own black box.

The Inverted Peter Principle. The Peter Principle, expounded by Dr. Laurence J. Peter, reads as follows:

> IN A HIERARCHY EVERY EMPLOYEE TENDS TO RISE TO HIS OR HER LEVEL OF INCOMPETENCE.

For example, in the strongly hierarchical organization of a university administration, if a professor proved hirself exceptionally capable of chairing departmental committees and other administrative duties, s/he would move up to the Chairperson position in the department. Then, if s/he were successful as Chair of the department, s/he would rise to the level of Dean of the College. If s/he were a lousy, incompetent Dean, s/he would remain in that position; that is, the level of incompetence had been reached. Hir competence at the department level gave no assurance of competence at the college level. (NOTE: this example is purely hypothetical!)

The Inverted Peter Principle, expounded by Arnold Schultz, reads as follows:

> IN ANY ANALYTICAL STUDY, EVERY INVESTIGATOR EVENTUALLY COMES DOWN TO HIS OR HER LEVEL OF INCOMPETENCE, THAT IS, TO HER OR HIS BLACK BOX.

The farmer, the dairy physiologist, the chemist, the nuclear physicist – each reaches at some point hir black box, from whence s/he must go on faith. Every scientist is a generalist to a scientist at another level. And there need be no innuendos about the caliber or status of either the generalist or the specialist.

METHOD BEYOND THE BLACK BOX

What can a scientist do when s/he reaches hir personal black box?

a) Cry
b) Guess

c) Have faith in experts at lower levels of organizations
d) Study harder
e) Kick the TV, the cow, the bucket
f) Retire
g) Employ the BLACK BOX method.

HOW TO INVESTIGATE THE BLACK BOX – THE PROTOCOL

The behavior of a black box is not simply the output. It is the relation between the input and the output, the hay/milk ratio, the Q/A combination. In statistics, the regression coefficient is a good example of such a ratio. To ascertain the behavior of a BB, the investigator must record the inputs with the corresponding outputs.

Suppose you are doing a fertilizer experiment in a hayfield. You apply different amounts of NPK (nitrogen + phosphorus + potassium) in field plots of alfalfa. The record of the input/output relations is called the *protocol*. If the experimental field acts as a determinate machine (repetitive), then the protocol will be simple. However, if the system is stochastic, then your protocol must be interpreted in terms of probabilities. If the system is completely unorganized, then you're in trouble; not much can be learned by the black box method.

Most experiments are studies using the black box method. Treatments are inputs; yields or responses are outputs. Did Newton use the black box method when he studied the solar system and arrived at the law of gravity?

HOW COMPLEX CAN A BLACK BOX BE?

Consider a black box with 8 input terminals and 2 output terminals. Each terminal can take on one or the other of two values, ON or OFF. How many different systems can such a box represent?

The total number of input states is 2^n where n = the number of input switches (terminals). So in our case there are 2^8 or 256 input states. With two on/off output terminals, the total number of combined input-output states is $2^2 \times m$ where m = the number of input states. Thus the total number of systems our BB could represent we have $2^{10} = 1{,}024$. So our 8-terminal input, 2-terminal output box is indeed complex!

ARE NATURAL ECOSYSTEMS BLACK BOXES?

By now, nearly everyone has heard about the "greenhouse effect." If not, here it is in a nutshell. Fifty years ago CO_2 comprised about 0.003% of the earth's atmosphere. In the last thirty to forty years, it has been increasing at the rate of 1 percent of that per year, which, if continued, would double the concentration of CO_2 in about 100 years. However, the increase is not linear; it is actually accelerating. One important question that ecologists have to answer is not directly related to the greenhouse effect: are the plants and animals living today physiologically able to adapt to this rapid rise in carbon dioxide in their environment?

Actually, carbon dioxide did not always constitute such a low proportion of the gases in the earth's atmosphere. During the first two billion years of the existence of our solar system (and earth), there must have been a thick blanket of CO_2, perhaps a thousand times heavier than the present; otherwise, any new evolving organism would have frozen to death. Sunlight could penetrate the blanket and warm the earth's surface, and the blanket would prevent the heat from radiating back out to the stratosphere. This phenomenon is known as the greenhouse effect. Sunlight penetrates the glass panes of the greenhouse, but the glass traps the heat and prevents it from going out.

Today, however, the earth's temperature is "just right" for our biota and also just right for human habitation – and comfort. However, some supposedly well-informed scientists think we are now in a warming period (as during periods of glacial retreat during Pleistocene), and this is being speeded up by the rapid increase in CO_2 accumulation in the atmosphere. They predict, first, that in 50 to 100 years the earth's average temperature may increase by 2 to 5 degrees Farenheit; second, extreme droughts of long duration will reduce productivity of land drastically; third, polar ice caps will melt and sea-level will rise 3 to 10 meters, inundating coastal cities around the entire world; and fourth, the heat alone will be unbearable for humans in some areas and our technology may not be able to cope with it.

So why is all this happening? What is the reason for the increase in CO_2? In the last 30 years or so more fossil fuels have been burned than in all previous history together. The tropical rain forests are being cut at such a rapid rate that if present trends continue there will be very little left by 2050. Trees absorb CO_2 and fix it as carbohydrates, cellulose, and lignin. The oceans, which have always been CO_2 sinks and which help to stabilize CO_2 in the air, are now themselves being polluted so that they are no longer as effective in that role.

Today there are some critics and opponents to the “greenhouse” theorists. They say that the evidence for the “greenhouse effect” is inconclusive and fails to rationalize the undertaking of a costly change in business-as-usual. Meanwhile, other scientists now believe that the global warming, by causing the ice caps to melt and inject freshwater into the Arctic Ocean, may halt the global thermal circulation provided by the deep-sea conveyor belt current, initiating a new glacial period. So where are we?

Now let’s go back to the original question: are natural ecosystems black boxes? Are they systems that can only be adequately studied by the black box or the experimental input-output method? How can we find out whether the world is heating or cooling? Monitoring is, of course, the usual way, but a large-scale experiment would be quicker and more definitive. Is destruction of rainforests causing the global climate to become more unstable? It would take a huge experiment, much larger than the National Science Foundation could pay for, to test this question. Cutting a square-kilometer plot in the Amazon basin wouldn’t put a blip on any global temperature recorder! But somebody is conducting that experiment on a very grand scale: the rain forest exploiters are doing it. If the entire rainforest gets cut down, then we will be able to tell dramatically what its influence has been in stabilizing our atmospheric gases, our earth’s temperatures, and our sea levels. Oops, too late. But anyhow, then we’ll know. Today, how badly do we want to know?

THE ANALYTIC METHOD

What is meant by *analysis*? The most common idea of analysis is the separation of substances or entities, either concrete or abstract, into their constituent elements or parts. People of the more "holistic" persuasion often think that analysts are those who take things apart (destructively) without necessarily putting them together again. In our present context, analysis will mean something quite different. A partial definition was give in the section about compartmental models.

We are concerned with both the structure and behavior of systems. In the case of the black box, we learn the behavior by studying the input/output protocol. If the resulting behavior matches up in our past experience with systems having similar behaviors (for which we know the structure), then we can deduce the apparent structure of our black box. Usually we won't know the structure.

But suppose that instead of ascertaining the behavior we happen to know the exact structure of our system (say, by taking it apart). That is, we know not only the arrangement of the parts but also the behavior of the individual parts. From this we should be able to figure out the behavior of the whole system. Thus, analysis is not just taking things apart, but doing it so that the behavior of the whole system can be determined.

THE METHOD OF SYNTHESIS

There are several different meanings of *synthesis*. The more common idea is that synthesis is the combining of the constituent elements of matter (or abstract entities) into a single or unified entity. It is often thought to be the opposite of the dictionary definition of "analysis." Or crudely, *synthesis* is putting back together what *analysis* has taken apart. Neither analysis nor synthesis are as simple as that. In the context of studying complex ecosystems, synthesis would mean design, that is, the design of structures, models, or plans to achieve a certain prescribed behavior.

Suppose we find a black box. Let's ignore the rule about black boxes and take it apart. The six sides of the box unfold. Three different squawkers (emitting "baa," "moo," or "meow" when turned upside down from being rightside up) are glued to three inside faces, while the letters A, B, C, D, E, and F are pasted on the outside faces. The task of analysis is to determine (without rebuilding the box) which rotations (A side down to B side down, etc.) will give certain outputs ("baa," "moo," or "meow," or quiet).

The task of synthesis would be: given a large piece of pasteboard shaped as an unfolded box; the letters A through F; lamb, cow, and cat squawkers; and some glue, to make a box that has exactly the same protocol as the one we have described with analysis. Thus, this is a design problem: the structural elements are known and must be put together so that a prescribed behavior is achieved.

A subdiscipline of ecology that is becoming increasingly important is *restoration ecology*. The idea is to restore perturbed ecosystems to the same or similar condition as the "original" (?) was thought to be. The "original" is the prescribed behavior while the structural elements are the species, the soil, and the water regime. A much harder thing to do is to create entirely new ecosystems "from scratch." Here the prescribed behavior might be dreamed up to suit practical or aesthetic objectives, while the structural elements might include genetically modified biota, introduced species, and prefabricated soil.

SOME LAST THOUGHTS ABOUT ECOSYSTEMS

I still have not given a textbookish definition of an ecosystem. I don't think it necessary. You have to experience and live in one. One of my graduate students in the ad hoc interdisciplinary Ph.D program, S. Loren Cole, wrote his dissertation on ecosystemology – the concept, not the course. In it he used *ecosystem* as a verb. That is, you can ecosystem something, akin to "thinking like an ecosystem thinks." We may be going too far to bequeath the thinking process to such higher levels of organization as ecosystems. We used to think that only human beings think. However, great progress has been made in recent years in training computers to think – not only to play chess, but really to do creative thinking. Of course, it all depends on how we want to define *thinking*.

Throughout this book I emphasize the importance of thinking laterally, thinking systemically, thinking holistically, and thinking transdisciplinarily. Ecosystem thinking covers all of them. It makes and stresses the assumption that everything is connected. Even if some of these connections are slight and tenuous, it is safer to assume connectivity than to assume independence. I believe it is a good paradigm. Let’s keep it until something better comes along. To learn to think this way, though, we’ll have to think more about *thinking* itself.

CHAPTER 7 : THINKING

Remember, this is a book on Ecosystem Thinking. In the introduction, reasons were given why we need to do ecosystem thinking – at least why we need to do a different kind of thinking than we generally have been doing in the past. Then in the chapter on paradigms it was pointed out that a different kind of thinking is already happening in many disciplines. This becomes evident in the paradigm shifts occurring all around us (though all too slowly!). Now we shall concentrate on the thinking process itself. Also, I'll introduce some methods for practicing a different kind of thinking than most of us have been subjected to in our education system.

Robert Hutchins was considered a brilliant educator and at the age of 28 he was hired as president of the University of Chicago. The first task that he undertook was to reform the University's education system. Hutchins' idea was to teach every student seven arts: Reading, Writing, Speaking, Listening, Observing, Measuring, and Calculating. It is interesting that measuring and calculating – usually considered the hottest stuff at the yuppiest institutions – are on the bottom of the list. Listening is something we do less and less well the more we learn and become "experts." Not only do we need to learn how to listen, but we need to learn the great importance of listening. Observing is another art that we simply take for granted that we know how to do naturally. Not so. Most people could make their lives much more satisfying if they took lessons in how to observe better. Two additional "arts" could have been included on the list, although they may be part of Observing or of the broader term Sensing, namely Tasting (aesthetics) and Feeling (emotions). Having a blind student in an ecology class points to how tasting and feeling are necessary substitutes for seeing. And oh, what seeing people miss when they use only their eyes for observing!

The main reason for bringing up the subject of Hutchins' reform at Chicago is this: I would have included still another skill and put it at the very top of the list: THINKING! Most educators do not believe that thinking can be taught. I tried to teach thinking in my ecology classes beginning in the early 1960's with little or no support from anyone else. I do not mean that I tried to coerce students into thinking certain things; I mean that I tried to train them to use their mental facilities more effectively than they had been.

It is important here to consider the difference between teaching and learning. With teaching we have the image of some learned person imparting knowledge to people who do not yet know. On the other hand, learning is something that can be done individually, by way of experience, and so on. So while I would rather be using the expression "learning how to think," nevertheless I feel that our education has come to the point where there needs to be someone to induce people to learn how to think, and that inducer might as well be called teacher.

There are several reasons why educators have hangups about the subject of teaching thinking and why it is difficult for them to consider thinking as a skill. Some say thinking cannot be taught at all, that one can only teach things to think about, namely content. Some say that everybody already thinks – it doesn't have to be learned. Then we hear it said that thinking is logic and logic has been taught since the time of Aristotle and Thomas Aquinas. So what's the big deal, since logic is a subject, not a skill? Finally, it is said that teaching thinking in the school can be dangerous and even more restrictive than the problem it is supposed to correct.

I can answer most of these criticisms out of my own experience. I used to think that my experiences were extreme ones, but the more I look into the matter, I see that they have been quite commonplace.

In 1978 I taught an ecology course at the University of Nairobi in Kenya. In the class were first-year students in a forestry program. In my lectures I stressed the need for “thinking through” problems because in the real world there are few, if any, pat answers. Facts have little meaning in themselves, so I encouraged the students to not memorize anything but try to think for themselves which facts and principles were relevant, say, to forest management in East Africa. None of the students were able to do it. Their idea of learning was by rote memory only. They “learned,” that is, they faithfully memorized everything I said or assigned from textbooks, with no ability whatever to discriminate the important, the relevant, or perhaps even the true from their opposites. One can only hope, in a system like that, that the teachers know what is relevant, important and true. This state of affairs was not an aspect of Kenyan culture only. The custom started at Oxbridge!

Now I hark back to my own undergraduate days at the University of Minnesota. I remember taking an Entomology course: Insect Taxonomy. At the end of the quarter I had over 200 pages of closely-packed notes – no margins left for doodling, because there was no time for doodling. I had to take down everything, literally everything the professor said, because he had told us that it would all be equally important. He made no attempt at building concepts upon already learned concepts. The only way to "get" the material was to memorize it. I passed the course but learned nothing. There was no time and no encouragement, except, of course, examinations, to think about the lecture content. So, as I said, it's not just in Kenya that you see the cultural pattern of not teaching students to think.

The majority of professors I had were afflicted with the "there is a right answer" mentality. That mentality is still around, yet for most important questions there are no right answers. If teachers deal only with subjects for which they know the answers – supposedly the mark of experts – then students will learn no more than what their teachers know, and no progress can be made.

One of the criticisms mentioned above is that everybody already thinks, so it doesn't have to be learned. This misses the point. Anybody, everybody can play the piano with one finger, without melody, but to do it with skill requires training.

Can the teaching of thinking be restrictive? Not if students are urged to think "outwardly" to as many factors as they can think of, instead of "inwardly" to just one; in other words, if they are taught to not to be satisfied in having only one answer. Consistently, in the Ecosystemology class, students, who at the beginning of the term could not think of many factors for decision making, would be able to tick off lots of them at the end of the term. I attribute this to "training" in thinking. Edward De Bono, of whom we shall hear more later, has given us a definition of thinking, including its purpose. He says, "...in thinking we are trying to broaden and change our perception, to explore the breadth of our experience and use it for some definite purpose." While this assessment seems reasonable, it also allows us to point out that usually we don't stretch our perception enough. Certainly, this is the whole point of ecosystem thinking and distinguishes it from atomistic or reductionist thinking,

To summarize this section on the meaning of thinking, let us just say that what we need are some tools for thinking, which are going to be different than the tools we use for handling content. If we treat "thinking" as a skill instead of some mental process which everybody does automatically and naturally to their full capacity, then we may make some progress in discovering such tools.

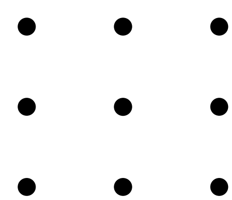
BLOCKS TO THINKING

Below is a series of exercises which illustrate the point that blocks to thinking exist. The blocks are of two kinds, cultural and conceptual. Some of these exercises have been published over and over, often simply as puzzles for entertainment purposes. Here they are presented mainly for the purpose of showing why the problems are difficult to solve. Two excellent books are available on this topic: *New Think* by Edward De Bono (1968) and *Conceptual Blockbusting* by James L. Adams (1974).

> A father and son were in an automobile accident. The boy was seriously injured. He was rushed to a hospital in an ambulance, taken to the emergency operating room, and a surgeon was called. The surgeon looked at the patient and said, "I cannot operate on this boy. He is my son." Explain the circumstances.

This is an example of a cultural block. There are several possible explanations. Discounting those who have already heard the story, not many people think first that the surgeon is the boy's mother. Also, I have found that women do not arrive at that answer any more readily than men.

One of the classics, and one which most people have seen by now, is the nine-dot problem. This is an example of a conceptual rather than a cultural block.



> Using four straight lines, and only four, connect the nine dots in the diagram shown above. The lines themselves must be connected and drawn without taking the pen off the paper.
>
> If you succeed in this problem, then do it with three lines. An answer to the three-line problem also suggests an alternative answer for the four-line one.
>
> If you succeed with three lines, then do it with only one line. In all cases the lines must be straight. Can it be done with two?

Someone has calculated that fewer than ten percent of Americans can do the four-line problem above, even when there are no time limits. Apparently there are no data for other countries. It is not the kind of problem one learns in school. Why is it so difficult? And why is it called a conceptual block?

Most people, in trying to solve it, will make the assumption that the lines must not extend beyond the square marked by the four corner dots; in other words, they assume that the working space for solving is inside that square. But it is an assumption not expressed in the rules. It was learned in first grade when you were told by the teacher not to color outside of the outlines in your drawing book. In the case of the three-line problem, a different assumption is usually made: that the dots represent dimensionless mathematical points.

> Read off aloud the following numbers to your mathematical friends and ask them to tell you in what order the numbers are placed:

8 5 4 9 1 7 6 3 2

Martin Gardener, who used to edit the Mathematical Games section of *Scientific American*, tells of presenting this problem to a noted mathematician who worked for days on it but could not come up with a satisfactory answer. A librarian, on the other hand, was able to solve it in a few minutes. Don't translate the numbers to Spanish or German! Especially not to Hebrew!

All of us have taken intelligence tests. One of the favorite kinds of problems posed for testing intelligence is the logical sequence, which is illustrated below:

? 6 9 13 18 24 ?

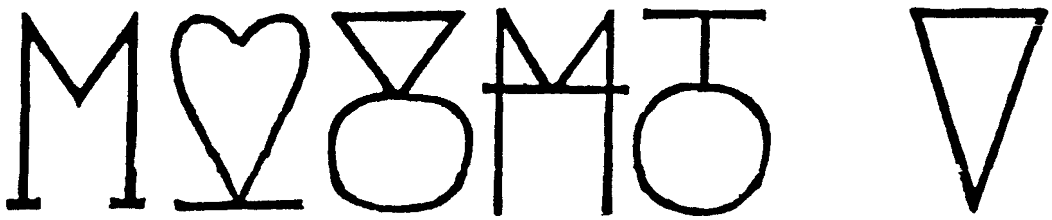
Z V X T V ?

If you want to be a member of MENSA you have to be able to solve this in a matter of seconds. In order to solve, one uses only linear or "vertical" thinking. Below is one more sequence to complete. Can it be done with linear thinking?

What letter follows in these sequences?

O T T F F S ?

Here is another sequence from *Scientific American*. You are to fill in the blank space to the left of the triangle with the missing symbol.



After working on the two problems, you may eventually come to the conclusion that neither can be solved with ordinary logic. The number series looks like it ought to be solvable mathematically. The second series looks like it is made up of a logical sequence of symbols. However, neither series yields to this kind of logic. Let's see what we can do with lateral thinking.

LATERAL THINKING

In schools in any Western country (and I would guess it to be so in Eastern countries as well) the emphasis has traditionally always been on linear (logical, step-wise) thinking. This certainly has been effective for solving many problems, but only for a certain class of problems; in other words, the kind of problems which require linear thinking. This may sound like a circular nonsense statement, but it is not, when we remember that we have been trained to see or conceive problems in terms of the tools we have for solving them.

For the very complex, dynamic, ever-changing wicked problems, linear thinking has been a total flop – it has not scratched the surface in providing adequate solutions. Linear thinking is far too selective in character. It needs to be supplemented with creative thinking.

I want to emphasize in this separate short paragraph that the two kinds of thinking, linear and creative, are not antagonistic. Both kinds of thinking are necessary. And both can be learned. So far, schools have concentrated only on the linear. In the rest of this chapter I shall describe and advocate the other.

Edward De Bono invented the term *lateral thinking*. The term describes the non-linear, generative or creative, and insight-structuring type of thinking that is quite different from the linear or the "vertical," one-step-at-a-time thinking identified with reasoning and logic.

I am not going to say that lateral thinking is the same as right brain thinking. However, I see a lot of similarities in what happens when people do practice "lateral thinking" and those qualities said to be associated with right-brain activities.

Many of you may now claim, "Why, I do this kind of thinking all the time," and I am sure that you do, but probably not in your formal activities, not when you are engaged in academic work, not when you are doing engineering or mathematical problems, and not when you are "supposed to be logical."

Difference between VERTICAL and LATERAL Thinking

Characteristics of Vertical Thinking (VT)	**Characteristics of Lateral Thinking (LT)**
VT is selective	LT is generative
Rightness matters	Richness matters
VT selects a pathway by excluding other pathways	LT does not select but seeks to open up new pathways
With VT one selects the most promising approach to a problem – the best way of looking at a situation	With LT one generates as many alternative approaches as one can
With VT one may look for different approaches until one finds a promising one	With LT one goes on generating as many approaches as possible even after finding good ones
With VT one is trying to select "best" approach	With LT one is generating the approaches, you might say, just for the sake of getting all of them
VT moves in a clearly defined direction towards the solution of a problem – a definite technique is used	With LT one moves for the sake of moving. One doesn't have to be moving towards something; it could be away from some thing. It is the movement or change that matters. You move not to follow a direction but rather to generate one.
With VT one designs an experiment to show some effect	With LT one does it in order to provide an opportunity to change one's idea
With VT one must always be moving in some direction	With LT you may play around usefully without any purpose in mind. One may play with experiments, models, ideas.
The Vertical Thinker says, "I know what I am looking for."	The movement and change in LT is just a way to bring about repatterning. "I am looking, but I won't know what I'm looking for until I've found it."

VT is analytical	LT is provocative
VT is sequential	With LT you can make big leaps
With VT one moves forward one step at a time. Each step arises directly from the preceding step and is directly connected.	With LT the steps do not have to be sequential. One may jump ahead and fill in the gaps later.
With VT one has to be correct at every step. This is fundamental to the nature of VT.	With LT one doesn't have to always be correct. Parts don't have to be self-supporting at every stage.
With VT one uses the negative to block off certain pathways, as in a flow chart.	With LT there are no negatives. Sometimes it may be necessary to be wrong in order to be right at the end.
VT works only within one frame of reference. You cannot jump from one logical type to another.	With LT there is not only the chance to jump to different frames of reference, but it should be encouraged.
With VT one concentrates, excluding what is irrelevant.	With LT one welcomes chance intrusions and even perpetuates irrelevancies.
With VT, categories, classifications, and labels are fixed.	With LT they are not fixed. The labels may change. There are no pigeon holes.
VT is a finite process – you come up with an answer. If you use a mathematical technique on a set of data, an answer is guaranteed.	LT is probabilistic. There may be no answer at all. It increases the chance for restructuring of patterns for insight.
VT promises at least a minimal solution.	LT increases the chances of a maximal solution but makes no promises.

LATERAL THINKING PRACTICE

By now you realize the value of being able to think in different ways. If during your lifetime, at least since kindergarten, you have been thinking vertically, it is because that mode has been drummed into you by repeated drill, and rewarded by success in school. So, in this book I will drum on lateral thinking instead. One of the best exercises in lateral thinking involves doing metalanguage (or cryptic) crossword puzzles. In a cryptic puzzle, each clue may itself be a puzzle, and it will usually require lateral thinking to solve it.

Before we go on, let's list some basic things about cryptic clues. Most cryptic clues have four parts: the definition, the subsidiary, the instruction that tells what to do with the subsidiary, and the number of letters in the answer. The clue itself will not tell which part is which – you have to figure that out (and linear logic may not help much). In addition, the sentence may have to be mentally repunctuated. There are several kinds of subsidiaries: anagrams, homophones or homonyms, containers, reversals, puns, double definitions, hidden words or combination words. Here are examples of five different kinds.

He thinks his poor help hangs well together (11). Here the definition is *he thinks*; the cryptic subsidiary is *his poor help*; and the instruction is to *hang* the subsidiary together. The answer is the eleven-letter word: **PHILOSOPHER**. In this case the subsidiary is an anagram.

The economist let oecologist find it over doors at Christmas (9). The answer is hidden in the three words: *economist let oecologist*. Instruction is *find it*. The answer is **MISTLETOE**, a hidden word.

Stamp collector gets a Greek letter and puts it on a recent roster (9). Let's try Φ (phi). Combine *phi* with synonyms of *recent* and *roster,* such as *late* and *list*. Answer: **PHILATELIST**, a combination word.

Top carnivore is shown to flow back on the trophic level chart (4). An example of a reversal. The word *back* instructs to reverse *flow*.

I'd like a little bit of peace and quiet (5). Here *peace* and **PIECE** (*a little bit*) are homonyms.

The definition part of a cryptic clue is always in object language (just as it is in the case of conventional puzzles). Thus, "a bird that can talk" would refer to the object *parrot*. But a subsidiary is usually stated in metalanguage, that is, language about language, or how the word sounds or may be spelled. Thus, "a talking bird becomes a predator" tells you not to change the object *parrot* but to change the word *parrot* to its anagram, *raptor*.

There are perceptual, conceptual, emotional, cultural, and intellectual blocks to thinking. Try the puzzlers below. Possible answers will be found in the box below.[1]

[1] Puzzles 1-8, 11, and 12 come from Paul Sloane, *Lateral Thinking Puzzlers*, New York: Sterling, 1991; 9 from Paul Watzlawick, *Change: Principles of Problem Formation and Problem Resolution*, New York: Norton, 1974; 10 from James Adams, *Conceptual*

1. This is one of the oldest and best known lateral thinking problems. It goes as follows: A man lives on the tenth floor of a tall building. He takes the elevator to the first floor every day to go to work or to go shopping. When he returns home, he always takes the elevator to the seventh floor and then walks the remaining three flights of stairs to his apartment on the tenth floor. Why does he do this?

2. Two grandmasters played five games of chess. Each won the same number of games and lost the same number of games. There were no draws in any of the games. How could this be so?

3. Anthony and Cleopatra are lying dead on the floor in an Egyptian villa. Nearby is a broken bowl. There are no marks on their bodies and they were not poisoned. Not a person was in the villa when they died. How did they die?

4. A woman had two sons who were born in the same hour of the same day in the same year, but they were not twins. How so?

5. The Greek geometrician, Euclid, had three cats and one chicken. He was challenged by his neighbor, Hector, to place all four animals in such a position that all were equidistant from each other. How did he do it?

6. Anne and Mary were sisters. Anne married Al. Mary married Mike. The strange thing was that Anne and Mike had the same wedding anniversary. Mary's anniversary was one month before this date and Al's was one month after it. None of them had ever divorced or remarried. What was going on?

7. Why are 1988 pennies worth more than 1983 pennies?

8. Ali, Benjamin, and Christopher were born in 1309, 1310, and 1311, respectively, in the same district of old Jerusalem. They grew up and lived all their lives in this same area. Each lived to be over 60 years old and each had a full and active life. However, the three men never saw each other. Why ?

9. When in 1334 the Duchess of Tyrol, Margareta Maultasch, encircled the castle of Hochosterwitz in the province of Carinthia, she knew only too well that the fortress, situated on an incredibly steep rock rising high above the valley floor, was impregnable to direct attack and would yield only to a long siege. In due course, the situation of the defenders became critical: they were down to their last ox and had only two bags of barley corn left. Margareta's situation was becoming equally pressing, albeit for different reasons: her troops were beginning to be unruly, and she had similarly urgent military business elsewhere. At this

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Blockbusting: A Guide to Better Ideas, New York: Scribner, 1974.

point the commandant of the castle decided on a desperate course of action which to his men (vertical thinkers) must have seemed sheer folly. What did the lateral thinking commandant do to get out of their predicament?

10. A man, on entering the waiting room of a veterinarian's office with his sick dog, sat next to a lady with her beautiful wolfhound. The wolfhound was very high-spirited and happily gamboled around the waiting room, as the man's own dog lay limply on the floor. Finally, curious as to why such an apparently healthy dog should be in a veterinarian's office, he turned to the lady and said: “Your dog looks so healthy that I'm surprised to see him visiting the vet. What is wrong with him?” “Oh,” she said, with some embarrassment, “he has syphilis.” The man said: “Syphilis! How in the world did he get syphilis?” So what did the lady answer?

11. The convict tried desperately to find a way to get out of jail. Finally, he got an idea with which he succeeded. He agreed to play cards with his jailers. How did this work for him?

12. A man hijacked a passenger flight at gunpoint. He ordered the pilot to fly to a different airport and radio his demands to the airport authorities. In return for the safe release of the plane and hostages, he asked for $100,000 in a bag and two parachutes. When the plane landed he got the money and the parachutes. Then he told the pilot to take off again and fly to the flight's original destination. When over a deserted part of the country, he strapped on one of the parachutes, clutched the money bag, and leapt from the plane. The second parachute was not used. Why did the hijacker ask for two parachutes if we assume he intended to use only one?

1. The guy's a dwarf. He can reach the elevator button for the first floor, but he can't reach the button for the tenth floor. The seventh is the highest he can reach.
2. Who said that they were playing each other?
3. Anthony and Cleopatra were goldfish. They died when their bowl was knocked over by a clumsy dog.
4. They were two of a set of triplets.
5. Euclid put his cats on the points of an equilateral triangle on the ground. The chicken was put on a tall box in the middle, thus simulating an equilateral pyramid.
6. This one involves a cultural block. Anne and Mary were ministers who could do marriage ceremonies. Mary married Anne to Mike (that's why they share the same anniversary). On a separate occasion, Anne married Mary to her husband.
7. Why are 88 pennies worth more than 83 pennies? The trouble here is caused by the brain's tendency to see numbers as dates. Use a comma: 1,988 and 1,983.
8. Ali was a Muslim, Benjamin was a Jew, and Christopher a Christian. The Muslim calendar starts in 622 CE. The Jewish calendar starts in 3721 BCE. Thus Benjamin was born over 3000 years before Christopher who was born 619 years before Ali.
9. He had the last ox slaughtered and had its abdominal cavity filled with the remaining barley, and ordered the carcass thrown down the cliff onto the meadow in front of the enemy camp. After receiving this scornful message from above, the discouraged duchess abandoned the siege and moved on.
10. "Well," she said, "he claims he got it from a tree."
11. The convict cheated when playing cards with the jailers. On discovering that, the jailers kicked him out of jail.
12. The authorities figured that the hijacker asked for two parachutes because he intended to take a hostage along for his escape. So they gave him two good parachutes. Had he asked for only one, they would have known it was for him, and could have given him a dud. By asking for two, he eliminated that risk.

GEDANKEXPERIMENTEN

I used to think that inventors and researchers would go into their labs and tinker around with equipment and all kinds of stuff that was physically present to be tinkered with. Maybe Thomas Edison did that, I don't know. But not Einstein. He tinkered with his brain. When I came to Berkeley I got well acquainted with a German-speaking (actually Swiss) professor who I mentioned before, Hans Jenny. He was a soil scientist and a clay chemist. He also had a lab in which he "tinkered" with soil, plants, and chemicals, though not haphazardly. I started to do research with him in the Pygmy Forest and found out how he really did his research: *Gedankexperimenten* – thought experiments. We would drive up to Mendocino together and on the way we would think through our research strategy for that day, that weekend, and the season ahead. At the same time an ecologist from Cornell was also investigating the pygmy forest. He brought with him four graduate students and a truckload of equipment; they had an entirely different approach and, of course, set out to answer entirely different questions.

We (Hans and I) would ask ourselves, “On the Blacklock soil, why does Bishop pine grow up to 25 meters tall while Bolander pine and pygmy cypress hardly ever get to be three or four meters tall?” We wondered why and how the pygmy forest had developed as it did, and so we had a lot of factors to think about and imagine at work. The Cornell crew didn't wonder about that – they asked physiological questions like, “How are elements like calcium, phosphorus, magnesium, etc., distributed in the two species of pine?” All they had to do was go out and measure things to get their answers. One of our concerns, however, was to minimize destructive sampling, since that ecosystem was threatened with extinction. Another concern was how to answer our questions on low budget!

Anyway, I became enamored with the idea of doing thought experiments first, and physical experiments second. During this same period I was also doing research on the Arctic tundra at Point Barrow, Alaska. Again on low budget, I needed to do a lot of thinking before acting. One of the budgeted items I had on my National Science Foundation grant was to bring to the tundra with me every year (for at least one week’s time) a thinker who was not an ecologist. So one year I brought Professor Ciriacy Wantrup, an economist. I think that visit did more for him than he did for me. Another year Hans Jenny, the pedologist, came with me. He did more for me than I did for him.

All of these experiences, working on two projects in totally different ecosystems, getting advice from different disciplines, and lots and lots of thinking resulted in learning how to teach about ecosystems. One example is the Instant Ecosystem Analyzer which you will find at the end of the chapter. It is designed to demonstrate the state-factor model of an ecosystem. It is an imaginary machine "built" like a phytotron (controlled temperature chamber). The investigator sets the five dials on the State Factor Control Panel at any combination he or she wishes: hot to cold climate, tropical to arctic flora, level to steep topography, basalt or granite parent rock, and 100 to 10,000 years of development. Like an automatic soft drink dispenser, you press for any desired datum on the Dependent Property Panel, say, you press the upper left button, the soil texture (clay, loam, or sand) reads out instantly. Press on *illimitable joy* and voila, it reads like the Grand Canyon below.

You already suspect it's a Black Box so don't ask about its mechanism inside. Analytic? Synthetic? Holistic? Reductionist? Real? Virtual? Educational? One of my graduate students, Fred Bunnell, actually wrote a program for it, using real data from many sources. Tropical climate and an arctic flora produces nothing, nor does alpine terrain with sedimentary rock.

Let me now give an example of how a bit of thinking beforehand can eliminate the need for some tedious experimentation and can obviate going in the wrong direction. It reminds me of something I read in the British journal, *The Listener*. The saying comes from India and it goes like this: The man who finds out how to measure something is worth his weight in silver. The man who finds out how to measure it better is worth his weight in gold. The man worth his weight in diamonds is the one who finds out that it does not need to be measured at all.

At the Arctic Research Laboratory at Point Barrow, Alaska, several geophysicists, who had been working there for ten years before I went there, were trying to find out why the depth of thaw of the permafrost fluctuated drastically from year to year. They suspected, as anyone else would, that yearly variability in solar radiation was the reason. It makes sense to think that in a warm year, the soil would thaw deeper than during a cold one. However, the problem was that the geophysicists could find no correlation between the two phenomena. My data about the lemming cycles covered the same period of time they were using. It showed a high correlation between peak lemming cycles and deeper thaw. When lots of lemmings were grazing on the meadow in the summer, they reduced the amount of vegetation (which is like a blanket covering the soil). Not only was the blanket thinner during a peak year, more black soil was exposed to sunshine, changing the albedo considerably. And the annually frozen soil would thaw deeper that year.

I told the geophysicists that they were looking at the wrong cause for the fluctuation: the lemmings were doing it. “No, no,” they complained. “How could a little animal (a big individual weighed less than 100 grams) have a greater effect than the sun?” They would not believe me. Perhaps they are still depending on solar radiation fluctuation to give them what they want.

Another example of thinking about phenomena that the “experts” do not want to believe is the story of Gaia – the living Earth. This story is told by Fritjof Capra in *The Web of*

Life.[2] It also illustrates how new ideas arise when people of different disciplines think together.

> "The origins of Lovelock's daring hypothesis lie in the early days of the NASA space program. While the idea of the Earth being alive is very ancient and speculative theories about the planet as a living system had been formulated several times, the space flights during the early 1960's enabled humans for the first time to actually look at our planet from outer space and perceive it as an integrated whole. This perception of the Earth in all its beauty, a blue and white globe floating in the deep darkness of space, moved the astronauts deeply and was a profound spiritual experience that forever changed their relationship to the Earth.
>
> "The insight for James Lovelock was so momentous that he still remembers the exact moment when it occurred.
>
> "'Consider Gaia theory as an alternative to the conventional wisdom that sees the Earth as a dead planet made of inanimate rocks, ocean, and atmosphere, and merely inhabited by life. Consider it as a real system, comprising all of life and all of its environment tightly coupled so as to form a self-regulating entity.'
>
> "The scientific backgrounds of Lovelock, an atmospheric chemist, and Lynn Margulis, a microbiologist, turned out to be a perfect match. Margulis had no problem answering Lovelock's many questions about the biological origins of atmospheric gases, while Lovelock contributed concepts from chemistry, thermodynamics, and cybernetics to the emerging Gaia theory.
>
> "At first the resistance of the scientific community to this new view of life was so strong that the authors found it impossible to publish their hypothesis. Established academic journals such as *Science* and *Nature* turned it down. One is tempted to wonder whether this highly irrational reaction by the scientific establishment was triggered by the evocation of Gaia, a powerful archetypal myth."

Again we see some scientific "experts" who are not experts in any kind of thinking other than the perfectly vertical. For learning Ecosystemology, however, vertical thinking is not enough – one needs lateral thinking and Gedankexperimenten in order to think like an ecosystem, or perhaps even to *perceive* ecosystems at all.

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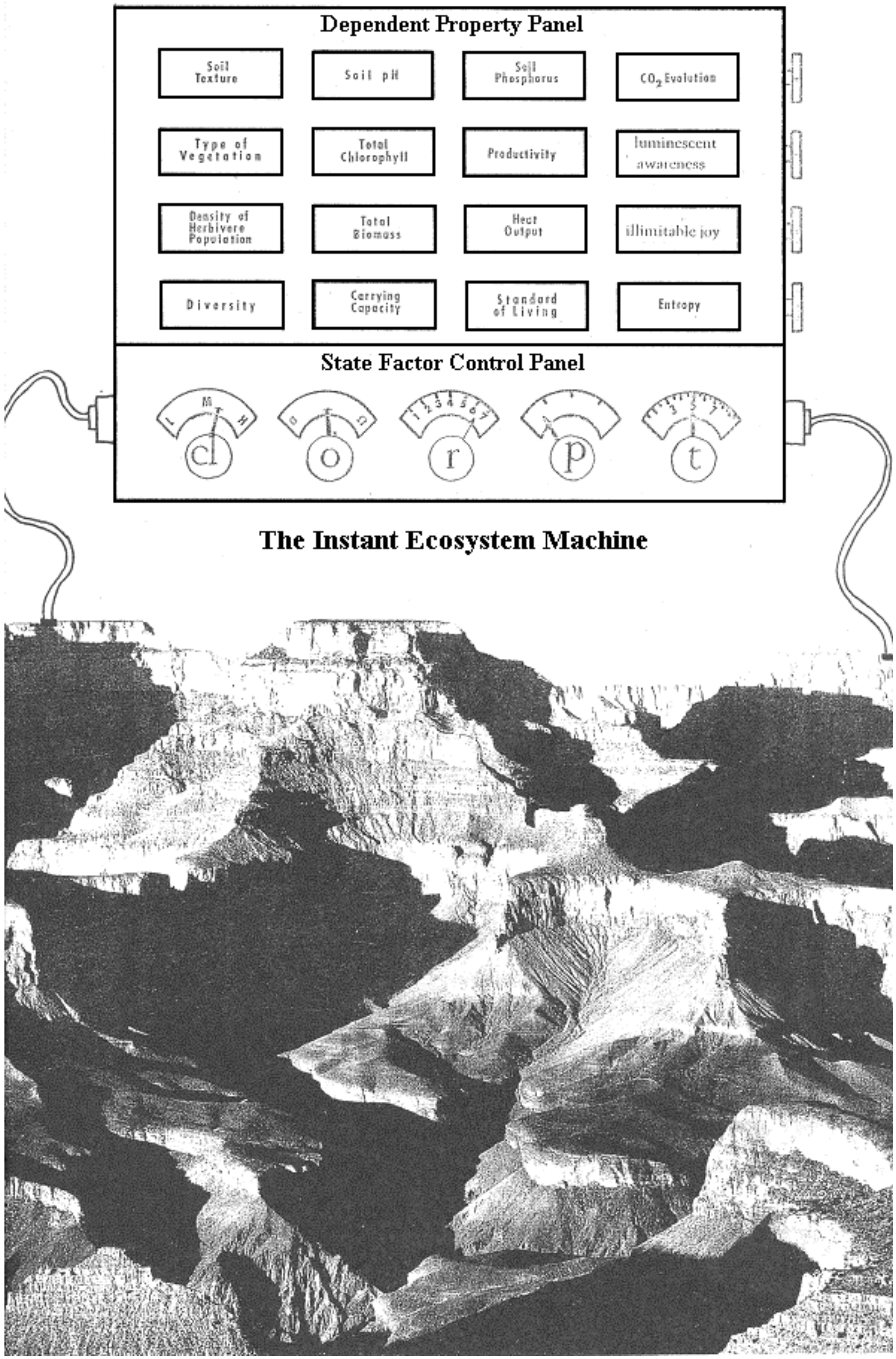
[2] New York: Anchor Books, 1996.



The Instant Ecosystem Machine

THE LEFT-BRAIN, RIGHT-BRAIN CROSSWORD PUZZLE

There are "left brain" answers and "right brain" answers to the clues in this puzzle – more of the former because that's still the dominant way of thinking. The answers are to be filled into the diagram, each kind in its own way. How will you know "left brain" clues from "right brain" clues, and how will you know which way to enter their answers into the diagram? Well, there are three ways to answer clues. First, you should realize that the two kinds of clues are quite different. Left-brain clues will always be straightforward definitions or synonyms, or statements that require only simple, logical answers, like the clues you see in most American newspapers' crossword puzzles. Right-brain clues will be obvious metalanguage statements, answers to which will generally require some lateral thinking. For example, you can be pretty sure that 1-across is "right-brained" and 2-across is "left-brained." Similarly, 1-down appears to be "left-brained" and 2-down seems "right-brained." There are some clues that could be both. Second, the answers themselves will be appropriate to either left- or right-brained thinking, respectively. For example, 24-down, "Founder of the Bank of America," is likely to be a left-brainer while 29-across, "Sad refrains to Amazonian vegetation," sounds like it ought to be a right-brainer. Third and finally, right-brain answers will be entered into the diagram differently than left-brain ones; and of course, you will get help from letters already placed into the diagram by other answers.

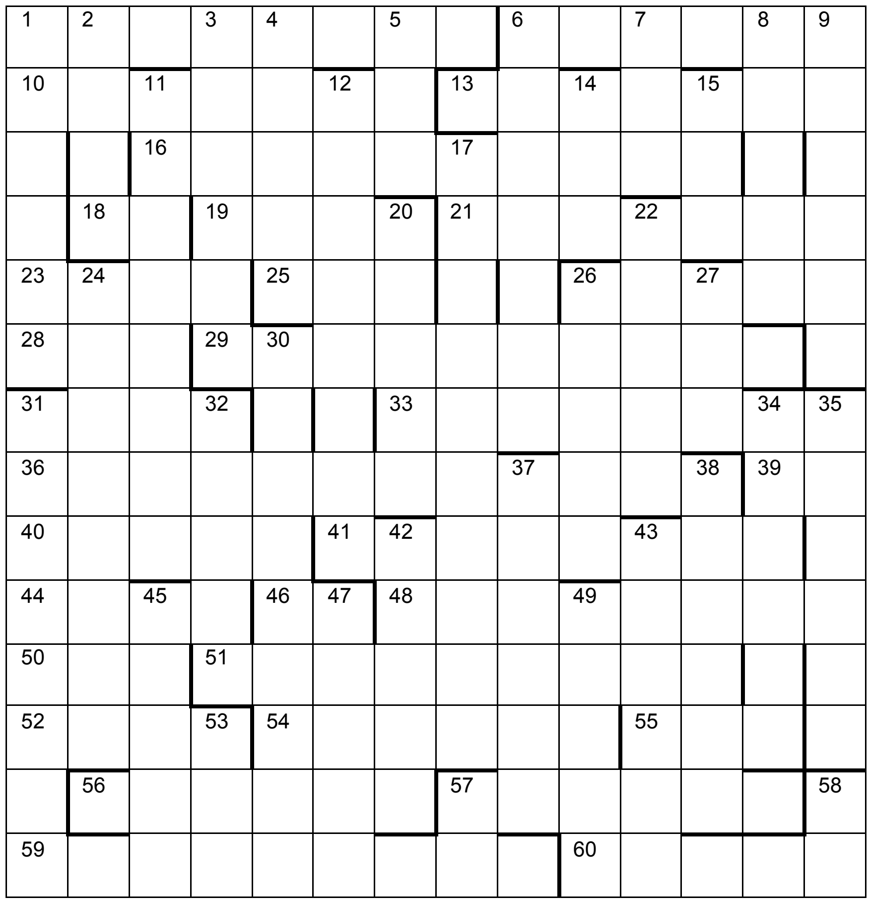
If this puzzle has any redeeming educational value, it will be the exercise that you get in using both sides of your brain alternately or simultaneously. In any case, have fun.

ACROSS

1. Applaud (part played back later) pretentious language (8)
6. Nag again (6)
10. Cover an empty space to fill in, and in Latin (7)
13. Confession of sin followed by forgiveness (7)
16. Zoo in Spanish resort gives way to early reconstruction of protective barrier (5,5)
18. Iowa to the Post Office (2)
19. He came to America before Christopher (4)
21. Nougats and truffles die in cans (7)
23. American Guild of Musical Artists (4)
25. Take off from office? Cool it! (3)
26. Hindu fate or destiny (5)
28. Draw (3)
29. Sad refrains to Amazonian vegetation (4,6)
31. First person after Christ and in the morning (4)
33. Without footwear, like outfielder Joe Jackson (8)
36. Coil that makes no noise entitles a best seller (6,6)
39. cc. (2)
40. Formal presentation, informal, abbreviated (5)
41. The tease, under a different spell, is very sensitive to beauty (8)
44. Enthusiastic prima donna returned (4)
46. Supposing that… (2)
48. Sold directly to consumers (8)
50. The black American cuckoo (3)
51. Scoring big to win in final seconds, not logically (9)
52. Ready to be plucked (4)
54. Bookkeeper's account book (6)
55. Conducted (3)
56. Put in the box again (6)
57. Aspire in a new way to express great admiration (6)
59. Drop from airplane with an umbrella (9)
60. Came in confusion with head of congregation, but it's the in-place to visit (5)

DOWN

1. Small patrol torpedo ship used in WWII (2,4)
2. A thought that may have come from an aide (4)
3. One's special natural ability is only slightly latent (6)
4. The person to whom money is paid (5)
5. Lawrence Berkeley Lab (3)
6. Take the top off softener more frequently (7)
7. Hit with ray gun part of highest city after LA (3)
8. The man with the simple philosophical razor (5)
9. Cadres shaken up, become scared, then religious (6)
11. Terrible dark item reaches its highest point (8)
12. Very particular extra-sensory perception precedes crazy Alice wherever she goes (8)
14. No, I flipped over a charged particle (3)
15. Not one way or another but soon, if after a (3)
17. The effect is sere enough when perturbed (10)
20. Rifts are straightened out before anything else (5)
22. I laid around, reading Homer's stuff (5)
24. Founder of the Bank of America (8)
26. Genuflected (5)
27. Attention: letters from REA are from an era past (3)
30. Whirl Poe's Lilacs about like a merry-go-round, or was it Walt Whitman's (9)
31. A dig into reconstructed ramp gives another world view (8)
32. A regular arrangement (5)
34. The wildest *madres* conjure up lovely reveries (6)
35. Representations of systems are seldom changed (6)
37. See the following simmer and boil over (6)
38. Merchant (6)
42. Make an exchange (5)
43. French port found in CAlifornia (L.A.) is nearest to England (6)
45. A poisonous serpent (5)
47. Raw meat (5)
49. Courtyards surrounded by porticos (5)
53. In places it always takes the king (3)
57. Extraterrestrial conjunction (2)
58. Part of to be in the morning (2)



CHAPTER 8 : PERCEPTION & LEARNING

At the beginning of every chapter, you will get a gentle reminder that this book is about ecosystem thinking. Some of the topics may appear to you as being far afield from what budding ecosystemologists ought to be concerned about. What is your perception of an ecosystem? What is your perception of learning? Or should we first ask, what is your perception of perception?

LEARNING

The most effective learning takes place when the learner understands the nature of knowledge and the process of learning. This understanding involves grasping the key concepts in the field of study and knowing how those concepts may have originated.

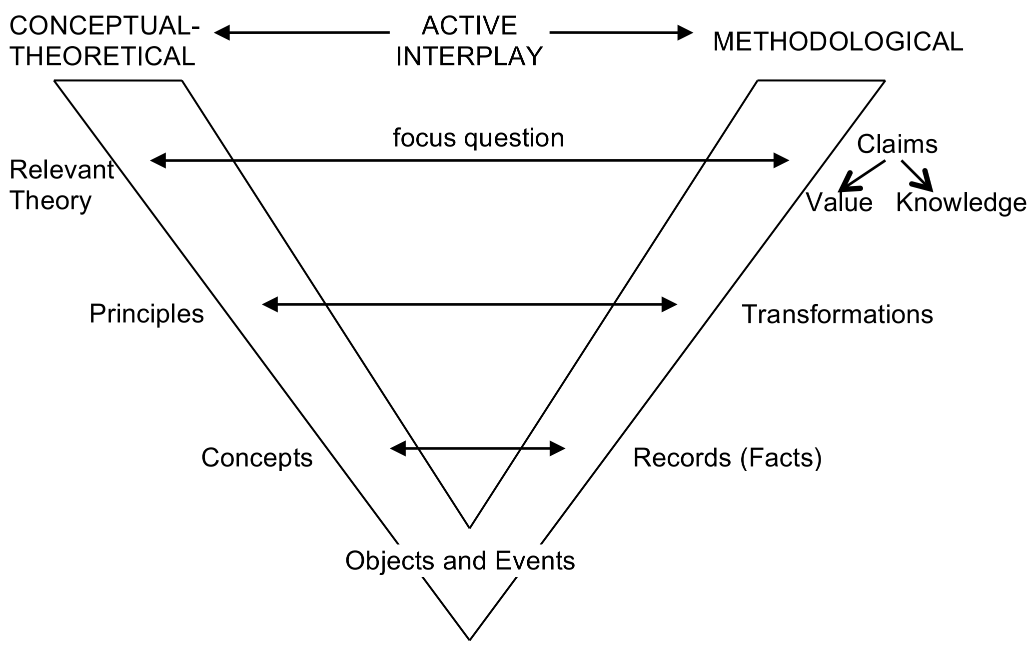
A *concept* can be defined as a regularity in events or objects, designated by some sign or symbol. An event which happens only once, or is not repeatedly observed, will probably not become a concept. Each concept derives meaning from all the other concepts to which it is linked (i.e., other concepts impinge on the *description* of the regularity designated by a given concept). One of the difficulties in teaching concepts, for example, in a field like ecology, is that these concepts tend to be unusually dependent on the meanings of many related concepts. Since the meanings of the related concepts (the new linkages) constantly develop, both within the discipline and within the individual learner, the learning of a concept is never completed! The meaning of any concept changes continuously. It is important to recognize that the train of experience that leads an individual to hir views of any regularity is unique, and, therefore, every concept a person holds is somewhat idiosyncratic to that person. I base my teaching philosophy on this idea, that every student could associate a somewhat different meaning with the name of a concept. A professor who expects the same answer from all students (on an objective examination, for example) does not understand the nature of concepts – and certainly does not understand hir students!

In this chapter we shall see how perception and conception contribute to learning.

THE EPISTEMOLOGICAL VEE

Ecosystemology is essentially about *epistemology*. Epistemology is an investigation into the nature of knowledge. We may think of it as trying to find out how knowledge originates. More specifically, we shall try to develop the habit of *ecosystem thinking*. (If you have read that phrase before, the repetition is for emphasis!)

On <<the top of the next page???>> is a diagram called the *epistemological Vee*. This device was constructed at Cornell University by Joseph Novak, who developed education theory geared towards special problems of environmental education and ecology.[1]



The right side of the Vee has the procedural aspects of knowledge production: methodology, data gathering and analysis, and formulation of claims. The left side has the conceptual/theoretic elements that direct our attention to specific objects or events and also guide our procedures for making records and transforming them, and for making value and knowledge claims. Note the continuous interplay between *theory* and *method*. Both are gradually modified as new objects or events are perceived.

Let us see how this interplay actually works. Assume you are doing research in the Pygmy Forest of Mendocino, or just trying to understand what is going on in that ecosystem. Consider the following set of questions.

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[1] Novak, Joseph D. *A Theory of Education*. Ithaca, NY: Cornell University Press, 1977.

1. What objects or events are in the focus of your interest? Do you direct your observations on the species, or the plants themselves, or the soi1, or the known geological history, or something else?

2. What concepts (or theory) lead you to focus your attention on those objects or events? Does your botanical or geological background influence this? Do you have any hypothesis about the ecosystem that was formed prior to any observation? If so, does your hypothesis determine what you look at first?

3. What kinds of records do you make? Do you make a list of species, count plants per unit area, make tree ring counts to determine age of trees, measure depth of soil horizons?

4. Next, what transformations of records make sense? To answer this, you have to refer back to the concepts and theories: concepts of that the ages and heights of trees, concepts of soil fertility, and theories about what causes trees to be of pygmy size.

5. What concepts do you apply in your transformations of records that come from other disciplines and other theoretic frameworks (e.g., use of statistical procedures, like regression or correlation)?

6. What knowledge claims are consistent with the transformed records? For example, can you now claim that the very small size of very old trees is due to some structural or chemical characteristic of the soil?

7. What concepts might guide you in making such knowledge claims? Concepts may

include impermeability (to root growth), deficiency of essential nutrients (pure quartz in the “E” soil horizon), and aluminum poisoning (quartz = aluminum silicate).

8. Where do you put *hypotheses* into the epistemological Vee diagram? For example, you may wonder which of the three concepts mentioned in (7.) is the most important.

9. Do the knowledge claims modify the meaning of or your understanding of the concepts? In the diagram, arrows from knowledge claims point to the conceptual/theoretical wing of the Vee. Explain that aspect of the interplay. How do the knowledge claims modify the theory?

10. What value claims (answers to “so what?” questions) can be made? Would it be easier to make value claims if this research were being made in a productive redwood forest rather than in the pygmy forest? Can value claims be made without records, facts, and data? For example, on what do you base the claims you make about tropical rainforests in Brazil?

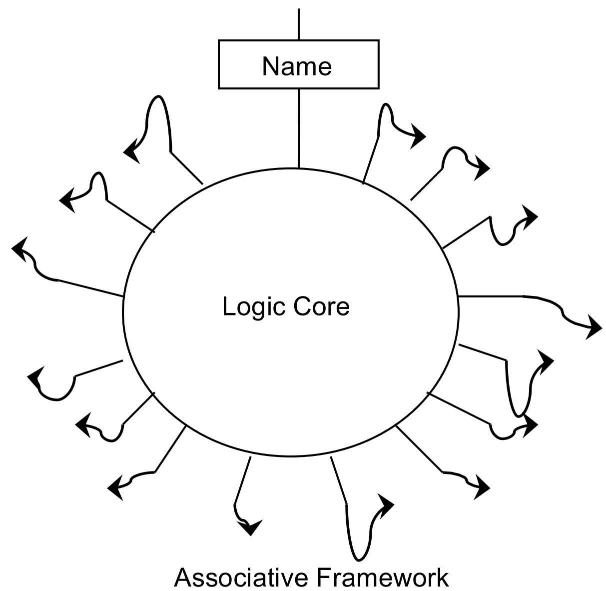
11. Where or how do you represent *feeling* in the diagram of the epistemological Vee? On which side of the Vee does it go?

12. How are value claims influenced by the theory or concepts applied?

13. Can you do any thinking at all without concepts?

BUR MODEL OF A CONCEPT

A concept has three important parts: (1) the *logic core*, (2) the *name*, and (3) the *associative framework*.



The *logic core* is the denotative "meaning" of the concept – the invariant logical structure, independent from individual cases or persons, which is representative for a particular class of things or events. This is the "regularity" aspect of the concept.

The *name* or *term* is a label which serves as a vehicle for communication between individuals. A name without a logic core would be meaningless. Is it possible for a logic core to not have a name? (For many years I was aware of the object concept of the little thingumajig on the end of a shoelace that keeps it from fraying. I could think of it, without having a name for it. Once I saw a name for it – which I promptly forgot.)

The *associative framework* constitutes the connotative meaning of the word, the network of ideas hooked on to the logic core. It is not invariant; that is, the associative framework differs from one individual to the next, depending on what each person has in hir head already.

Whenever we do any thinking, we will always be dealing with concepts. Only about half of any concept is invariant across individuals; the rest is highly individualized. Too much of education has been designed to remove the individual part. Our school system, especially science education, tries to make us all think alike, and tests us by objective examinations, where questions are each supposed to have one right answer. Too much potential knowledge is lost with such an approach.

I honestly believe that the single most important message that I can get across, particularly to those of you still going through the educational system, is this: Don't lose your individuality! The diversity of your associative frameworks is one of your most valuable assets!

BATESON'S THEORY OF LEARNING

Gregory Bateson, anthropologist, philosopher, one of Margaret Mead's several ex-husbands, Professor Emeritus at UCSC, and Regent of the University of California, wrote an "ecology" book: *Steps to an Ecology of Mind*.[2] It is not an ecology book like Eugene P. Odum's or Robert Leo Smith's textbooks. One chapter of Bateson's book gives his theory of learning.

[2] New York: Balantine, 1972.

All learning denotes *change* of some kind. We can imagine several types or orders of change:

CHANGE O – stable; no difference

CHANGE I – simple change; a difference

CHANGE II – process; a change in change; meta-change

CHANGE III – evolution; a change in process; a change in the changing of change; meta-process

CHANGE IV – no name for this concept; a change in evolution. It is likely that few human beings can comprehend what *Change IV* would be like. But perhaps unwittingly, mankind is changing the earth's evolution significantly. One philosopher, Erich Jantsch, argues that we should *design* our evolution.[3]

The simplest and most familiar form of change is motion; similarly, there are different orders of motion.

MOTION O – position; no motion

MOTION I – constant velocity; change in position at uniform rate

MOTION II – acceleration; change in velocity

MOTION III – jerk; change in acceleration. Note that we have nearly run out of terms. The concept is more difficult to imagine than the first three.

With these examples of logical typing to guide us, let us now turn to types of learning,

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[3] *Design for Evolution* (1975).

and follow the same analogy:

LEARNING O – reception of information from an external event, in such a way that a similar event at a later time will convey the same information. “I learn from the factory siren that it is 12 o’clock.” The specificity of response is not subject to correction. An example would be university students note-taking from lectures, verbatim, and learning without choice. This type of learning is *zero learning*!

LEARNING I – a change in specificity of response, by correction of errors or by exercising choice *within a set of alternatives*. An example is classical Pavlovian conditioning in which at Time 2 the dog salivates in response to a buzzer, which he did not do at Time 1. Another example is the phenomenon of rote learning, in which a behavior of the individual becomes a stimulus for another item of behavior in sequence.

LEARNING II – a change in the process of Learning I; e.g., a corrective change in the set of alternatives from which a choice is made, or a change in how the sequence of experience is punctuated. For example, a student learns how to get a good grade not by making right choices within the set of alternatives given by the professor, but by doing something outside of the set, changing the set itself.

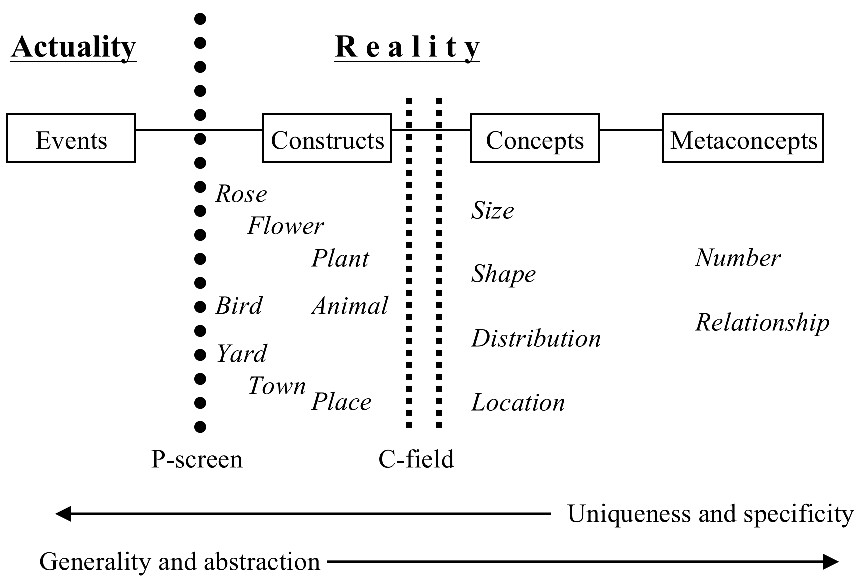
LEARNING III – a change in the process of Learning II; e.g., a corrective change in the system of sets of alternatives from which choice might be made. (This level of performance is rarely attained – perhaps only under pathogenic conditions or with the aid of hallucinogenic prompters. Timothy Leary may have been there!)

LEARNING IV – would be a change in Learning III, but probably does not occur in any adult living organism on earth; perhaps it has been attained on other planets. It may take Change IV to achieve Learning IV.

So what is the significance of all this for Ecology? Certainly there is *lots of room for improvement* in our teaching techniques and our learning processes.

PERCEPTION

Events occur in the universe whether they are observed (perceived) or not – we think. Not until they pass through a "perception screen" do we consider the events to be reality. Thus, we need another concept for the occurrences before they are perceived: for this we have the term *actuality*. The model below shows the distinction between *actuality* and *reality*. It shows the continuum from perceived entities through constructs, to concepts, and to meta-concepts.[4]



It should be noted that this model is but one of many that can be used to depict reality. Its main value is in showing the relationships between the fleeting act of apprehension (with the senses) and the more enduring act of comprehension (with the mind).

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[4] Adapted from Ronald Abler, John S. Adams, and Peter R. Gould, *Spatial Organization: The Geographer's View of the World*. Englewood Cliffs, NJ: Prentice-Hall, 1971.

In the diagram, circles immediately to the right of the P-screen are the singular unique objects or events that are perceived (and therefore reality), before they have been classified or converted into a concept. Any concept which has empirical content (i.e., you can point to it and say, “This is an example of a place or a rose or a bird”) is named a *construct*. Pure concepts have no empirical content. Constructs and concepts are separated by the “conceptual field” or C-field. Metaconcepts are concepts of concepts.

Actuality itself is a concept (an idea thought up by the mind, certainly not perceived), so we come full circle – the model should be a cylinder where the left edge meets the right.

So, where does our knowledge come from? Some comes from the left, through the perception screen. Through the process of induction we build our empirical observations into concepts. Other knowledge comes from our experience on the right side – concepts already formulated, named, and defined by others. Not only are such concepts learned, often by rote, but applied deductively to special cases, i.e. the objects or events of perception.

Are the concepts that come by way of the perception screen valid? In other words, should we believe all that we see? The converse of that question is, don’t we often see what we already believe is true? On these next several pages, I shall show some examples of the following types of observations: (1) Seeing things that aren’t there; (2) Seeing things that are suggested; (3) Not seeing things that are there; (4) Interpreting things that can be seen in several ways.

And what does all this have to do with ecosystemology? Science teaches us to rely on objective measurements, which are, after all, the perceptions. Some scientists have realized the problem of *complementarity*, that there may be two or more ways of looking at a phenomenon. (We'll have more on this subject in Chapter 13!) In ecosystemology, we want not only to get into the practice of *thinking* all ways, but also *seeing* all ways.

In the quotations from the *Tao of Physics* (box below), systems thinker Fritjof Capra implies that the classical Western world view lies in the past. Yet despite Einstein's remarkable discovery, we persist in "seeing" three-dimensional objects in space as separate entities – and to many of us, the Eastern mystics seem flaky. To most Westerners, reality lies in the parts and the whole is an abstraction; to the philosophers of the East (and the modern physicists!), the whole is the reality and the parts are abstractions. Can we learn to see things in the latter way? Is it necessary to see things that way? I have no Western-world proof that it is necessary. My intuition tells me that it would be good to see everything both ways!

> Modern physics has confirmed most dramatically one of the basic ideas of Eastern mysticism; that all the concepts we use to describe nature are limited, that they are not features of reality, as we tend to believe, but creations of the mind; parts of the map, not of the territory. Whenever we expand the realm of our experience, the limitations of our rational mind become apparent and we have to modify, or even abandon, some of our concepts.
>
> Our notions of space and time figure prominently on our map of reality. They serve to order things and events in our environment and are therefore of paramount importance not only in our everyday life, but also in our attempts to understand nature through science and philosophy. There is no law of physics which does not require the concepts of space and time for its formulation. The profound modification of these basic concepts brought about by relativity theory was therefore one of the greatest revolutions in the history of science.
>
> Classical physics was based on the notion both of an absolute, 3-dimensional space, independent of the material objects it contains, and obeying the laws of Euclidean geometry, and of time as a separate dimension which again is absolute and flows at an even rate, independent of the material world. In the West, these notions of space and time were so deeply rooted in the minds of philosophers and scientists that they were taken as true and unquestioned properties of nature.
>
> Eastern philosophy, unlike that of the Greeks (and Western world), has always maintained that space and time are constructs of the mind. The Eastern mystics treated them like all other intellectual concepts: as relative, limited, and illusory.
>
> – Fritjof Capra, *The Tao of Physics*.
> New York: Random House, 1975.

Let us return for the moment to the question of reality versus actuality. Bishop Berkeley, the English philosopher after whom my University town was named, doubted whether objects continued to exist when they were not sensed. What evidence could one get regarding the question? But rather than bequeathing to objects a jerky life (on again, off again) he supposed that they did, in fact, exist continuously because God is always observing them – and circuitously, this was Berkeley's argument for the existence of God.

How much of "seeing" is owed to the brain, and how much to the eyes (or other sense organs)? And which came first, the eye or the brain? Recognizing that the two organs are inseparably tied to the "seeing" process, let us now look at some examples of the "problems" listed above.

PERCEPTION AND CONCEPTION

The perception model on page **<??>** and the epistemological Vee on page **<??>** both purport to show the close relationship between seeing and thinking. It follows that just as we expend great effort in enhancing students' reasoning powers, so we should also be putting effort into improving the perceptual ability of students, and especially researchers. Psychologist Rudolf Arnheim's *Visual Thinking*[5] bemoans "the widespread unemployment of the senses in every field of academic study." Arnheim's book is sadly underrated. Bookstores classify it with Arts and sometimes Psychology; it is seldom read by the natural scientists and professionals by reason of this categorization, except perhaps for "relaxational" reading – a reason decried by Arnheim from the beginning.

Arnheim contends that the cognitive operations called "thinking" are not the privilege of mental processes above and beyond perception; they are the essential ingredients of perception itself. The cognitive operations he speaks of are the very processes that all scientists use in research, including active exploration, selection, grasping of essentials, simplification, abstraction, analysis, and also synthesis, completion, correction, comparison, problem solving, combining, separating, and putting into context. There is

[5] Berkeley: University of California Press, 1972.

no basic difference in this respect between what happens when a person looks directly at the world and when s/he "thinks" with hir eyes closed. In "cognition" Arnheim includes not only memory, thinking, and learning, but sensory perception as well – all mental operations which involve the receipt, storage, and processing of information.

The senses did not evolve as instruments of cognition for cognition's sake, but as biological aids for survival. Perception is both purposive and selective. The beginnings of concept formation arise from the perception of shapes. Upon looking at the full moon, for example, the optical image that is projected on the retina is a mechanically complete recording of the moon's precise shape, but the corresponding visual perception in the mind looks different than the retina image. In other words, there is a lot of other stuff going on besides what flashes onto the retina – and this influences what we see. An object someone is looking at can be said to be truly perceived only to the extent to which it "fits" some organized shape.

An important question has been raised as to whether perception, say shape perception, occurs spontaneously without any preparation, or whether it is made possible by a gradual learning process. It probably takes time to perfect the art of grasping the structure of a visual pattern, rather than simply remaining unable to see certain shapes because there hasn't been a similar experience to which the stimulus can be compared.

PERCEPTION ILLUSIONS

From a scientific standpoint, perception illusions are considered to be erroneous ways of seeing. Yet illusions are more than errors – they are visual experiences and therefore should be used to shed light on reality. No one seems to doubt that illusions are phenomena of perception; since they defy physical explanation, they cannot be phenomena of the "real" world which consists of physical objects.

When you look into a mirror your face seems to appear on the other side, although you know that it is actually on your side. So the knowledge does not correct the "error." Also, you see yourself reversed left-to-right, but you are not upside down. Why is that? Can the mirror distinguish between horizontal and vertical images? Is the answer found in the field of optics (i.e. physics), or in physiology, or in psychology, or perhaps in the nature of consciousness? We come again to the consideration that there is a lot more to perception than direct or intuitive sensing: we have to call upon concepts stored in our memory bank, make comparisons, do some classifying, and make some decisions. It's all a part of seeing.

Illusions serve to tell us that perceptions are not direct, and that some intuitive knowledge is false – indeed, it is possible that any perception could be false. This is a bad state of affairs, especially for scientists who rely so much on empirical observations and inductive methodologies.

How can we be sure that illusions are not deviations from physical fact? Random deviations beset any observation that we make by our senses or by instruments. On the other hand, illusions always "deviate" from fact systematically. What is fact, anyway? Is it that which is generally accepted to be true, or is it that which *is* true? The approach to answering these questions has gradually become physiological, seeking the connections between the eye and the brain in terms of physiological mechanisms. Another approach is that of the Gestalt theorists, who try to link the intuitive notion of perceiving wholes with physiological explanations – a holistic viewpoint buffered with some mechanistic reasoning.

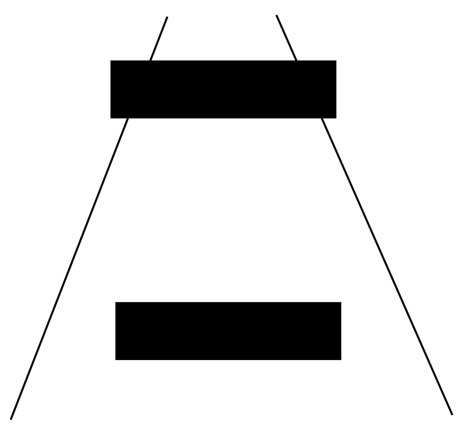
The following classification of perception illusions was taken from the excellent book *Illusion in Nature and Art* by R. L. Gregory.[6]

Illusions due to "calibration" errors. Painters and paint blenders must frequently re-standardize their color vision. Or if you are in a room with a strong odor, your nose will gradually lose its sensitivity to that odor. All senses become adapted with constant stimulation. Engineers would call this phenomenon, if it occurred in a machine, "loss of calibration." If the perturbed calibration goes uncorrected, it will produce errors which are seen as illusions. In organisms, the various senses tend to check each other, giving information for recalibration. This substantiates the argument that we should encourage the use of as many senses as possible for any problem situation.

Illusions due to misplaced assumptions. Suppose you have two jars of exactly the same weight, but one is much larger than the other. The small jar will feel much heavier than the large one – as if you are discerning density, not weight. An explanation of this illusion is that your muscles get set to lift the object which ought to be the heaviest, and this creates the illusion. Primary sensations and perceptions are affected by prior knowledge of objects. Such perception illusions are comparable to scientific errors generated by inappropriate hypotheses.

[6] New York: Scribner, 1973.

Illusions due to inappropriate data-processing or scaling. An astronomer may estimate the distance of a star by its brightness (although some of its light may be lost on the way). When driving in fog, our distance signals are changed. Because objects can be at any distance from us, our stored-up hypotheses rely on signals of distance rather than distance itself, and this leads to illusions in object distance when we wrongly interpret signals. When we look down a railroad track or roadway, the convergence gives a sense of scale, but when convergence is shown on a flat surface, it creates a distortion. This matter of inappropriate scaling is the basis for the Ponzo or railroad track illusion (see below).

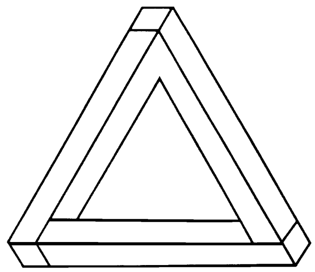


Illusions generated by failure to derive object-hypotheses from patterns. A printed picture, as in the newspaper, is made up of many dots. Each dot provides information and the object is recognized when there are enough dots (data points). If the object is familiar, then relatively few dots are necessary to recognize it, but if the object is an unlikely one, then more dots would be necessary. The same principle holds for a scientific research hypothesis: an unpopular or non-paradigmatic hypothesis would not likely be accepted without an excessively large amount of data; worse still, wrong or inappropriate (but paradigmatic) hypotheses may be perceived as valid despite an insufficient amount of supporting data. Clever abstract art brings out this principle quite clearly.

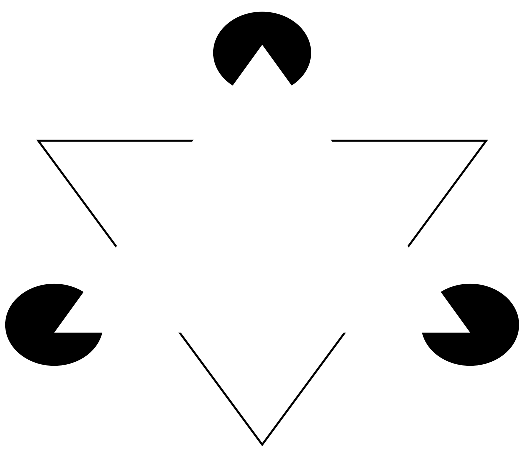
Illusions generated by misleading laws and theories. Have you ever walked up a stationary escalator when you thought it was moving? Often one assumes the simplest description or explanation is true, in order to quickly decide what is there. Science uses the same principle: Occam's razor says that the simplest theory, the one accounting for all given evidence while introducing no extra ideas, is the best one to use.

Illusions generated by ambiguity (complementary perceptions). These illusions were used to great advantage by Escher. They involve directional rotations of cubes, of staircases, etcetera. In science, the lesson is: hypotheses affect data and data affect hypotheses. By means of spontaneous switching (or entertaining of alternative hypotheses), new appraisals and often new insights can be gained.

Illusions generated by paradox. These illusions happen when the data selected are incompatible or juxtaposed in ways which would not physically occur (i.e. the Penrose triangle, below). For example, through a paradox illusion Maurice Escher created a perpetual motion machine, while in the real world technology has not succeeded in this feat. Scientific hypotheses may be found to be paradoxical; because paradoxes cannot represent reality scientifically, we have to restructure the hypotheses before they can be tested. Is there such a thing as an anti-paradox?

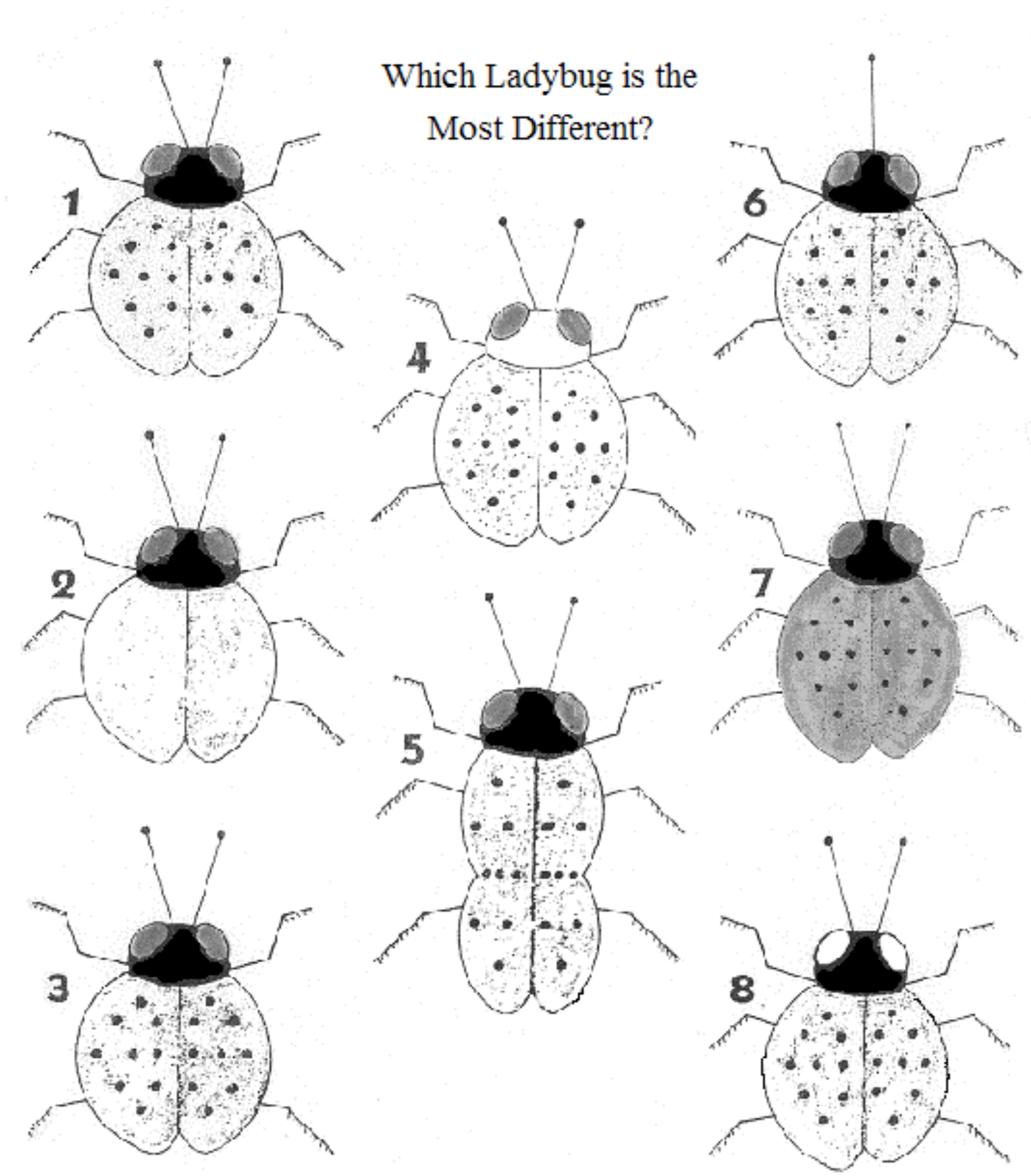


Illusions generated by creating fictions. You may remember that in order to recognize an object, one has to separate the object from its background. If there is no background, there is no visible object. Now what if no object is directly perceived, but part of the expected background is missing? There would have to be something in the foreground that masks out the background! The illusory triangle below is an example. We postulate a nearer object (whiter than the white background), but it is a fictitious postulate.



Gregory discusses a few additional interesting aspects of perception which, though not illusions, should be presented here. One relates to the question of number of data points necessary for object recognition. In some cases, recognition is possible with relatively little information. Imagine a pointillist painting, where the image consists only of small dots. One might think that recognition could be improved by making the points more distinct. Yet just the opposite is true! By squinting your eyes to make the transitions from point to point fuzzy, the image stands out clearer than before. In fact, this becomes a very important principle for Ecosystemology. Holistic perception of ecosystems is much clearer when we fuzzy-up the subsystem boundaries. We need to "squint" our brain when we try to perceive ecosystems.

Ambiguous figures, said to be illusions because we don't know how they should be looked at, deserve additional mention. The phenomenon was noted by physicist Niels Bohr in another context and called *complementarity*. It was mentioned briefly earlier and will be discussed in greater detail later on in Chapter 13. For now it will suffice to say that the wave versus particle theory of light is a classical example of complementarity, but it should be recognized that there are many other examples all around us. The only reason we don't realize it is that we believe so strongly in the one right answer and we generally refuse to look for alternatives. Why can't a person have two or more world views at the same time? Especially if having more than one world view would help hir deal with the complexity around hir?



An entomologist might argue that Ladybug #1 represents the primitive form and the other seven are mutations from it. But the variations involving color could be induced environmentally, for example the elytra in #7, the spots in #2, the head in #4, or the eyes in #8. Single antenna in the middle of the forehead or the loss of the middle legs may be the least likely variation to occur, and in that sense "more different" from any of the others. These are qualitative considerations. A more decisive "most different" candidate can be derived from quantitative considerations. Each of the ladybugs from #2 through #7 have one unique feature. #1 has no unique features. The difference between zero and one is greater than the difference between one and a million; it's the difference between *something* and *nothing*. Therefore we can say that Ladybug #1 is the most different.

CHAPTER 9 : COMPLEXITY & SCIENCE

Ever since humans began to think, they have had to contemplate and cope with the complexity of the world around them. Many attempts have been made to solve complexity. The first attempt was through Magic, then Mythology, and then Religion. Man invented gods to handle the tough issues which he could not handle by himself. By man, of course, I mean *Homo sapiens*, but I also mean the male *Homo sapiens*. Women would have come up with quite different strategies if they had been put in charge. Astrology was invented to make sense out of the morass of stars in the heavens and to explain how the arrangement of these heavenly bodies influenced human lives. The last and most successful attempt to solve complexity was Science.

How has Science gone about "solving" complexity and in what sense has it been successful? Let's answer the second question first. Many people today, environmentalists among others, would say Science has been a failure, while others might say that it has been too successful. Out of Science came Technology, and certainly for most of us, living has become more comfortable because of it. The advances in transportation and communications have been phenomenal, as have those in genetic engineering, pharmaceuticals, and chemical production. Physics has given us the opportunity for obtaining unlimited sources of energy. Economics has helped us to get the best for the most people and the most for the best people. Medicine has found cures for many diseases, allowing more people to suffer nothing but old age senile happiness. Engineers have perfected space travel to be more certain and safer than driving a car down Telegraph Avenue in Berkeley. By all standards, that is, by the standards of Science and the scientists, of technology and technologists, and of most University professors, these are all great and wonderful successes! They have been called the Great Victories of Science.

We can call them first-order Victories. Science has looked for and found the extremes of order in the universe. Technology has designed and built instruments and structures based on the principles of that order. All Nature obeys the natural laws! Everything works!

But alas, Science and Technology have not been able to keep up with the second-order effects which are produced by the first-order victories. Worse yet, for a long time scientists and engineers would not even recognize the occurrence of second-order effects and, of course, neither would they accept the blame for causing them. Only recently did economists begin to talk about the concept of externalities; only recently chemists and pharmacists began to talk about the concept of side-effects. Edward Teller, known as the Father of the Hydrogen Bomb, spent all his time trying to convince the public that our nuclear plants don't do anything but produce good, clean, cheap energy.

So, the good invariant laws, like Newton's Law of Gravity, work fine in the simple case. When the system gets complex (the Federal Government, for example), we may have to look to other laws – perhaps to Murphy's Law. This is by no means a facetious

> If anything can go wrong, it will.
> – *Murphy's Law*

statement. Complex systems often obey Murphy's Law: where nothing works! However, instead of going all the way from the satisfying position of scientific hypotheses and invariant natural laws to the pessimistic admission that nothing works, we should explore the possibility that complex problems are not to be solved at all, at least in the sense that we usually think of solutions. This hearkens back to the notion of the wicked problems confronted by social planners.

Unlike the invariance we usually bequeath to our natural laws, the laws enacted by congresses and parliaments change from time to time, passed and repealed, repealed and re-passed. This happens as new political parties are elected, as new judges are appointed, as the media gets wiser or dumber, and as our social institutions evolve or fall apart. Then our government, our society, and eventually our culture must learn how to cope.

Most of this chapter was first written around 1980. Since then, *complexity* has become a whole new science – one of the system sciences you read about in Chapter 5. "The Architecture of Complexity," an essay by mathematical economist Herbert Simon,[1] was vital to the inclusion of the subject in Ecosystemology. Herbert Simon won a Nobel Prize in Economics in 1979. Another source for many of the ideas for this chapter is *Introduction to General Systems Thinking* by Gerald M. Weinberg.[2]

Now let's see how Science has traditionally tackled complexity. Two processes have been used: first, simplification and second, randomization. To illustrate the

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[1] *Proceedings of the American Philosophical Society*, 106:6, pp. 467-482. 1962.
[2] New York: Wiley, 1975.

simplification process, let us imagine what we might find by peeking into Isaac Newton's notebooks, where he worked out his derivations of the Law of Universal Gravitation between 1666 and 1713. We will make a few "corrections" in it along the way, allowing for the fact that the ninth planet, Pluto, and other stuff in the solar system had not yet been discovered in Newton's time. Our "review" of his work may make Newton seem more all-knowing than he really was!

Any two bodies in the universe attract each other in proportion to the product of their masses and inversely as the square of their distance apart.

$$\mathbf{F} = \frac{\mathbf{G \cdot M \cdot m}}{\mathbf{r^2}}$$

– Newton's Law of Universal Gravitation, 1665

SIMPLIFICATION

Of all the sciences, physics enjoys the highest status among academicians, and even the lay public is more impressed by the discoveries of the physicists than by the advances of any other field. Physics is the Raisinology of Science. Within this field, the subdiscipline of mechanics enjoys preeminence. Sir Isaac Newton had a lot to do with this. The study of mechanics has given us a beautifully well ordered view of the world – a model that is so compelling, so simple and comprehensible that we tend to accept it without skepticism, in spite of the fact that other models suggest the mechanical view to be far from how the real world functions.

Machines that work determinately have very few parts. Most have only two, some may have 10, and a few may have as many as 50 identifiable parts. To study formally (mathematically) the interaction of the parts, 50 is too many. Two parts are easy to solve, and indeed, the early physicists concentrated on such simple models. Until the advent of computers, the best physicists could do with systems of more than 10 parts was to write down the equations relating the behaviors of the parts – but there were too many to solve simultaneously. Even high-speed computers cannot handle 50 equations simultaneously. (We soon shall see how quickly a mechanical computation becomes complex.) It is apparent that the formal methods employed in mechanics are quite limited – and so we should wonder why physics, especially mechanics, has become the ideal model for all the sciences. The answer lies not in the formal methods that are used but in the informal methods.

Complex mechanical systems are always reduced to simple ones. This reduction is the informal part of the process; only after the complex system has been made simple can the formal or mathematical specification methods be used. We think of our solar system as consisting of the sun and nine planets in motion around it – ten bodies in all. However, we know that there are thousands of lesser celestial bodies in our solar system; in addition, there is matter which does not occur in the form of bodies. But these bodies and matter are deliberately ignored when planetary motions are analyzed. They are too small, insignificant, and cannot possibly have any effect on the calculations for planetary motion (it was said by the physicists). This is the informal step in the method, ignoring those components of a system that are thought to be inconsequential.

Consider now a different system: the human body. The average adult human body weighs about 80,000 grams. At the base of the brain lies a tiny piece of tissue called the pineal gland, which regulates the entire endocrine system and secretes melatonin, the hormone that makes you sleepy. It weighs around $1/10{,}000^{th}$ of the total body weight. It is so small that it is scarcely visible to a pair of tweezers. Can physiologists ignore the pineal gland because it is "insignificant" in size or weight?

The natural laws used to describe mechanical system determine the behavior only of the objects of interest, and only under specific conditions. Weinberg concludes: "Mechanics, then, is the study of those systems for which the approximations of mechanics work successfully. It is strictly a matter of empirical evidence, not of theory, that the human body cannot be understood by considering only the gravitational attractions between its parts."

Let us suppose that Newton had been able to see or somehow measure all 100,000 bodies in the solar system, and furthermore, that he was convinced all of them had to be taken into consideration for the computation of planetary motion. Why, he would have gone back to teaching school! Neither Sir Isaac nor anyone else would have been able to make the necessary calculations, even today, with the biggest computers. There would now be no ideas based Newton's Law of Universal Gravitation. What is the significance of that?

The significance is that one of the most important deterrents to the study of complex systems is the cost of computation, in both time and money.

Consider first a two-body system, like the earth and the moon. How many equations do we need? We need four: the first and second are the descriptions of the behavior of each body in an "isolated" state; the third is the "interaction" equation, i.e. how the two bodies affect each other; and the fourth is the "field" equation, i.e. how things behave when neither body is present. In a three-body system, there would be three isolated equations, six interaction equations (considering all kinds of interactions, including two bodies together interacting with the third body), and one field equation – ten equations in all. When the "Three-Body Problem" was first posed during the 1700's, less than a century after Newton's famous solution to the two-body problem, it remained unsolved until the 1890's, when the French mathematician Henri Poincaré proved that no closed-form solution existed! Going from two to three bodies involved a leap into unsolvable complexity: the only way to calculate the trajectories of three interacting bodies is to choose a set of initial positions and plug through a step-by-step approximation of their movement over time (preferably with a computer). Different initial positions of the three bodies yield extraordinary differences in system behavior. In fact, ideas from the three-body problem eventually led to what we now call chaos theory – a system science from Chapter 5.

Adding more bodies to the problem would make the computer very slow in plotting the trajectories. Field equations remain constant at one, and the number of isolated equations increases linearly, but the number of interaction equations rises exponentially. For *n* bodies, we need a little more than 2^n equations – each added body roughly doubles the number of equations. In a system with, say, one sun and nine planets (10 bodies), we need around $2^{10} = 1{,}024$ equations, and for the system with 100,000 bodies,

$10^{30,000}$ separate equations. You can tell how prohibitive the cost of computation would be for the 100,000 body system.

It's not really necessary to have this cost in dollars and hours; what we do need is to know how the cost increases as the size of the problem increases. Unless some simplification is made, the amount of computation increases as the *square* of the number of equations. So if the problem increases by a factor of ten, you will need a computer 100 times as big. This is called the *square law of computation*.

It should now be clear that something has to give when we deal with large, complex systems. Either we simplify by reduction, exemplified by reducing the number of equations, or we sacrifice precision by not insisting on strict mathematical measurements. But hang on – there may be still other ways to study complexity. Besides simplification by reduction of numbers of components, Newton made another simplification. He made the assumption that gravitational attraction was the only important interaction. He didn't consider magnetic effects, light pressure, electrostatic forces, personalities of the planets, chemical composition, and many other factors that conceivably could be measured. Newton's answer to this could have been: "For the purposes of mechanics, nothing but gravity needs to be measured and plugged into the equations." (This answer may not always suffice. Precise predictions of the orbit of the Echo satellite, which was a large inflated Mylar sphere launched in 1960, were not satisfactory. The use of classical gravitational equations wasn't doing the job. Eventually, programmers realized that Echo was much "larger" than a natural solar body of the same mass, because of its lesser density. The pressure of sunlight, previously ignored, made the difference by radiating on its “larger” surface. In effect, *light pressure* was knocking Echo off its predicted path.)

Still another form of simplification is implied by Newton’s Law of Universal Gravitation (which has been called the greatest generalization achieved by the human mind). The equation for this Law (shown on page <??>) implies that no other equation is needed. Thus, the force (F) of the attraction between the two bodies (M and m) will not be affected by the presence of a third body (m’). Only pair-wise interactions are important, and all pair effects can be added together to describe the whole system. Wow, this would make things simple for anthropologists and psychologists in group and kinship studies!

Ten things can be taken together as pairs in 45 different ways. 45 equations are a lot fewer than 1024 – a 95% reduction. But Newton was still not satisfied. In the case of the solar system, there was one body with a mass greater than the mass of all the other bodies together. This suggested to Newton to take the next step in simplification: to ignore all of the pair equations which did not involve the sun. (It would have bothered the Pope to know that the earth was believed to have no effect, but Copernicus had fought most of that battle some 125 years earlier.) By now Newton had reduced the 45 equations to nine – another 80% simplification.

One more step remained for him to take. Since the mass of the sun was so overwhelmingly dominant, Newton felt that he could treat the sun-earth relationship, the sun-Mars, sun-Mercury, etc., each as a separate system; that is, the sun and the earth constituted a system, thus relegating the sun-Mars, etc. relations as non-interacting systems. This is a favorite trick of systems analysts today: dealing only with objects of interest, and considering the rest as non-interactive. (Astrologers do not think that way – but then, they have been discredited as scientists for a long, long time.)

Just for review, let us construct a table to show the various steps taken in the simplification process:

Basis for Simplification	Total Number of Bodies	Number of Equations to be Solved
	100,000	$10^{30,000}$
Too many bodies which are too small	10	1,024
Pair-wise interactions are most important	10	45
Only sun relationships are important	10	9
Each sun-planet system is unaffected by the others	2	1

RANDOMIZATION

So far we have discussed only one complex system: the solar system with its 100,000 objects of which 10 are interesting. Now next consider another kind of complex system – a bottle filled with air molecules. How do these two kinds of systems differ? They differ in three ways.

(1) There are at least 10^{23} molecules m the bottle, not just 10^5.

(2) The physicists who are interested in such a system are not interested only in ten of the molecules, but in all of them.

(3) If they had been interested in only ten molecules, they would still have had to study all 10^{23} of them, because no ten molecules could be singled out or marked.

How should a simplifier of this complex system now proceed? One way would be to take only the pair-wise relations; this would reduce the number of equations somewhat. But that's not enough. An entirely different approach is needed: instead of being concerned about the precise properties of selected objects of interest, the interest is switched to a few average properties of the molecules. There aren't many of such properties in a gas – average velocity of molecules, diffusion rate, and heat capacity, to name a few. So, in one giant step we can reduce the system to about a half dozen equations. The precision of prediction for these average values is excellent because the numbers are so large. In fact, whereas having a lot of equally important objects makes simplification a difficult task, in *randomization*, the larger the number of equally important, fundamentally similar objects, the greater the precision in describing average properties. This principle is called the *law of large numbers*. We're not able to say anything exactly about a particular molecule, but the larger the population of molecules, the more likely we will find some that our average values give good predictions. The vast, important field of statistics is based on the law of large numbers.

Just as in mechanics, assumptions have to be made to achieve the simplification achieved by randomizing. In statistics, the assumption is that if a large random sample is taken from a population, the average of the sample members will tend toward the average of the entire population. We have said that "mechanics is the study of systems for which the approximations of mechanics work successfully." We can also say that "randomness is the property that makes statistical calculations come out right."

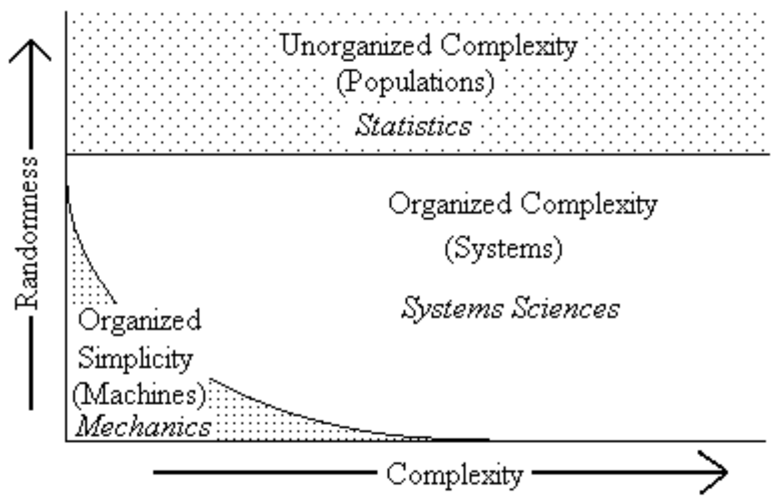
Are there any other kinds of systems which are not simulated by the two examples we have discussed? Yes, there are, and these will be the primary subject matter of this book. The diagram below will explain the relationship between three kinds of systems.

We now know that the world is not a machine, although some philosophers, such as Enlightenment thinkers Thomas Hobbes and René Descartes, said it was in fact entirely mechanistic. Hobbes held that everything in the universe was subject to purely mechanical cause-and-effect type explanations – even the actions and destiny of man (sic). The whole universe is motion; thoughts or ideas are nothing but motions in the brain. Good and evil, pleasure and pain are simply matters of motion and therefore predictable by having a complete knowledge of mechanics. Descartes also held that all nature can be explained mechanically. The spiritual is not part of nature, and must be reconciled with nature's mechanics. Man (sic) is a part of nature; he (sic) is a machine which operates by natural laws as surely as a clock works.

To be sure, many things in Nature are predictable, and to that extent, they can be construed to be mechanical (determinate). But certainly this does not apply to everything.

Also, we now know that the world is not a random jumble of elements, although the Second Law of Thermodynamics claims that eventually it will become that. There are, indeed, many events and phenomena in nature that are not explainable except by invoking chance, probability theory, and the law of large numbers. In other words, we seek probabilistic explanations for the part of the world that seems to be unorganized – a subject for the study of statistics, and a mechanistic explanation for the rest (and only the greatest simplification yields to mechanics).

In between organized simplicity (the world of machines) and unorganized complexity (the world of large random populations) lies the area which can be called *organized complexity*. This is the area in which we must seek the order that exists, and so far, the best way found to do it is through a systems approach.



Understanding and further developing a systems approach is a major part of ecosystemology. I believe it wrong to think of this as a science in the same way that mechanics and statistics are called sciences. There are too many important aspects of systems that do not come under the traditional purview of science; and many would be considered by "good" scientists to be counter-scientific. The "good" technology that came with mechanics has left out people; the "good" averages we get from statistics leaves out the individual; and the "good" objectivity with which scientists pride themselves leaves out feelings and unquantifiable things that make life worth living – even the lives of scientists. In another chapter we shall pick up this theme again, when we talk about qualitative methods in inquiry and research.

So, in this book we will be dealing with the broad middle area of the diagram shown on page <??> – the area of systems, systems with extreme complexity, systems which have not been well-studied by conventional scientific methods in the past. In the next chapter we will look deeper into organized complexity and ways to make complex systems more comprehensible.

CHAPTER 10 : ORGANIZED COMPLEXITY

Organized complexity has three characteristics which permit its simplification. They are hierarchy, redundancy, and near-decomposability. First we shall discuss hierarchy.

HIERARCHY

Consider a taxonomist. She sees groups (say, of plants or animals) whose members have certain common properties or relationships. Looking closer at each group, she sees subgroups, again whose members have particular relations not shared with members of other subgroups. She can now make up a dichotomous key that can be used by students to identify specimens they are examining. The key represents a hierarchical order.

There are many familiar examples of hierarchical organization. The topical outline for a term paper is one. The administrative structure in a big university and the table or organization in the Army or Navy, any government bureau, or any big corporation is a formal hierarchy. A genealogy of the Royal Family or of purebred poodles is hierarchical. Galaxies, the human brain, the parts of the body, and digital computers – all have hierarchical structure. Indeed, it is nearly impossible to think of anything big and complex that does not have hierarchical organization.

Has the world really been "organized" this way or is hierarchy an invention of the human brain, and thus something that we impose or "map" onto the real world in our attempt to organize it? Many scientists, including several Nobel prizewinners, think that the world is naturally hierarchical, and would be so even if there were no human observers. Herbert Simon (the economist mentioned earlier) thinks so and has an explanation for it: only structures that are hierarchical have a chance to become complex! The argument is that systems evolve and such evolution takes time. Complex systems take longer to evolve... well, I'll let the following story explain it.

This story was first told by Herbert Simon in "The Architecture of Complexity," then retold by social philosopher Arthur Koestler in *The Ghost in the Machine* (1976). Later, I wrote the script for a play using the parable for the plot. The play was produced by Ecosystemology students as a class project in 1980. Simon's version of the story tells about two watchmakers named Hora and Tempus (here I change Hora to a she).

Parable of the Two Watchmakers

Each of the two watchmakers had hir own shop. Both were highly regarded, as they made excellent watches, and customers wanting to buy were constantly calling them. So their phones rang often. In time, Hora became rich, but Tempus became poorer and poorer and finally went bankrupt. Why did this happen?

Both made the same kind of watch. Each watch consisted of a thousand parts. The difference, however, was in how the parts were put together.

Tempus assembled his watch piece by piece; but when he had to put his partly assembled watch down for some reason (such as answering the telephone), it would fall apart. It made no difference whether he had assembled 2 pieces or 998. So, guess what happened when a customer called up to order a watch. Old Tempus would either lose the sale or the headway he had made on another watch. And the more satisfied people were with his watches, the more frequently new customers would ring him up, and the more difficult it was for him to find enough uninterrupted time to complete a watch.

Hora made the same kind of watch out of the same number of pieces. She designed it, however, so that she could put together subassemblies that would not fall apart when completed. Each stable subassembly consisted of ten pieces. Ten of these subassemblies could then be put together into a larger assembly, again so they would not fall apart when set down. Finally, the ten second-order assemblies could be put together as a finished watch. Thus, at different stages in the completion of a watch, Hora had on her bench 1,000 elementary pieces, or up to 100 stable first-order assemblies, or up to ten stable second-order assemblies, or a final watch. When she had to put down a partly assembled subassembly to answer the phone, Hora didn't lose much time since she had at most nine pieces to put back together afterwards. She could build her watches much faster than Tempus could. If we say that the probability of being interrupted while adding another piece to an assembly is one percent, then Hora could put together about 4,000 watches in the time it took Tempus to make just one. And because Hora organized her watch-making business hierarchically, she is still in business.

Arthur Koestler's version of this story renamed the two watchmakers. He called them Bios and Mekhos. This emphasizes the organizing (Bios) and the time-consuming (Mekhos) capabilities of the successful and the unsuccessful watchmaker, respectively. I didn't think "Mekhos" was descriptive enough so in my play script I renamed him "Chaos" – Bios and Chaos.

Can this parable shed any light on the evolution of complex organization in general? Let's take a giraffe as an example of an organization that might not be invented very often. Suppose we take a fully-built giraffe, and through dissection, solution, and other analysis we determine all its ingredients on, say, the atomic or the molecular level. Our task now is to reconstruct the giraffe out of this pile of ingredients. So we put them into a huge flask with a long neck in proper amounts and proportions, suspend in a warm bath, and gently agitate the flask. How long does the agitator have to run before we can expect a fully formed giraffe to appear? Will, by chance, some usable holons or stable subassemblies form to shorten the time?

The parable assumed that Hora knew her parts well enough to design stable subassemblies. Is it not possible that Tempus, naïve as he might have been at design, would stumble onto at least some completely stable ten-part units? The real question is, did he have enough time? Consider this: after choosing any given piece as nucleus or starting point, there are about 10^{27} ways of adding nine other parts, only 100 of which are stable. A ninety-year-old -watchmaker has only 3 x 10^9 seconds in hir lifetime. So the answer to the question is: no, unless many of the pieces are identical and interchangeable like the rods and spools of tinkertoys, and unless a unit can contain several of such identical parts.

Another story with almost the same plot has been told by chemist Melvin Calvin. Different parts, subassemblies, and products are involved and The Designer isn't mentioned by name. However, hierarchical organization is as prominent a THE feature in Dr. Calvin's story as it was in Dr. Simon's. (I am trying to tell Simon's and Calvin's stories so that they can be understood by children, but they are not intended to be kids' stuff! Both men are Nobel laureates!)

Melvin Calvin's Story

The earth, some four and one-half billion years ago, was surrounded by a very primitive atmosphere composed mainly of atoms of hydrogen, oxygen, carbon, and nitrogen, all in a fully reduced form. (Did God begin His (sic) career as a reductionist?) The relative prevalence of these atoms was probably in the order just given, since it is believed that hydrogen is the predominant element in the cosmos, followed by oxygen, carbon, and nitrogen. Today, hydrogen accounts for more than 90 percent of the total number of atoms in the universe and about 75 percent of the mass. Consequently, the primitive atmosphere of the earth consisted of atoms of hydrogen (H), oxygen (O), carbon (C), nitrogen (N), and perhaps a little sulfur (S) and a pinch of phosphorus (P). Each atom as it floated around would pick up one or more atoms of hydrogen, which hook onto these single atoms, making primordial subassemblies (simple molecules) of molecular hydrogen (H_2), methane (CH_4), water (H_2O), and ammonia (NH_3). Another type of molecule frequently formed was carbon dioxide (CO_2). After a time, loose single atoms floating around the atmosphere became less probable than simple molecules.

Starting with these four or five primeval molecules, and given such available energy sources as cosmic radiation, ultraviolet light, radioactivity of minerals in the lithosphere, and electric discharges from lightning, chemical evolution began. It began as soon as the earth was formed. Calvin's story continues by showing how these energy sources could break up the molecular bonds of the simple assemblies and cause them to recombine in different, more complicated ways to form primitive stable organic molecules.

Calvin not only is the storyteller but watch-assembly-maker as well. Using a mixture of carbon dioxide, hydrogen and water energized with ionizing radiation from an accelerator, Calvin experimentally produced formaldehyde, acetic acid, and other primitive organic molecules. Now listen to this: two other chemists, Stanley Miller and Harold Urey, produced the following complex substances (we call them organic) from a mixture of ammonia, water, methane and hydrogen – there were no plants or animals involved:

Molecule	Structure	Yield (micromoles)
Formic acid	H-COOH	2,330
Glycine	H_2N-CH_2-COOH	630
Glycolic acid	HO-CH_2-COOH	560
Alanine	H_2N-CH(CH_3)-COOH	340
Lactic acid	HO-CH(CH)-COOH	310
b-Alanine	H_2N-CH_2-CH_2-COOH	150
Acetic acid	CH_3-COOH	150
Proprionic acid	C_2H_5-COOH	130
Iminodiacetic acid	HOOC-CH_2-NH-CH_2-COOH	55
Sarcosine	HN(CH_3)-CH_2-COOH	50

a-Aminobutyric acid	$H_2N-CH(C_2H_3)-COOH$	50
Hydroxybutyric acid	$HO-CH(C_2H_3)-COOH$	50
Succinic acid	$HOOC-CH_2-CH_2-COOH$	40
Urea	$H_2N-CO-NH_2$	20
n-Methylurea	$H_2N-CO-NH-CH_3$	15
n-Methylalanine	$HN(CH_3)-CH(CH_3)-COOH$	10
Glutamic acid	$H_2N-CH(C_2H_4COOH)-COOH$	60
Asparic acid	$H_2N-CH(CH_2COOH)-COOH$	4

Notice that these long, complex molecules are made up of smaller molecules (COOH, H_2N, CH_3), and those smaller molecules are in turn composed of H, N, C and O. Koestler states, “If there is life on other planets, we may safely assume that, whatever its form, it must be hierarchically organized.” Why must we assume this?

Annual composites – weeds like the dandelion – are believed to be recently evolved plants. Their cell walls, chloroplasts, mitochondria, and other structures are almost identical to those in primitive plants, e.g. clubmosses, horsetails, and ferns. Thus, the chloroplast didn’t have to be invented over and over every time a new species evolved. Likewise, the properties (charges, mass, weight, etc.) of electrons, neutrons and protons are the same no matter what atom they belong to. Atoms vary merely by the number of these “pieces” present. “If you’ve seen one electron you’ve seen ‘em all.” So, the electron didn’t have to be re-invented every time a new element came off the assembly line, either.

Suppose you had the task of designing an automobile or some electronic device. Would you build the entire thing from scratch? Wouldn’t you go to an auto supply store or to Radio Shack to get some existing subassemblies? You wouldn’t re-invent the wheel!

The only reason that great conquerors like Alexander could build an empire so quickly is that the conquered states remained intact as stable subassemblies. A few key generals had to be killed here and there, that's all it took.

Once things organize into stable assemblies, those assemblies can then assemble into larger assemblies… and complexity unfolds. The hierarchy comes from the order in which small pieces form systems, and then those systems become the pieces that form even bigger systems, and so on.

Well, there seems to be overwhelming evidence that the world is hierarchically organized. But is it really? One question has not yet been answered satisfactorily: is the world really hierarchic or have we mentally put a hierarchic grid or map over it, so that it seems to come out that way? Later on I will argue that it is NOT hierarchic! The world has a relational order, not a hierarchic one.

REDUNDANCY

The second characteristic of complexity which permits its simplification is redundancy. Consider again the taxonomist who has piles of animals in front of hir. All the fish have scales; all the mammals have hair; all the birds have feathers. Redundancy is an important component of order. It makes crossword puzzles possible by restricting the possible arrangements of the letters of our alphabet. Redundancy occurs in proteins; proteins are arrangements of the alphabet of 20 amino acids. Notice in the table on page <??> how often the carboxyl radical (COOH) was repeated in the Miller-Urey experiment. Redundancy makes it possible to have natural laws. To discover a natural law, an event must happen more than once. If an apple, when dropped, fell upwards, sideways, or in unpredictable directions instead of always earthward, we would have no law of gravity. If every organism were a different phenotype and genotype, evolution would not have been discovered.

Once more we'll call on Herbert Simon (with no disrespect intended, I have been known to refer to Herbert as "Complexity made Simple" Simon) to show us how to simplify complexity, particularly how a complex array of symbols can be described economically (after all, Simon's Nobel was in Economics!)

Think of the "Hail, Mary" recitation, the Kyrie, or a litany, mantra, or other chant. The repetitiveness of these incantations makes them easy to describe compared with the words in a volume of *Encyclopedia Britannica*. How could you efficiently describe a "manuscript" produced by a monkey pecking at a typewriter for, say, a period of ten years? To put the problem succinctly, consider this scenario. You are writing a book and the manuscript is too heavy to mail to a printing press. You need to send them an abbreviated code which gives full and adequate instructions on how the book is to be printed. Here, for example, are a few pages of your book.

This is Jack. See Jack run. Run, Jack, run.	This is Jill. See Jill run. Run, Jill, run.	Jack is back. See Jack play. Play, Jack, play.	Jill is back. See Jill play. Play, Jill, play.

Each triplet of this exciting story is to be on a separate page. Let's say there are ten children (Jack, Jill, Betty, etc.) and ten activities (run, play, work, etc.), which would make 100 pages. Can you write an algorithm or a code which would give a printer complete directions for the full book?

This has been, of course, an extreme example, but the fact is that most books do have a tremendous amount of built-in redundancy. Simpler codes could be written.

Sometimes plots can be predicted, occasionally entire sentences, very frequently certain words, and most often letters. When there's a "q" a "u" is sure to follow, except in Qantas, qoph, and Iraq.

> A stranger once walked into a hall where there was a great deal of laughter. Someone would shout, "Number twenty," and the room would shake with laughter. Then another person would call out, "Sixty four." Again guffaws. Then the stranger called out, "One hundred and twenty five," but nobody laughed. The people in the hall scowled at him, and shouted, "There are only one hundred jokes in the book." All the jokes in a joke book had been memorized and identified by number. Instead of telling the joke, only the call number was needed to evoke laughter.

Claude Shannon, the man who developed information theory, played around with this matter of redundancy in the English language. He was an employee of the Bell Telephone Company. His work was of great value for the United States Armed Forces in World War II, as it dealt with coding of secret messages and decoding. None of Shannon's work was released to the public until WWII was over.

First of all, Shannon made a completely random selection of characters from an alphabet composed of the twenty-six English letters and the space (between words). The sequence that he got from this was called the zero-order approximation to English. Here is the actual sequence that Shannon published:[1]

XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSGHYD QPAAMKBZAACIBZLHJQD

These "words" are long, unpronounceable, and you would need a very good memory to learn to spell them. The most commonly used letter E occurs only once in the entire sequence of 60 characters, and T not at all. A real Czech tongue-twister!

For first-order approximation to English, Shannon used a table of individual letter frequencies (as given below) and a table of random numbers. Each successive letter could be chosen independently but each would have the same probability it has in English. The process that produces a sequence of symbols according to certain probabilities is a *stochastic* process.

Suppose a typesetter had broken up all the English type she had used during one year and tossed the individual letters (including spaces) into a bin, all mixed up. The proportions would be about the way they are shown below. In fact, this is the way Samuel F. B. Morse determined which letters of his telegraph code should be simple (E = • ; T = -) and which should be complex (Q = ••-•). It is a good example of how the rules of a system can be discovered and then played back to reconstruct a system.

Table of English Letter Relative Frequencies
(numbers in parentheses are values ascribed to the letter on Scrabble tiles)

[1] "A Mathematical Theory of Communication." *The Bell System Technical Journal*, 27, pp. 379-423 and 623-656. 1948.

Space	16.83	(0)	H	4.37	(4)	P	1.65	(3)
E	10.89	(1)	D	3.15	(2)	W	1.28	(4)
T	8.71	(1)	L	2.82	(1)	B	1.20	(3)
A	6.78	(1)	F	2.43	(4)	V	0.77	(4)
O	6.64	(1)	C	2.30	(3)	K	0.35	(5)
N	5.90	(1)	M	2.11	(3)	X	0.14	(8)
R	5.68	(1)	U	2.05	(1)	J	0.11	(8)
I	6.28	(1)	G	1.66	(2)	Q	0.10	(10)
S	5.07	(1)	Y	1.65	(4)	Z	0.07	(10)

From the table it can be seen that English words are, on the average, six letters long, and every word over seven letters long is likely to have an E in it. Scrabble is not equitable in the middle range of probabilities.

Out of a bag containing 1,000 characters in proportion to their relative frequencies in the English language (as listed above), I drew the following sequence of letters:

T WCIETSHHVNDICSU REEDG TBSNH D SERIRMLHWM F AGEEAH LNNTDOCAC SPNFNETDRETTOTTEENHIR NAULGE IS ELEP

Obviously this first-order approximation is not very good English. Two 4-letter word combinations can be found in the entire sequence and a few 3-letter ones.

The process for second-order approximation is to find diagram structure, with the probability that each letter follows the one which has just occurred being the same as is found in English. Shannon did this by selecting at random a letter from a book and jotting it down. Then opening the book to another page, he read until that letter first appeared, and recorded the letter which followed it. On another page that second letter was found, and the succeeding one recorded. And so on. Using a Welsh bible, the following second-order approximation to the Welsh language was attained:

RFODDI HEI YR AD IDDDYNH YTHI DDU DDYNASTHOH AUNWAIOD YN AIC YMADITYROD DD B ANEFEFRNNAI N EWYSTHEFYNA FYR

And using an old German botany book printed in 1860 the following second-order approximation to the German:

DINGST SELBSTUNGEN DEN ALLEGEBRUHT WELLURCHTATS ZWUSCHNLICHN LOSTIMA

For third-order approximation trigrams (two consecutive letters followed by a third) Shannon got the following sequence:

IN NO IST LAT WHEY CRATICT FROURE BIRS GROCID PONDENOME OF DEMONSTRURES OF THE REPTAGIN IS REGOACTIONA OF CRE

Already some pretty good-sounding "words" emerge; a few like "grocid" would come in handy if you were composing nonsense verse for a children's book. With fourth-order approximation, almost all combinations are valid English words, but sentence structure has not been achieved. For this, Shannon switched to first-order word approximations. Here *words* are chosen independently but with their appropriate frequencies:

REPRESENTING AND SPEEDILY IS AN GOOD APT OR COME CAN DIFFERENT NATURAL HERE HE THE A IN CAME THE TO OF TO EXPERT

GRAY COME TO FURNISHES THE LINE MESSAGE HAD BE

With second-order word approximation the same technique was used as with second-order letter approximation, except that the units are words instead of letters. A sample given by Shannon:

THE HEAD AND IN FRONTAL ATTACK ON AN ENGLISH WRITER THAT THE CHARACTER OF THIS POINT IS THEREFORE ANOTHER METHOD FOR THE LETTERS THAT THE TIME OF WHO EVER TOLD THE PROBLEM FOR AN UNEXPECTED

What is the point of all this? What does this have to do with Ecosystemology? Well, remember, we are still talking about complexity, and how much redundancy there is in complex systems. The English language is said to be at least 75 percent redundant. If it were not, nobody would be able to learn it. But language is a man-made system and may be expected to be redundant. What about complex natural systems? Let's look at DNA.

Organic Alphabets and Coding

Twenty-"Letter" Amino Acid Alphabet

1. Glycine*	11. Aspartic acid*
2. Alanine*	12. Glutamic acid*
3. Serine	13. Lysine
4. Cysteine	14. Arginine
5. Cystine	15. Phenylalaline
6. Threonine	16. Tyrosine

7. Valine	17. Tryptophan
8. Leucine	18. Histidine
9. Isoleucine	19. Proline
10. Methionine	20. Hydroxyproline

* compare with table on page <??>

We consider our written alphabets to be very ancient, dating back to at least the 9th century BCE. But, of course, an alphabet was invented as long ago as the time of the evolution of the amino acids. Above are listed the “letters” of a twenty-“letter” alphabet. Were there no natural constraints to how these letters (amino acids) could be put together to form “words” (proteins), as many different kinds of proteins could be formed as there are letter combinations.

In our English language alphabet of 26 letters, there are about 309 million possible 6-letter “words” (calculated as 26^6), twenty-six times as many seven-letter words, and so on. But there are perhaps no more than 6,000 legitimate six-letter words and about 6,500 seven-letter words (counting proper names). This reduction is due to the redundancy rules built into our language.

With proteins, there are 64 million (i.e., 20^6) possible six-acid combinations, but again, due to natural “rules” or constraints, only several thousand occur naturally or can be produced in the laboratory.

If every possible English letter combination (up to, say, groups no longer than 15) were a word – with an associated concept and definition – a single copy of the required unabridged dictionary would cover most of the UC-Berkeley campus. An English student would take years just to page through to find the meaning and correct spelling of KZQFYQIU.

Likewise, if every possible combination of amino acids were represented by an actual protein (naturally produced by organisms), there would have to be so many different kinds of plants and animals that there would not be room for all of them on earth, and no room left over for ecologists or taxonomists. The complexity of the world would be astounding. Now we can begin to appreciate redundancy!

To continue the analogy of letters and amino acids: words = proteins; sentences = protein chains; paragraphs = tissues; chapters = organs; books = organisms; volume sets = species; libraries = the entire gene pool.

One part of the analogy has not yet been addressed: the equivalent of the "instructions to the printer." An individual organism such as a redwood tree or a giraffe is exceedingly complex by itself (although it exhibits a lot of redundancy). All redwood trees (it has reputedly been said) are pretty much alike, and so are all giraffes. Yet the instructions on how to build them are packaged in something much smaller than the organism itself. This blueprint is the DNA and RNA – two nucleic acids (deoxyribonucleic and ribonucleic) which are in turn made up of a much smaller (four letter) alphabet. This alphabet consists of four bases: (A) adenine; (G) guanine; (C) cytosine, ad (T) thymine. Uracil is substituted for thymine in RNA. In this case, diversity is produced by the length of the "word" rather than by variety of letters.

NEAR-DECOMPOSABILITY

One of the problems anyone faces in writing a book is being locked into a hierarchical format. For example, the title of this chapter is Organized Complexity, and under it comes four sections: Hierarchy, Redundancy, Near-Decomposability, and Relational Order. The previous chapter, Complexity & Science, was also on complexity, with two sections: Simplification and Randomization. In other words, the problem of complexity can be divided up into broken into at least two sub-headings, which can in turn be broken into six total parts, or sub-problems.

Another way to say “this is *complex*” (as a problem) is “this is *decomposable*.” It does not mean that it's decaying or rotten at the core. The word *decomposable* refers to those systems in which we clearly recognize separate and independent subsystems. These subsystems can stand by themselves or can be considered bona fide systems in their own right.

A second problem faced when putting this book together is that for the best understanding of the concept of decomposability, the chapter on System & Environment should come first. How can we talk logically about subsystems before we know something about systems? This indicates that our fixation on hierarchy needs to be reviewed; the last section of the chapter, Relational Order, will do this. Suffice it to say at this time that reading about decomposability will help us to understand systems as much as reading about systems helps to understand decomposability.

Let us consider two systems: one is not at all decomposable and the other is completely decomposable. Right away you will say: impossible! They are figments of imagination. True; both are mental constructs. Philosophers and scientists have long used such constructs, even though they are fictions, in order to gain insights on reality. So after this justification, let us imagine that we have in hand the first of the two constructs – a thing which cannot be subdivided in any way – and reflect on it.

The Greeks had the perfect word for such a thing: *atom*. [*a*-, not; *tomos*, to cut; *atom,* uncut, indivisible]. After a slow start, the "cutters" were able to separate out electrons, protons, and neutrons, each of which was then proclaimed to be indivisible. Today, more than thirty other parts of the supposedly indivisible atom have been found. The Greeks gave us another fine word: *monad* [*monas*, a unit, unity; *monos*, alone]. For the philosopher Leibniz, monads were self-contained units, the building blocks of the universe, and each monad was considered to be completely insulated from outside influences. So, you see that it's not entirely crazy to think of something that's down to its final cut and literally stands alone.

Think of a hard, heavy sphere, like a billiard ball. Imagine that it cannot be crushed into fine power or subdivided in any way. It is just one solid piece, with only one part – itself.

Now let's go to the other "end" (you suspect correctly that we are going to generate a continuum) – a system that is completely decomposable into its smallest subunits and these can exist alone, that is, there's no interaction with other subunits. (Remember, we are still talking about mental constructs). Of course, these fully decomposed subunits are themselves monads or (original) atoms, which means that the continuum is not a line but rather a circular band, without ends, like a Mobius strip. The idea of a system in which the parts are so widely scattered that there is no interaction between them was first proposed by physicists long ago: they call it the *perfect gas*. Closer to reality is the *rare gas* in which the molecules are so far apart that their interactions cannot be measured – or at least they are negligible for calculations. In terms of Newton's simplification problem, there are no interaction equations to consider.

So on our Mobius strip continuum, we go from the perfect gas to the rare gas to a normal gas, then through liquids and solids until we get to the solidest "solid" we started with.

We can apply the same idea to social organizations. We have the individual: independent, non-schizoid, single-minded, an indivisible unit and "perfect solid." We have the "perfect gas" society in which no one meets or interacts with anyone else, with one person in the middle of every 10,000 square mile block. The latter is especially hard to imagine, given the way people reproduce. In between this condition we have anarchist, democratic, and fascist societies, all with various degrees of cohesion.

Mental Constructs

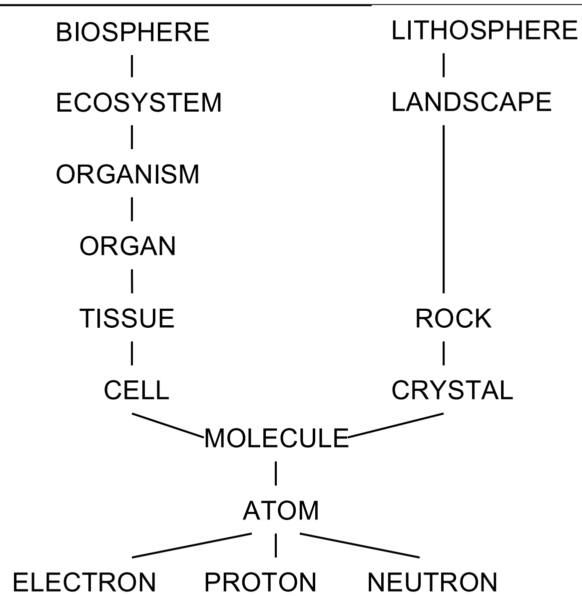
The billiard ball is smooth and round,
Hard and heavy, structurally sound,
Yet decomposable into parts.
Ball bearings bearing greater mass
Are better examples for this class,
Yet can be shattered into parts.
Take now nucleus of atom gold
And look within: we there behold
How protons swim around inside;
Though strong the bond, the space is wide;
So when we dig down… smaller, smaller more,
There's nothing indivisible.
Only in our mind we find
The construct we are looking for.

We wonder now what we have learned.
Degrees of bonding have been discerned
And all related to some extent.
How far apart must pieces be
To be completely, truly free?
To find them, again we must invent.
The perfect solid, the perfect gas,
Without parts and without mass.

Only twixt/between these be
What we know as reality.

– AMS

Still another example, particularly of interest to us in Ecosystemology, is the continuum called *levels of organization*: atoms, molecules, cells and crystals, tissues, organs, organ systems, organisms, ecosystems, biosphere. (See diagram below.) The strengths of the interactions within these various levels are of different orders of magnitude. Thus, within the atom, nuclear forces are stronger than molecular forces. Molecular forces are stronger than inter-molecular (mixtures, intra-cellular) relations. All of these lower level structures have stronger internal forces than are found in ecosystems. Indeed, it has been said by many scientists, including ecologists, that ecosystem "forces" are so weak that ecosystems are not viable units of study, but mere abstractions. This argument was taken up fully in Chapter 6, Ecosystems.



Levels of Organization

In Chapter 12, Holism and Reductionism, we shall talk about still another way to think about complexity. As we go upwards through the levels of organization, at each level we have all of the diverse parts at the level below, but we find one or more additional <u>emergent qualities</u>. These emergent qualities clarify the increase in complexity as we go from the primitive molecules to a giraffe.

It appears that systems toward the non-decomposable part of the continuum are relatively simple, in that they yield to the methodologies of mechanics and obey the natural laws precisely. This is not to say that such systems are unimportant. Physicists, chemists, and engineers handle them well. Systems tending toward the decomposable part of the continuum are generally complex: they include things like the federal government, large corporations, the human brain, and, of course, ecosystems.

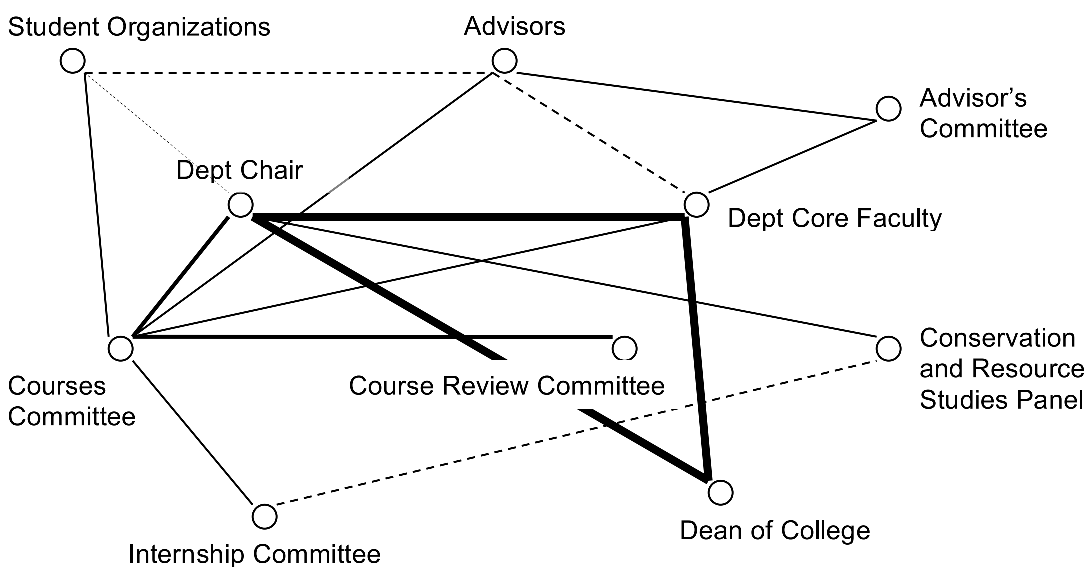
Interaction between parts or subsystems, though it may be weak, is not negligible. We call these *nearly-decomposable* systems. Because they can be seen as assemblies of many subunits, we can describe them hierarchically. In these systems, however, the subassemblies will overlap and interact with one another in important ways, and the hierarchic order alone will not explain these interactions.

RELATIONAL ORDER

This is the antidote to hierarchy. Relational order preserves complexity, making it understandable without simplifying it into artificially isolated segments. We shall first contrast hierarchical and relational order by giving a relevant example from an Ecosystemology class at a major university.

The description of the Ecosystemology course was submitted to the College of Natural Resources courses committee for their approval, and then to the campus-wide Courses Committee for the final O.K. Subsequent revisions had to go the same route. The department's chairperson also had a say in the matter, if he or she chose to do so, as well as the CRS (Conservation and Resource Studies major) panel. Although the instructor provided most of the "software" for the course, he usually passed much of the year-by-year decision making on to teaching assistants. In good democratic fashion, students' suggestions and critiques were honored and incorporated whenever feasible.

Here you see a chain of command from the Courses Committee to the students enrolled in (or auditing) the class. The top of the chain makes the ultimate decision whether or not the course will be offered. At the bottom, the students are more or less passive recipients who at best can modify some objectives or formats (although during the riotous 1960's, mass walkouts by students were powerful disapprovers!) The chain of command just described is hierarchical. But is that really the way most courses are organized and installed? Hardly. The following diagram (in graph theory called a *graph*) describes the process much better.



The diagram shows spatial and temporal interactions having mutual-causal feedback relations between the nodes of the graph. The strength of interaction between any two nodes will vary. The relative strength of each interaction can be shown on the graph in various ways; here, thicker lines denote stronger interactions. The relations are not unidirectional as in the hierarchical scheme, but symbiotic and to varying degrees beneficial to all parties, not just to the top or the bottom of the hierarchy.

In his article “The Metaorganization of Information,”[2] Japanese systems philosopher Magoroh Maruyama chooses to identify hierarchical order as *classificational*. The classificational universe consists of substances, material, spiritual, or conceptual, which: 1) have duration i.e. persist in time; and 2) obey the laws of identity and mutual exclusiveness. These substances are classifiable into mutually exclusive categories; the categories can be divided into subcategories and combined into supercategories; and there exists the largest category which includes all others, namely, the universe.

The *relational* universe, in contrast, is event-oriented rather than substance-oriented. The events may be fleeting or enduring as processes, but no attempt is made to chop up time into discrete segments or to reduce overlap of events. Instead of being preoccupied with the ontological or causal priority among substances and their parts, relational order is concerned primarily with the mutuality of interactions. “Definition” is not given by categories and subcategories, but by interactions and interrelations in a situation or context. An example of such a definition is war: war is that which ends with peace and peace is that which ends with war. In classification the basic question is, “What is it?” while in the relational universe it is, “How does it relate to other things in the universe?”

It is helpful to look at ecosystems using the relational approach. One can, of course, divide ecosystems into biological, geochemical, social, and other components and make subcategories of each of these. To the dead-centered biologist who doesn’t understand, say, geology or economics or anthropology, it is not reasonable to clutter up hir study

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[2] *Cybernetica* (Belgium), pp. 224-236. 1965.

with “extraneous, irrelevant” data. The same applies to the anthropologist and all the other mono-disciplinarians working in a particular ecosystem. See the Ecosystems chapter for ideas about the relational order of ecosystems.

This has been a long chapter, but length alone does not equate with complexity. Many related ideas have been brought up, and it is the number of ideas and relationships between them that produce complexity. We saw that people use several different approaches to dealing with complexity in general. In the next chapter, we will see how educational systems use disciplines and disciplinarity to deal with the complex task of teaching students about the complex universe.

CHAPTER 11 : DISCIPLINES

"What's your major?"

Physics for Scientists and Engineers -- Physics (PHYSICS) 7A [4 units]
Course Format: Three hours of lecture and four hours of laboratory/workshop per week.
Prerequisites: High school physics; Math 1A or 1AS; Math 1B or 1BS (which may be taken concurrently).
Description: Mechanics and wave motion.

General Chemistry -- Chemistry (Department Of) (CHEM) 1A [4 units]
Course Format: Three hours of lecture and four hours of laboratory per week.
Prerequisites: High school chemistry recommended.
Credit option: Students will receive no credit for 1A after taking 4A.
Description: Stoichiometry, ideal and real gases, acid-base and solubility equilibrium, oxidation-reduction reactions, thermochemistry, introduction to thermodynamics, nuclear chemistry and radioactivity, the atoms and elements, and the periodic table. Laboratory sections focusing on environmental chemistry are available. See Schedule of Classes for details.

General Biology -- Biology (BIOLOGY) 1B [4 units]
Course Format: Three hours of lecture, three hours of laboratory, and one hour of discussion per week.
Description: General introduction to plant development, form, and function; population genetics, ecology, and evolution. Intended for students majoring in the biological sciences, but open to all qualified students. Students must take both Biology 1A and 1B to complete the sequence. Sponsored by Integrative Biology.

General Psychology -- Psychology (PSYCH) 1 [3 units]
Course Format: Two hours of lecture and one hour of discussion per week.
Credit option: Students will not receive credit for 1 after taking 2.
Description: Introduction to the principal areas, problems, and concepts of psychology. This course is required for the major; students not considering a psychology major are directed to 2.

**Introduction to Biological Anthropology --
Anthropology (ANTHRO) 1 [4 units]**
Course Format: Three hours of lecture and one hour of discussion per week.
Description: An introduction to human evolution. Physical and behavioral adaptations of humans and their prehistoric and living relatives. Issues in evolutionary theory, molecular evolution, primate behavior, interpretation of fossils. Prehistoric activities, racial differences, genetic components of behavior are defined and evaluated.

Course descriptions from the 2003-2005 UC Berkeley General Catalog. Copyright 2000 UC Regents.

"I guess maybe it's anthropology. Last year it was biology, and the year before that it was physics. Maybe I'll end up in medicine, or history. I guess I'm really interdisciplinary!"

Not necessarily. Just switching from one field to another doesn't make one an interdisciplinary student. Let's see what is meant by *interdisciplinarity*. Often it is confused with *multidisciplinarity*, and just as often, inter- and multi- are thought to mean the same thing. And along comes still another term: *transdisciplinarity*. Perhaps we had better get them all straight in our minds. A good way to start is at the beginning, the bottom of the ladder, which we can call *monodisciplinarity*, or simply:

DISCIPLINARITY

A disciple is a follower. When a professor lectures about hir favorite subject, s/he professes to know something about it, or even everything about it. Hir students will "buy it," that is, become followers, and sooner or later they, too, become professors lecturing on the same subject, and viola! A discipline is born. Perhaps this is too much a caricature of how disciplines come about, so we'll try another version.

The early universities, like Salerno, Bologna, Paris, Oxford, and Cambridge started with faculties of medicine, philosophy, theology, and law. These pretty well covered all the knowledge of the time. (Perhaps, if there had been a Salerno Institute of Technology in those days, there may have been a department of alchemy.) The faculties divided up the special areas so that they wouldn't all be dealing with the same thing, although it is believed that in this early period of universities, all faculty members were versatile and omniscient – forerunners of the Renaissance men (always men!).

As time went on, faculties became more and more specialized. Disciplines splintered into ever finer specialties; subdisciplines arose and multiplied. A book was published by the University of Illinois around 1950 that listed over 1,100 known scientific disciplines, not even including any of the humanities!

The close association between disciplines and departments (as administrative units) is quite a modern phenomenon, happening in the late 19th century in the United States. However, departmentalization has had a significant effect in keeping disciplines apart, because of competition for the same pool of university funds, jealousy about prestige, vying for the best recruits and for the best students, and fear of being obliterated or merged by the philistine higher administration.

As one might expect, disciples will develop strong loyalties to their fields. They may feel that theirs is the most important discipline in the entire university (if not the universe). Some mathematicians feel that way, and many physicists. I have known economists who paid servile homage to sacred economic theory, rather than to the objects or subjects that economics ought to help (except for banks, maybe). The existence of such economists may explain why E. F. Schumacher subtitled his book, *Small is Beautiful* (1973), "Economics as if People Mattered," and why Hazel Henderson dedicated her book *Politics of the Solar Age: Alternatives to Economics* (1981), "to Ali and all the world's young people; to the Earth-keepers, the servants of Gaia and the planetary citizens of the dawning Solar Age." It would be difficult to get agreement on criteria for determining "most important" disciplines. People do matter.

The Earth matters, both the living and the non-living parts. Theories do not matter. And why should mathematics matter at all?

We shall discuss the disciplinary-to-transdisciplinary continuum from the standpoint of an innovative education system. That education system idea, as well as the classifications to be outlined shortly, comes from a 1971 article by Erich Jantsch.[1] From this point of view, knowledge (especially scientific knowledge) that has been packaged into disciplines derives primarily from empirical observation. The various disciplines tell us what the world is like, what exists, what happens, and allow some speculation about why it exists and why it happens. Disciplinarity in science is a static principle and it becomes almost meaningless when it is considered in the framework of a dynamic, *purposive* system.

Disciplinarity (that is, *monodisciplinarity*) represents specialization in isolation. An intelligent person can study physics, for example, and understand it quite well without knowledge about chemistry, biology, or other fields (but maybe mathematics is important after all). Many people study one discipline in this way. It is possible to study and understand biology without physics or psychology. Think of an array of sciences, from left to right across a page or on the blackboard:

physics   chemistry   biology   psychology   sociology   anthropology

We see them connected logically horizontally rather than vertically when we consider them to represent the empirical level in the innovative education system. Below you

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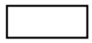
[1] "Inter- and Transdisciplinary University: A Systems Approach to Education and Innovation." *Ekistics*, 32: 430-437.

will see how this system is constructed.

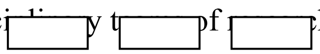


Disciplinarity: Specialization in isolation

MULTIDISCIPLINARITY

A student may have two majors or a major with one or more minors. In other words, anybody may be studying more than one field simultaneously or sequentially, but without making explicit connections between the fields. For example, one might study chemistry, sociology, and linguistics, say, with enough depth to be considered an expert in each field, yet there would be no necessary cooperation between the three disciplines. It's like a physics book and an English grammar book side by side on a shelf: there's no diffusion of information between the covers.

While monodisciplinarity is at one level and one goal, multidisciplinarity is also at one level but is multigoal.

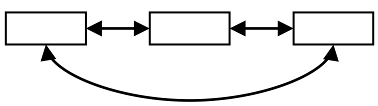


Multidisciplinarity: no cooperation

Multidisci y t f hers an y. Team members make their studies separately, write their reports separately, and the resulting publication consists of several reports stapled together and bound under one cover. There is no cooperation between the workers and no final integration of the reports.

PLURIDISCIPLINARITY

As the diagram below indicates, pluridisciplinarity implies cooperation without coordination. It is the juxtaposition of two or more disciplines, usually at the same hierarchical level (i.e., the empirical or pragmatic level – see diagram on bottom of <<next page?>>), grouped so that the relationship between them is enhanced. Like the multidisciplinary approach, the pluridisciplinary one is one-level and multigoal, but unlike the multidisciplinary approach, there is cooperation among the involved disciplines.

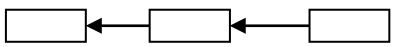


Pluridisciplinarity: cooperation without coordination

An example of pluridisciplinarity would be the combination of physics, chemistry, and geology. They could be studied in any order. Understanding of geology is enhanced by taking physics and chemistry, and studying chemistry helps in learning either of the others. Students often take courses in two or three of these, in any order or concurrently. Another example might be history, sociology, and political science.

CROSSDISCIPLINARITY

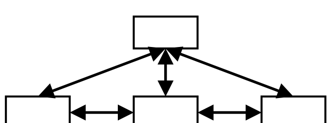
In crossdisciplinarity, the axiomatics (i.e., the self-evident principles) of one discipline are imposed on other disciplines at the same hierarchical level, thus creating a rigid polarization toward a specific monodisciplinary concept or goal. Here we are back to a one-level, one-goal situation, essentially the same as monodisciplinarity. This is familiar to students in the sciences. Remember prerequisites? Let's say your goal is physiology. First you must take biology. In order to take biology you have to take chemistry, preferably organic chemistry which has the prerequisite of general chemistry. Or if your goal is soil science, you may have a geology prerequisite which may have a physical chemistry prerequisite. Comparing with the previous diagram, note that with pluridisciplinarity the connecting arrows face both directions while in crossdisciplinarity they go only one way, toward your final goal.



Crossdisciplinarity: rigid polarization towards specific monodisciplinary concept

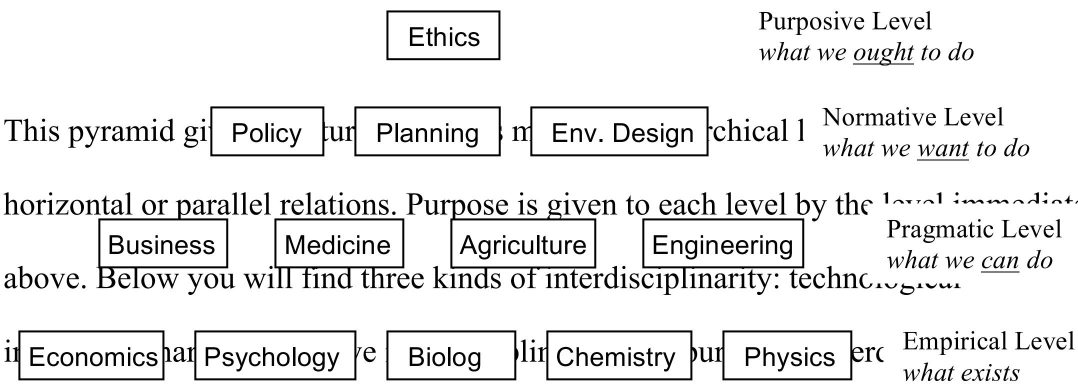
INTERDISCIPLINARITY

Interdisciplinarity is two-level and multigoal. It connotes coordination of the lower level by the higher. It has to be understood as a teleological as well as a normative concept, which means asking, "Interdisciplinary *to what end*?" Another way to say this is that a sense of purpose is introduced when the common axiomatics for a group of related disciplines is defined at the next higher hierarchical level.

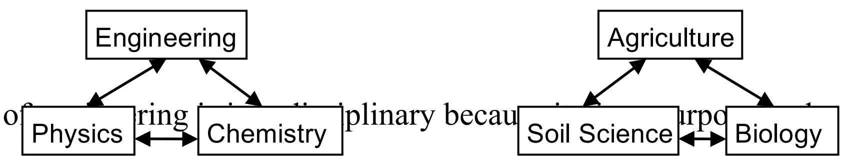


Interdisciplinarity: coordination by higher-level concept

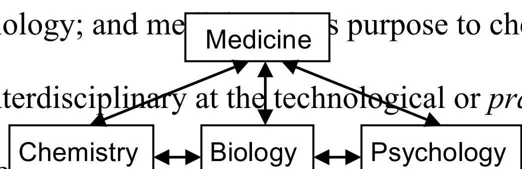
So what do we mean by *hierarchical level*? The empirically-based single disciplines which we arrayed on a horizontal line in the previous diagrams can be thought of as the base of a pyramid: the empirical level. Immediately above this level is another group of disciplines which constitute the pragmatic level. These would include engineering, agriculture, medicine, business, and so on. The third tier, going up, is the normative level, which includes planning, policy, environmental design, etc. The top level of the pyramid can be called the purposive level: "value" disciplines such as ethics and philosophy.



This pyramid gi[illegible]tur[illegible] m[illegible]rchical l[illegible] the horizontal or parallel relations. Purpose is given to each level by the level immediately above. Below you will find three kinds of interdisciplinarity: technological i[illegible]ar[illegible]e [illegible]lir[illegible]ur[illegible]er[illegible]



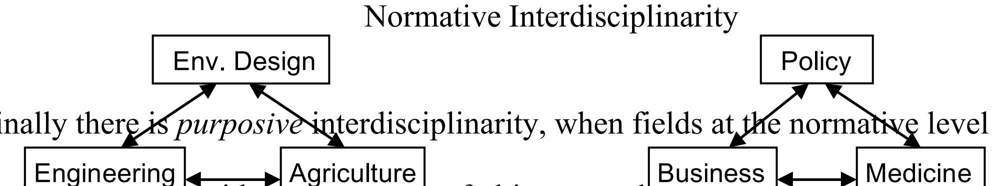
The field of [illegible]ring [illegible]plinary becau[illegible]rpo[illegible] empirical fields of physics and chemistry; likewise, agriculture gives purpose to soil science and biology; and me[illegible]s purpose to chemistry, biology, and psychology. These are interdisciplinary at the technological or *pragmatic* level (lowest and second lowest tiers).



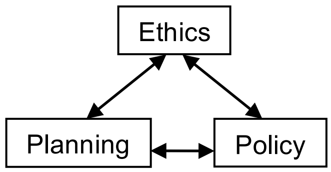
Technological or Pragmatic Interdisciplinarity

An example of *normative* interdisciplinarity is environmental design actively using and giving purpose to the pragmatic fields of engineering and agriculture (landscape architecture); another is policy giving purpose to business and medicine (health policy).

Normative Interdisciplinarity



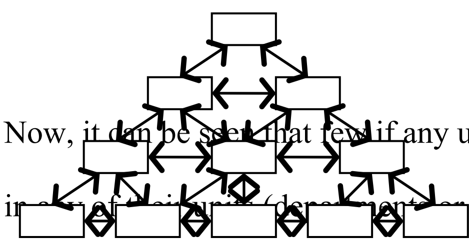
Finally there is *purposive* interdisciplinarity, when fields at the normative level are studied together, with consideration of ultimate goals for society coming from a field at the purposive level. An example is study in ethics relating directly to issues in planning and policy.



Purposive Interdisciplinarity

TRANSDICIPLINARITY

Erich Jantsch defines *transdisciplinarity* as the coordination of all disciplines and interdisciplines in the education/innovation system on the basis of generalized axiomatics (introduced from the purposive level) and an emerging epistemological pattern. It is multilevel *and* multigoal – the coordination of the whole system toward common goals.



Transdisciplinarity: multilevel coordination of entire education/innovation

Now, it can be seen that few if any universities … sciplinarity in any of their units (departments or colleges) or in the institutions themselves. Certainly it can be said that the undergraduate programs at most institutions teach at the empirical level: the main disciplines and departments are the individual sciences and humanities, that is, the natural and social sciences and the liberal arts. The pragmatic level is best developed at Institutes of Technology (like MIT and Caltech), where many of our engineers and architects come from. The normative level in education is not often found as a main thrust; however, graduate schools specializing in city planning, environmental design, or public affairs fit this role. It may be said that seminaries and religious schools teach at the purposive level and, certainly, values and morals are the common fare at such institutions as Berkeley's Graduate Theological Union. Programs such as UC-Berkeley's Peace and Conflict Studies are also focused at the purposive level. In any case, transdisciplinarity implies that an institution or a unit within an institution is devoted to the coordination of all four levels.

There is a more meaningful, descriptive way to characterize the levels than calling them empirical, pragmatic, normative, and purposive. The disciplines at the lowest level in the diagram bottom of <<page ??>> describe and seek to explain the world *as it is*. Here we learn about the physical laws of nature and the principles that have been discovered about life and society. As taught, these laws and principles are value-free. We can say that this level asks and answers the question, "*What exists*?" Through physics we know about quanta, through astronomy we know about quasars, and physical sciences tell us about laws of thermodynamics and of gravitation. Biology tells us about the evolution of life and how organisms defy entropy as open systems. On the other end of the horizontally arranged array, sociology and economics describe and explain the behavior of rational human beings. These are examples of how the question, "What exists?" is answered at the empirical level. The "language" which organizes this level is logic.

At the next level up, the disciplines are technological in nature. At this level the question asked (and answered) is, "*What are we capable of doing* (with what is known to exist)?" Thus, we know how to build dams, bridges, and freeways; we know how to construct irrigation systems in deserts; we know how to make powerful chemicals capable of exterminating any plant or animal on earth or on Mars; in fact, we are now capable of going to Mars to do the necessary spraying. The pragmatic level does not tell us *whether* we, as a society, think that these capabilities are expedient or should be implemented. For years, the Army Corps of Engineers and the Bureau of Reclamation in our Department of the Interior built dams almost willy-nilly, because there were engineers capable of doing so. The technological or pragmatic level provides the high standard of living that people of the developed world enjoy: the automobile without which we cannot get along, and the large amounts of available electricity we are now accustomed to. The organizing language for the pragmatic level can be called cybernetics, or machine-language, since this level emphasizes the machine-like properties of nature and society.

The normative level asks, "*What do we want to do* (with our technological capabilities)?" In a democratic society, the decision is often put to a vote. Society does not vote directly on whether a dam should be built on a particular river site; rather, it elects an administration which has a propensity for building dams or one which does not. One of the best things that came out of the Environmental Movement of the early 1970's was the advent of the environmental impact reporting process. Herein citizens have a say about what they want to have happen or not happen in their neighborhood; before, the dominant voice (never the majority) came from industry, commerce, developers – big business! Today society looks to the planning process and the development of sound policies to determine "what we want to do." The organizing language is planning.

The purposive level asks, "*What ought we to do*?" It looks beyond the self-centered society; it looks to the concerns of the unborn generations, for society in the long run, for the earth, and maybe even for our solar system. It considers economics as if people mattered. It seeks ethical answers. What would the organizing language be? Erich Jantsch thinks it should be anthropology in the profound sense (not the discipline found at the empirical level): the complete concern for the human species. I feel that this leaves out too much; it should be an idea that espouses deep ecology.

Is there somewhere in the world a transdisciplinary university?

CHAPTER 12 : HOLISM & REDUCTIONISM

Since the advent of television, computers, the Internet, and paperback books, our potential for communication has increased a thousand times since the first half of the 20^{th} century. Such communication should unleash reason, enlightenment, analysis, and adventure, all rolled into one golden age where we all approach omniscience. The environmental crises we face today prove the opposite to be true; it works more like an age of stupidity. The cases listed at the beginning of Chapter 2 are all disasters that occurred within the last twenty-five years.

Why did these events happen? Many factors have been singled out as reasons for ecological disasters and depreciation of our environmental quality. Controls of these factors have been singled out as solutions. But no matter how sweepingly conceived, single causes and single solutions will fall short of stopping calamities or of improving our situation. Why? Because we need an overview, a perspective that can come only with a holistic approach.

There are two kinds of people in the world: those who divide everything into two kinds, and those who don't.
Of the former, we shall discuss those who divide people into holists, on the one hand, and reductionists on the other. Of the latter, we must be aware that there might be some in-betweeners. However, you will see that if you want to make distinctions, important distinctions, the best way is to establish sharp dichotomies. Thus: holists versus reductionists. Some systems thinkers are holists; all holists are systems thinkers. Some reductionists are systems thinkers but never *whole systems*

Look back at some of the factors that have been considered single causes: population, technology, legal and political institutions, religion, education. Let's discuss each of them briefly in terms of whether we can treat them as "solutions" to environmental problems.

Population? Certainly, deterioration of environmental quality is caused by people. Population increases are exponential, still rising too fast for us to make suitable adaptations to our environmental constraints. Biologist Paul Ehrlich's books make the case for population control quite well. There is no need to repeat it here. However, under the most favorable conditions, it will take at least seventy years to stabilize the world's population. For our ecosystems, seventy years may be too late. Unless we do a lot more than reduce population growth, the quality of our environment will continue to deteriorate.

Technology? Yes, most of our environmental problems arise from technological feats. Engineers "reconstruct" our river systems; chemists outdo nature in synthesizing compounds for every need; and except for a few stubborn diseases, medicine has foiled nature's best strategy for population control. There are some who say, "Technology got us into this mess, and technology will get us out." In his classic essay "Tragedy of the Commons,"[1] biologist Garrett Hardin argues that there is no technical solution to the problem of freedom in a commons; in this case, to the problem of environmental deterioration of the planet.

Given a civilization that learns, it is inevitable that technology should advance. The real question is why "advancement" has taken the direction we have seen. Can technology itself answer that question? Perhaps not technology, but science can, says environmentalist and biologist Barry Commoner in *The Closing Circle* (1971). Science must be able to predict disasters and thus inform us what we can do and what we must not do.

Form of government? Indeed, governments aggravate environmental problems. A sluggish democratic society, where indifferent citizens hold up impetuous action, reacts perhaps too slowly and incautiously to a crisis. A totalitarian society can act quickly, and also incorrectly. As actual cases show, it makes little difference what kind of government is there. Lake Baikal in Russia and Lake Tahoe in the U.S., the two deepest, clearest lakes in the world, are going the same route – eutrophication and gradual death – for almost the same reasons. Both lakes have become dumping basins for people and industry.

The Aswan High dam in Egypt is as ill-conceived as any of the dam capers in America. Whalers are whalers, no matter what flag their ship flies. We must conclude that

[1] *Science*, 162:3859, pp. 1243-1248. 1968.

environmental problems the world over have common denominators other than form of government.

Religion? There is no question that religion is involved in the problem. In her classic essay, *The Historical Roots of Our Ecologic Crisis*,[2] Lynn White, Jr. blames Western civilization for responding to the Biblical mandate that man "subdue and have dominion over the earth."

Education? Education seems the most likely candidate for direct change. Modifying educational philosophies through changing curricula does not impede our freedom. It is quite different from revising our government, our religion, or our feelings about procreation. Indeed, we all agree educational changes are necessary and desirable. In fact, from time to time, we have demanded that they be made. This is not to say there would be no debate about the content of a new curriculum, as we had, for example, with the "New Math" movement of the early 1960's. Nor will it be easy to change curricula. Euclid's geometry and Newton's physics are so sensible and so satisfying to teach; our strong traditional disciplines are hard to set aside. They got us to believe that the natural way for man to think is in discrete blocks. It will be difficult to change from inward thinking (mechanism) to outward thinking (purpose).

Sound and lasting solutions to environmental problems will always be adaptive ones. Learning is adaptive. Population trends, technology, government, and religion inevitably will change. But to impose such changes abruptly from the outside presupposes a wisdom man does not have. Those four "solutions" are themselves

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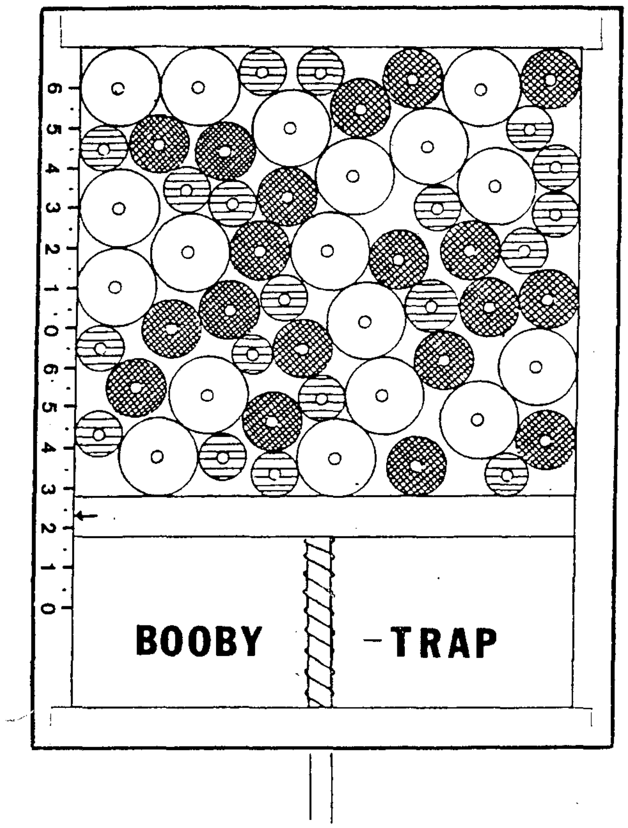
[2] *Science*, 155:3767, pp. 1203-1207. 1967.

dependent properties of the system they try to fix. This means that they will undergo adaptive changes, that is, evolution, along with the dependent biological and physical components of the ecosystem. It takes place through mutation and adjustment. The part education must play is to lubricate the processes of mutation and adjustment.

One of education's roles is to broaden our vision, to present all possible views of the world. The worldview which has had the least attention in our education system is the *holistic* one.

There is an interesting toy called the Booby-Trap. A set of discs is confined in a square tray. Constant pressure on one side of the tray forces the disks to assume a certain compact arrangement. In a game, a player removes discs, one at a time, in such a manner that the pressure bar is unaffected and none of the other discs are shifted in position. The degree of disturbance caused by a removal can be measured as a displacement of the bar along the ruler. Any disc that is independent of the others can be lifted out freely and nothing else will happen.



The object of the game is to find the least dependent members of the set. The rule is that this must be done by visual inspection of the set. If you happen to pull one which supports another member, the remaining discs abruptly “adjust” to a new pattern. For you, the jig is up. You’ve lost your turn.

In playing, some decisions are easy to make. Clearly there are discs more isolated than others and these can be manipulated without trouble. Then there are some whose independence seems probable though not definite; you would like to test them gingerly, but the rules won’t allow it. The crunch comes where all remaining members are known to be interdependent. What do you do then? Pass? Pluck one out at random? Try to figure out which one can be removed so as to cause the least disturbance? Change the rules of the game? Or simply refuse to play anymore?

Outside of the world of toys and parlor games is another world we seek to manipulate. Of course, the art of manipulating the real world – the ecosystem game – is not quite the same as playing a parlor game. The part about having to design a best strategy is similar, but the part about the rules is vastly different. In handling the real world, we actually know very few of the rules *a priori*. They are not given to us in a pamphlet that comes with the box containing the world. They must be discovered from the properties of the world itself. Likewise, the ecosystem game does not tell us how to declare the winner or loser. In the real world the loser is often the host, the non-playing third party, which is the world itself.

The Booby-Trap provides a good analogy for our manipulations of ecosystems. For instance, how many times have we pulled the wrong plug and thereby jerked the parts of our ecosystem into strange, new patterns? How crude are our conceptual tools for separating dependent and independent parts. We would like to think that all parts are independent because that would make the outcomes of our manipulations certain and singular. How lax we are in imposing stiffer penalties for bigger disturbances! We mitigate the catastrophic accidents perpetrated by man as easily as the catastrophic acts of God. Man does not often think seriously about losing the ecosystem game!

Now, after we have finally – and painfully – learned that all parts of our ecosystems are inextricable intermeshed, what do we do? Or, have we not really learned this idea yet?

Many of us decide to “pass.” This means we let the other guy make the move. Such a strategy has been going on between industry and government for a long time.

Sometimes we take the random shot-in-the-dark approach. Congress resorts to this occasionally. Sprays of bills are introduced which pepper away on all sides of an issue. The ones which carry are often passed for reasons unrelated to the qualities of the issues.

A logical strategy would involve figuring out what can be removed or added to a system while causing the least possible disturbance. Remember, however, that we have very little experience at doing things this way. Heretofore the emphasis has been on maximizing benefits minus costs, but costs have not been equated with ecosystem disturbances. Marketplace expenses are always considered and sometimes the most obvious of externalities are factored in as well. The strategy of manipulating with least disturbance is for ecology and economics to work out. As in Booby-Trap, it will be easy when dealing the simple systems which have few or remote parts. But with greater complexity, more sophistication is necessary to tackle the job. This is the domain of operations research which uses such techniques linear programming, computer simulation, and sensitivity analysis. There remains still another question, an ethical one: *Ought* we to add or remove anything from the system at all, let alone what and how much?

Occasionally we want to change the rules. For example, there are those who think we must change our Constitution, our laws, and our form of government before any true relief can be found from population and pollution problems. They are not willing to look for solutions within the constraints of these political sideboards.

The chapter on Complexity implied that complex systems can be broken down into parts, that is, analyzed, or simplified, as Isaac Newton did, by ignoring many of the parts. What if all the parts are necessary and the whole cannot be decomposed into separate subsystems? We suspect that ecosystems are such systems – they cannot be broken down and they cannot be simplified. They must be studied as *wholes*.

HOLISM

In 1926 Jan Christiaan Smuts, formerly the Prime Minister of South Africa, published a book entitled *Holism and Evolution*.[3] In it he developed the concept of holism which is usually expressed as the following statement: *The whole is greater than the sum of its parts*. This can be written in the form of an equation:

(1) $$[\text{The whole}] > \Sigma\,(\text{parts})$$, or

(2) $$[\text{The whole}] = \Sigma\,(\text{parts}) + x$$.

So what is x? We call it an *emergent quality*. Let us explain x by talking about a common chemical compound we know as water.

One of the properties possessed by any chemical compound is its atomic weight. A molecule of water has an atomic weight of exactly 18.01534. We can write this in the form of an equation:

[3] New York: Macmillan, 1926.

(3) at. wt. (water) = at. wt. (hydrogen) + at. wt. (hydrogen) + at. wt. (oxygen)

18.01534 = 1.00797 + 1.00797 + 15.9994

A very precise chemist might want to carry out the calculation to a few more decimal places, providing hir balance is sufficiently sensitive. In any case, *quantitatively* both sides of the equation are equal. In terms of equation (2), x is zero.

At ordinary room temperature hydrogen and oxygen are both colorless, odorless gases. When two atoms of H and one of O are joined, a liquid results. Liquidity is a quality, not a quantity. The x in equation (2) is the emergent quality we can call liquidness. The molecule of water has different properties than those possessed by its parts. Now if we dissociate water, the liquidity is lost and the gaseous atoms reappear.

Living organisms can be dissociated (as we decomposed the giraffe) into atoms of carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium, etc. Quantitatively, nothing is lost; but qualitatively, life is lost. The organism is no longer living.

Take a heap of bricks, a bag of mortar and a pail of water. Taken themselves and weighed separately each has its own special properties. But only when the bricks are cemented together and a wall appears, does a unique property emerge, namely, “wallness.”

Let us postpone for the moment further discussion about emergent qualities and get back to holism itself. We can play a little game called “I am holisticker than thou.” The point of the game is to think of a whole system and describe it completely. But it will never be complete, never whole, because another player can add something else. Then we realize that the infinite number of parts derive from how finely we divide them, that is, the level of resolution. Finally we realize that this is a senseless game, because maybe the parts are not the best way to conceive the whole. It reminds one of Zen. Zen is holism carried to its logical extreme. As we have seen, holism says that things (entities) can only be understood as wholes and not as the sum of many small parts. Zen goes on a step further: it says that the world cannot be broken into parts at all – it is completely non-decomposable, like the billiard ball construct we developed in Chapter 8, Complexity. Zen Buddhists will maintain that if we try to divide the world into parts, we miss Enlightenment.

THE FIRST LAW OF ECOLOGY

Is holism a fact? Is it a theory? Or is it a belief? Holism is now a buzzword and a concept not accepted by everyone. I am a strong believer (a disciple!) in the whole being greater than the sum of its parts, but I cannot prove it. It remains a belief.

Who else believes it? Ostensibly, many ecologists do, most environmentalists do, and all poets do. Barry Commoner in *The Closing Circle* lists the Four Laws of Ecology. The First Law states, "**Every thing is connected to everything else.**" This sweeping statement means that there is some level of bonding between all entities and events in the universe. It was said by Frances Thompson when he wrote in "The Mistress of Vision" that "**Thou canst not stir a flower without troubling of a star.**"

Science in general wants to believe that, except in machines, most events can be assumed to be independent while dependence must be proved. What would the world be like if it were the other way around: every thing is assumed to be dependent on everything else, and *independence* must be proved? This question is germane to our patent process. In applying for a patent, an inventor makes a claim as to what hir creation will do, that is, what it was invented to do. S/he does not have to show, or even mention, what else the invention can or will do. What if Nickolaus Otto, the German inventor of the internal combustion engine which was eventually used to power the modern automobile, had anticipated the effect his seemingly innocent device would have on smog in Los Angeles, on the proliferation of streets and roads in cities and countrysides, and on the incidence of fatal accidents on highways? No, neither Herr Otto nor the patent office was concerned about the consequences (dependencies) of the invention, only whether the claim was achieved, whether the invention served the use for which it was invented.

Economists for a long time were not concerned about costs that accrued outside of their system, and when these costs were eventually acknowledged, they came to be called *externalities*. Pharmacists and chemists talk about *side-effects* – unintended things that happen when their products are used – as if they were outside of the system.

Respect for the First Law of Ecology would tell us that there are no externalities and no side-effects; all are direct whole system effects.

Still another way to understand holism is to see it as an antidote to reductionism. This must wait until later in the chapter. Now let's turn to the notion of emergent qualities.

EMERGENT QUALITIES

The notion of *emergent quality* (sometimes called *emergent property*) has come to us by way of three philosophers and their books which have similar titles: Henri Bergson in *Creative Evolution* (1911), Lloyd Morgan in *Emergent Evolution* (1915), and Jan Christiaan Smuts in *Holism and Evolution* (1926). The concept was further explicated by James K. Feibleman in his short paper on "Theory of Integrative Levels" (1954), published in the *British Journal for the Philosophy of Science*. Without referring directly to these original sources, I shall write what understanding I have gleaned from all of them together.

Nobel prizewinners and chemists like Harold Urey, Stanley Miller, and Melvin Calvin have hypothesized the evolution of inorganic matter to organic compounds, starting with the elemental forms of H, C, N, and O in the atmosphere of the primitive earth, progressing through H_2, H_2O, NH_3, CO_2, and CH_4, thence to formaldehyde and amino acids, and on to complex polymers, and so forth (recall the discussion from Chapter 9). At each evolutionary step two things are evident: the new arrangement of atoms and molecules is novel, i.e. it has never occurred before, and the new compound has properties not possessed by the parts that make it up. These new, never-before-seen properties are the emergent qualities that we have been talking about. They are qualitative rather than quantitative in character. For instance, when the single atom of carbon and the four odorless atoms of hydrogen come together to make smelly methane, no matter is lost or gained – the atomic weight of methane is exactly equal to the sum of C and 4 H's. Yet many of the properties of methane are different than any of those of carbon or hydrogen alone. Even if only one property was new and different, it would be an emergent quality. Thus, an emergent quality arises when in the process of evolution, the product (i.e. the newly created entity) has some (at least one) attribute which none of the building blocks had. Lloyd Morgan stipulated as part of the definition that the emerging property must be unpredictable from knowledge of the parts, but I don't see the necessity for stipulating non-predictability. The thing we call life (actually it's a quality, not a thing) emerged from non-living matter: it was definitely a new property, and certainly different from the organic molecules comprising it, but as to its predictability, what difference does it make? (Discounting the fact that there were no predictors around when it first happened.)

Examples given thus far have been naturally occurring instances of emergence: inorganic evolution has led to ever-increasing complexity (more to say about this point later), each incremental step involving one or more emergent quality. These qualities emerged without enhancement by the human mind. But we must also consider an entirely different class of emergent properties, namely those constructed by the human mind. When we mentally aggregate individuals into populations, we derive birth rates, mortality rates, densities, and frequency distributions. And when we aggregate populations into communities as plant ecologists and sociologists have done, we derive such "measures" as constancy, fidelity, diversity, and homogeneity. These are all attributes of certain organizational levels which have no meaning at the organizational level below. An individual has no mortality rate; it applies only at the population level. Similarly many of the plant biologists' measures apply only at the community level. For example, one could say that density as a property (or quality) of a system emerges at the population level.

Related to this point is the concept of *relationship* in systems language. A system has three components: objects, attributes, and relationships. For instance, in natural systems, the objects are real; they may be trees, or birds, or protons. The attributes also are real enough, although we choose which attributes we wish to measure. The relationships, however, are mentally constructed and expressed as ratios (e.g., C/N), as indices of various kinds, or as regression or correlation coefficients. So what happens, in effect, when we conceive a system is that we select a certain set of objects and/or their attributes because we think they bear a certain relationship to each other. These relationships "emerge" from the conceptual act of putting the objects/attributes together. In my Ecosystemology class I have one lecture on systems terminology. I use a set of tinker-toys. The spools represent objects, their various colors are attributes, and the rods represent abstract relationships. When the rods connect the spools in some new arrangement, the system itself takes on properties which the loose pile of spools did not have before. Thus, I think of the relations in systems as emergent qualities, similar to the derived mental constructs described in the previous paragraph.

RELATION BETWEEN EMERGENT QUALITIES AND COMPLEXITY

This can best be stated by quoting from James Feibleman in his "Theory of Integrative Levels." The first two laws are given as follows: (1) *Each level organizes the level or levels below it plus one emergent quality*, and (2) (a corollary), *Complexity of the levels* *increases upwards*. The supposition is that through evolution the integrative levels accumulate upwards, that is, become more complex. The two laws taken together state that the higher levels become more complex from the incremental adding of emergent qualities, not from adding more objects. Simply adding more bricks to the wall does not make the wall more complex. Adding a third dimension (three more walls and a roof) to form a building, i.e. adding "buildingness" to "wallness," makes the whole structure more complex. This is why we consider humans (and maybe also cetaceans) to be the most complex of organisms, because the emergent quality of mind has been put on top of the emergent quality of life.

Even if we allow that simply adding more objects (more bricks) to the respective levels make them more complex, this increase in complexity will only be linear. On the other hand, if we see the emergent qualities such as relationships, the resulting increase in complexity will be exponential. This, in fact, is taken into consideration by the Shannon-Weaver Index, a measure of ecosystem diversity. The Shannon-Weaver Index captures the uncertainty of a randomly chosen individual being of the same species as an initial randomly sampled individual, thus reflecting the diversity in relative abundances of species in the area as well as the sheer number of species.

EMERGENT QUALITIES AT THE ECOSYSTEM LEVEL

We can now put the question: are there any non-trivial emergent properties at the ecosystem level that do not obtain at levels below? Thinking about this question will involve ideas brought up in Chapter 6, Ecosystems. The reader may wish to review that chapter and then come back to this point.

One September evening Wes Jackson, Hans Jenny, ecologist Stan Rowe, historian Joan Scott and I were driving up to the Ecosystemology Caucus at Comptche (in Mendocino County), and the aforementioned question came up. I have re-read carefully Joan's notes of the entire caucus, and I must confess that I didn't get much enlightenment from our discussions about emergent qualities. Yet it is fair to say that when four principal "experts" on ecosystems get together and spend so much time on one topic, it has a good chance of being something important.

Let me ask the question a different way. Why are we not studying the pygmy forest on an individual basis, that is, plant by plant or population by population? Or why are we not studying it as a plant community? Have we ever explicitly stated why we chose the ecosystem level for studying the pygmy forest?

The answer must be something like this: Studying individuals or populations, or the soil as a separate entity, does not answer some of the crucial questions about the pygmy forest. For instance, it is unlikely to tell us how the soil, the vegetation, animal populations and other ecosystem properties evolved together. Similarly, the methodology of plant community ecologists puts undue emphasis on vegetation processes over, say, geological processes. The time scale that community ecologists have used to build their theories is very short, consequently the ecologist's climax falls short of a true steady state. In other words, *ecosystems have special properties which are not discernible at the level of community, population, or individual*.

Now we come to the hard question. What are those special properties? According to what I have been teaching my ecology students all these years, there are at least four such properties. One, perhaps the most important one, is *self-regulation*. This I found to be especially relevant in my study of the Arctic tundra ecosystem. In fact, I think it could be called *sustainability*. Self-regulation is meaningless in terms of the plant community or in terms of species populations. A second ecosystem property is *diversity*. Of course, community ecologists also talk about diversity, but they mean only variety of organisms. In an ecosystem context, diversity includes the heterogeneity of soil types, pH "species," management treatments, etc. It is a much richer concept than species diversity. A third property is *productivity*. Contrary to usual opinion, productivity is not just characteristic of the crop, of the genotype, of the species. It depends on the fertility of the soil, the amount of moisture in the system, the temperature, etc. Thus it is a bona fide ecosystem property. The last one is *stability*, including related qualities such as resilience. Like diversity, stability means much more when applied to ecosystems than to communities or populations. There may be additional properties to these four.

These important emergent properties of ecosystems justify our use of the ecosystem level for studying nature. Intuitively, we know that this is the proper level to use in studying the marine terraces of the Mendocino coast or in establishing an agriculture that simulates tall grass prairie.

John Harper, a Welsh ecologist and geneticist, states that the holistic approach is safe but ignorant. The best retort to that statement I have ever seen was written by the French philosopher Albert Camus in his essay, "The Myth of Sisyphus" (see box on next page).

Of whom and of what indeed can I say: “I know that!” This heart within me I can feel, and I judge that it exists. This world I can touch, and I likewise judge that it exists. There ends all my knowledge, and the rest is construction. For if I try to seize this self of which I feel sure, if I try to define and to summarize it, it is nothing but water slipping through my fingers. I can sketch one by one all the aspects it is able to assume, all those likewise that have been attributed to it, this upbringing, this origin, this ardor or these silences, this nobility or this vileness. But aspects cannot be added up. This very heart which is mine will for ever remain indefinable to me. Between the certainty I have of my existence and the content I try to give to that assurance, the gap wilt never be filled. For ever I shall be a stranger to myself. In psychology as in logic, there are truths but no truth. Socrates’ “Know thyself” has as much value as the “be virtuous” of our confessionals. They reveal a nostalgia at the same time as an ignorance. They are sterile exercises on great subjects. They are legitimate only precisely in so far as they are approximate.

And here are trees and I know their gnarled surface, water and I feel its taste. These scents of grass and stars at night, certain evenings when the heart relaxes — how shall I negate this world whose power and strength I feel? Yet all the knowledge on earth will give me nothing to assure me that this world is mine. You describe it to me and you teach me to classify it. You enumerate its laws and in my thirst for knowledge I admit that they are true. You take apart its mechanism and my hope increases. At the final stage you teach me that this wondrous and multi-colored universe can be reduced to the atom and that the atom itself can be reduced to the electron. All this is good and I wait for you to continue. But you tell me of an invisible planetary system in which electrons gravitate around a nucleus. You explain this world to me with an image. I realize then that you have been reduced to poetry: I shall never know. Have I the time to become indignant? You have already changed theories. So that science that was to teach me everything ends up in a hypothesis, that lucidity founders in metaphor, that uncertainty is resolved in a work of art. What need had I of so many efforts? The soft lines of these hills and the hand of evening on this troubled heart teach me much more. I have returned to my beginning. I realize that if through science I can seize phenomena and enumerate them, I cannot for all that apprehend the world. Were I to trace its entire relief with my finger, I should not know any more. And you give me the choice between a description that is sure but that teaches me nothing and hypotheses that claim to teach me but that are not sure.

From *The Myth of Sisyphus and Other Essays*, tr. Justin O’Brien.
New York: Knopf, 1955.

CONCLUSIONS ABOUT THE VALUE OF EMERGENT QUALITIES

I sometimes ask my students how they would measure the temperature of an atom – where would they stick the thermometer? One answer, of course, is that atoms by themselves do not have temperatures. Here is a phenomenon that occurs (emerges?) only at the molecular level. It would be nice to have some kind of meter to "stick" into an ecosystem and get a quick reading on some distinct emergent quality of that system. No one has come up with either the technique or the instrument.

The problem has to do with our ability to perceive as well as our ability to conceive. Ecosystems are largely full of air, which is transparent. When we are looking, our vision stops at the boundary of the tree, the deer, the rock, the soil surface. These are the objects which we name, classify, and measure. It is impossible to see the whole ecosystem because our line of sight stops at the part. We have few, if any, terms for whole-system phenomena, let alone ways to measure to them.

I have thought that one good way to get a "holistic" measure of ecosystems for comparative studies is to get total heat output with infrared remote sensing. By photographing in daytime and at night one could separate the reflected heat from the heat held by the system. This is an example of an emergent quality that could be useful for ascertaining catabolic or anabolic trends of whole ecosystems of any size. It seems to me that one has to think in terms of emergent qualities in order to devise such measurements.

REDUCTIONISM

Often a textbookish definition is not the best way to grasp an idea, in this case the distinction between holism and reductionism. Douglas Hofstadter, a cognitive and computer scientist who is also a science historian and philosopher, borrowed a technique from Lewis Carroll in *Alice in Wonderland* for his book *Gödel, Escher, Bach: An Eternal Golden Braid*,[4] and created a cast of characters whose animated dialogue presents the essence of complex ideas easily. In "Ant Fugue," Anteater says: "Reductionism is the most natural thing in the world to grasp. It's simply the belief that a whole can be understood completely if you understand its parts, and the nature of their 'sum.' No one in her left brain could reject reductionism." This was said in rebuttal to Crab's defense of holism.

Crab had said: "Holism is the most natural thing in the world to grasp. It's simply the belief that the whole is greater than the sum of its parts. No one in his right mind could reject holism."

Population scientist Richard Levins and biologist Richard Lewontin in *The Dialectical Biologist*[5] said:

> "Despite the repeated demonstration in philosophy of the errors of vulgar reductionism, practicing biologists continue to see the ultimate objective of the study of living organisms as a description of phenomena entirely in terms of individual properties of isolated objects.

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[4] New York: Vintage Books, 1979.
[5] Cambridge, MA: Harvard University Press, 1985.

"In ecology reductionism takes the form of regarding each species as a separate element in an environment that consists of the physical world and of other species. The interaction of a species and its environment is unidirectional: the species experiences, reacts to, and evolves in response to its environment. The reciprocal phenomenon, the reaction and evolution of the environment in response to the species, is put aside."

Hans Jenny, a soil scientist, did not have this pure biologist's bias. He saw that soil (as environment to plants and animals) did respond to the species, as well as the species responding to the soil – an ecosystem. His 1980 book *The Soil Resource* illustrates this idea perfectly. The first half of the book is reductionist and treats soil formation at the molecular level; the second part is holistic and deals with the whole system.

Holism and reductionism: two opposite ways to look at the world. Is one way more "right" than the other? (And if so, does that make the other way wrong, or just left-brained?) The reader may find a more clear position on this question after reading and pondering the concluding chapter.

CHAPTER 13 : TRANSFORMATIONS

FOUR STORIES FROM THE JOURNAL OF COMPLEMENTARITY

Niels is the general science teacher at the local high school. With his boundless enthusiasm, he always manages to get most of his pupils to submit projects for the Science Fair. One day, in his physics class, Niels was explaining the nature of color when suddenly he had a brilliant idea. “This subject of color is of interest to everyone who attends the Fair. Why don’t some of you team up and demonstrate what color is. You have one week to prepare a project.” Two boys immediately volunteered, Ike and Wolfgang. The younger boy, Wolfy, went to his father’s paint store and got a wide variety of pigments; his idea was to demonstrate the sensuous perception of color and show how people’s feelings about color define what color really is. “Nonsense,” said Ike. “We all know it’s nothing more than wave lengths of refracted light. The color of the sky and of grass is there, even if there were no eyes to see it. If we want to win we’ve got to be intellectual about this.” The boys’ arguments got more and more heated and it looked like they would never come to an agreement. Finally Niels had to intercede. “You are both right,” he said, “but I think it best for you to enter as separate projects instead of trying to work together.”

Robert O. is a very wealthy man. He owns lots of land in one state in the West, second only to the U.S. Government. But Robert O. is a good guy. He does good things with his money. He is known as a philanthropist. Once he bailed out a famous old monthly magazine that was about to go under and now we can all enjoy the Harper's Index. Robert O.'s money fueled the Aspen Institute, an organization of great intellectual value to the world. The things that he has done have improved the quality of life for many people – isn't that what philanthropy is all about? A friend once asked me, "What does the 'O.' stand for?" I said, "Oil, man, oil. He's one of the richest men in America, and it all came from oil!"

Salvatore is a consultant. The first time I ran into him was in court where he testified on the behalf of the gas and electric company in a suit brought against the company regarding supposedly irreversible damage to the landscape. Sal was well armed with data, charts, and affidavits from a variety of credible sources. His arguments were most compelling. One could see that he believed devoutly in every point he was making. It is fair to say that his testimony easily won the case for the utility company. Eight weeks later I encountered Sal again, in the very same courtroom. Now he was on the other side; he was the expert witness *for* a well-known environmental club which was suing another utility for damaging the landscape. And he was using the practically the same evidence he had used in the first case, but in the opposite way. I recognized one of the graphs; he had the slide upside down and backwards in the projector. "Sal," I said to him, "doesn't this bother you at night, or on Sunday morning, this switching from side to side?" "Not really," he answered. "There are always two sides to every question, and two sides on which one can stand. I am able to stand on both sides. Isn't that what complementarity is all about?"

Two young physics professors, bored with their menial task of being potential Nobel Prize winners, decided to take up hobbies to relieve their boredom. They enrolled in a night pottery class. It was fun at first, but as they got better at throwing pots they became quite competitive about their creations. One of the men became skilled at making vases. “Ha,” said he to the other. “I’m sure you can’t make as fine a vase as this one.” The other said, “Your boast is silly. You made this vase out of clay; I can make a vase out of clay; I can make vase out of nothing! I’ll show you.” So he made two human heads with big noses and prominent chins. The busts were identical. After the figures were fired he set them facing each other. “Ah,” muttered the first physicist. “I see the vase in between. Very clever indeed.” By and by they became disenchanted with their hobbies and went back to the laboratory where they worked on the phenomena of light. One set up apparatus that showed light diffracting, which proved that light was a wave phenomenon. The other set up photon scattering experiments, proving that light was a particle phenomena. Again, a vicious competition fumed between them, with heated arguments regarding the true nature of light. Finally their department chairwoman advised them to retire to the campus pub and fight it out amicably over a beer. The bartender overheard the argument about light and came to their table. “Gentlemen,” he said, “you are both wrong. Lite tastes great and is less filling *all at the same time*!”

NIELS BOHR AND THE CONCEPT OF COMPLEMENTARITY

We know of no Journal of Complementarity, but if such a periodical had existed, its editor might have been Niels Bohr. Bohr, a Danish physicist who was born in 1885, won the Nobel Prize for physics in 1922. Among his many discoveries and accomplishments, Bohr noted the conflicting results that were showing up in elementary particle physics. Contradictory observations that were being made on light are the best known examples.

During the 19th century the wave model of light gained almost universal acceptance among physicists. This model was supported by experiments as well as by theory. Scottish physicist James Clerk Maxwell demonstrated the electromagnetic character of light waves in 1873, validating earlier physicist Michael Faraday's ideas and unifying ideas of electric field, magnetic fields, and light within a single theory. Older scientists advised young would-be scientists to go into fields other than physics, since there seemed to be nothing new or important to discover in that discipline.

However, at the beginning of the 20th century some new properties of light were discovered. These could not be explained when light was seen as a wave phenomenon. They could only be explained with a particle or corpuscular theory, in which light was seen as particles or photons. These photons were found to contain energy and momentum localized in discrete packets, resembling many other material particles in elementary physics.

What a dilemma! How could this be – two models of light which were diametrically opposed to each other, but each *successfully* explaining the phenomenon of light! Along came Bohr and the new field of physics, *quantum mechanics*, to point out the problem. Bohr realized that in physics or in any other field, one model may never be adequate to describe the nature of the phenomena. The wave model gave the correct interpretation when the equipment and techniques to measure light was of a certain kind. With other ways of measuring, the different corpuscular model gave correct results. What it amounts to is simply a different way of looking at something.

Sir Isaac Newton explained color strictly as a wavelength phenomenon, but Johann Wolfgang von Goethe (1749-1832), a German poet, painter, physicist, and theoretician, was not satisfied to see colors as objective phenomena that existed outside of the involvement of the eye. Both were brilliant men: their technique, their results, and their arguments impeccable. Who was right? Both were.

In his book *Atomic Physics and Human Knowledge*,[1] Bohr states that the concept of complementarity can be applied to situations other than just physical ones. In chemist Thomas R. Blackburn's article "Sensuous-Intellectual Complementarity in Science,"[2] he applies complementarity to countercultural epistemology and its difference from the "value-free" scientific orientation. Blackburn lists seven characteristics which define complementary realities:

1. A single phenomenon (for example, light) manifests itself to an observer in conflicting modes (e.g., as "waves" or as "particles").

2. The description or model that fits the phenomenon depends on the mode of observation. (In this way, the idea of objectivity is somewhat broadened but not eliminated.)

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[1] New York: Wiley, 1958
[2] *Science*, 172:3987, pp. 1003-1007. 1971.

3. Each description is "rational," that is, language (including mathematics if necessary) is used according to the same consistent logic in either description, with no appeal to revealed truth or mystical insight.

4. Neither model can be subsumed into the other. Thus, for example, classical and statistical thermodynamics do not constitute complementary formulations, even though they can be developed from apparently independent axiomatic bases.

5. Because they refer to a (presumably) single reality, complementary descriptions are not independent of each other. For example, the differential equation of wave motion used in the description of an electron in an atom must be "normalized," that is, its integral over all space must correspond to the quantity of mass and electrical charge carried by one electron.

6. Complementarity is not mere contradiction. The alternate modes of description never lead to incompatible predictions for a given experiment, since they arise from different kinds of experience.

7. It follows from (6) that neither complementary model of a phenomena is complete; a full account of the phenomena is achieved only by enlarging the frame of reference to include both models as alternative truths, however irreconcilable their abstract contradictions may seem.

Fritjof Capra, in his now classical book *The Tao of Physics*,[3] makes the following controversial statement about the concept of complementarity:

[3] New York: Random House, 1975

> "The notion of complementarity has become an essential part of the way physicists think about nature and Bohr has often suggested that it might be a useful concept also outside of physics; in fact, the notion of complementarity proved to be extremely useful 2,500 years ago. It played an essential role in ancient Chinese thought which was based on the insight that opposite concepts stand in a polar (that is, complementary) relationship to each other. The Chinese sages represented this complementarity of opposites by the archetypal poles *yin* and *yang* and saw their dynamic interplay as the essence of all natural phenomena and all human situations.
>
> "Niels Bohr was well aware of the parallel between his concept of complementarity and Chinese thought. When he visited China in 1937, at a time when his interpretation of quantum theory had already been fully elaborated, he was deeply impressed by the ancient Chinese notion of polar opposites, and from that time he maintained an interest in Eastern culture."

Capra has detractors who feel that the Eastern philosophers and the Western physicists are far more opposite than Capra thinks. The critics say that it takes a distorted view of modern physics to draw the close correspondence with Taoist and Buddhist thought that Capra sees. However, if complementarity means any situation that has opposites, yin and yang fit the term as well as wave and particle theory of light.

TESSELLATIONS

M. C. Escher has used the figure-ground phenomenon in a large number of sketches. These are called *tessellations*, perhaps derived from the term *tessela*, the interlocking tiles in a Byzantine mosaic. Americans were first introduced to Escher in 1958 when one of his celebrated tessellations appeared on the cover of Scientific American. It showed variously colored geese flying to the right and white geese flying to the left. Other motifs used by Escher subsequently were boxer dogs, knights on horses, and butterflies. In tessellations the dark and white figures are the same size and shape. It is the color which differentiates figure and ground.

COMPLEMENTARITY IN EVERYDAY LIFE

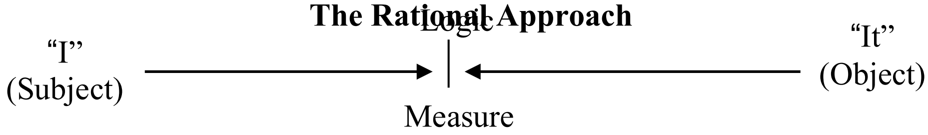
In the chapter on Paradigms and Paradigm Shifts (page <<??>>) we showed a lens which determined what we perceived, that is, determined our reality. The same actual events passing through two different perception screens or "lenses" will present different realities, even different truths to respective lens-holders.

Nowhere today is complementarity in daily life more apparent than with environmental concerns. Confronted with the same problem statements and datasets, environmentalists have different perceptions than those of developers and those of some bureaucrats. Try to apply the seven characteristics given by Blackburn to issues like oil drilling in the Alaskan National Wildlife Refuge, clearcutting of timber in the Tongass National Forest, or any event in tomorrow morning's newspaper.

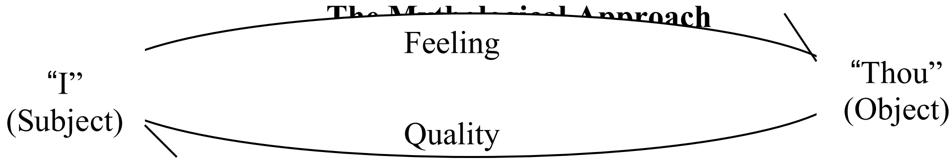
MODES OF INQUIRY

Now we shall look into the different modes of inquiry, the possible ways to ask questions and do research. These approaches are concerned with the relationship between the subject and object, between observer and observed. In fact, the basic modes of inquiry depend on differences in perception. Erich Jantsch in *Design for Evolution*[4] calls the three modes the rational, the mythological, and the evolutionary. See the following diagrams:

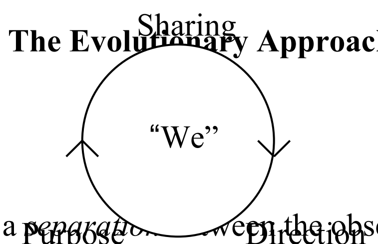
The Rational Approach



The Mythological Approach



The Evolutionary Approach



The rational approach:

> assumes that there is a *separation* between the observer and the thing observed;
> focuses on an impersonal "it" which is supposed to be assessed objectively and without involvement by the outside observer;
> is organized by the basic principle of *logic* (recall the empirical disciplines in the Transdisciplinary University of Chapter 9);
> the results are achieved by *measuring* and are expressed in *quantitative* or structural terms;
> the dynamic aspects are perceived as *change* (refer to Bateson's Theory of Learning in Chapter 8).

The mythological approach:

> establishes a *feedback link* between the observer and the observed;
> focuses on the relationship between a personal "I" and a personal "Thou";
> is organized by the basic principle of *feeling*;
> the results are obtained through *feeling* and are expressed in *qualitative* terms;

[4] New York: George Brazilier, 1975

the dynamic aspects are perceived as *process* or order of change.

The evolutionary approach:

establishes a *union* between the observer and the observed;
focuses on "We" which combines the pronouns "I" and "Thou" – "We" represents
identity forces acting within the world of the observer and the observed;
by virtue of this identity, the organizing principle is *tuning-in*;
results are expressed in terms of *sharing*;
the dynamic aspects are seen as *evolution* or order of process (or order of order of change).

The rational approach gives a detached view, taking the posture of being value-free; it is not interested in purpose. It is this perspective that has divided the world into disciplines. It has spawned an objective science that permits the complex nature of the world to be blamed on something called chance, out of which some order can be abstracted, namely the natural laws. These laws are assumed to be in force forever; in other words, the rational approach is geared to a static system – very convenient for scientists who seek to unravel the world's unchanging structure.

Science has taught us very little about the dynamics of processes and nothing about changes in structure which these processes have brought about. Are the laws which we call "natural" and assume to be unchanging really eternal, or do we think they are static because we feel more comfortable with static things? Suppose the law of gravity were to change over time (not just the law, but the phenomena from which the law is derived); or, say, the second law of thermodynamics! If we could travel to another galaxy, might the laws we calculate there be different than those derived from our solar system (check with Isaac Newton and his simplifying assumption, Chapter 9)? It sounds preposterous, doesn't it? Well, our experiences with paradigm shifts occurring through human history suggest that it could happen, although the rational approach tells us it is impossible!

The mythological approach gives better access to an undivided, holistic reality which includes personal people ("I's") and personal things ("Thous"). It explores the wealth of qualities arising from our psychic response to the world, with which we directly interact. It corresponds to the existential view of life – to the conditions of human activity in a world which is "happening to them." Even today in this extreme scientific/technological age, we are largely living in a mythological everyday world, where order is built from subjective qualities. Scientists are rational at the office, in the lab, and in front of the classroom; most are mythological at home. We came across one example of the mythological approach in the section on complementarity, where Wolfgang Goethe's theory of colors considers the human interaction with the "reality" of wavelengths.

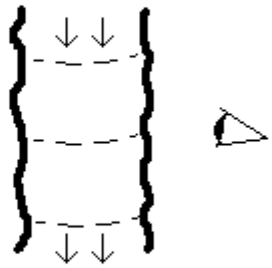
The origins of art and religion are found in the mythological mode of inquiry. As people interact with the world, the world gives something back. We see this kind of questioning being applied by deep ecologists. Farmers who feel bonded to their land have long used this approach. But farmers do not have to publish in order to be promoted (to what?). They won't perish by not doing research; the potato farmers in the Peruvian Andes do research, breeding hundreds of varieties of potatoes, but they do it to subsist rather than to advance in their careers. Farmers' peers are their neighbors who also see the "Thou"-ness in their land. A new kind of relationship develops when farmers or even scientists begin to see the “spirits” in plants, emotions in animals, and soul in the soil. But don’t hold your breath – Universities are not yet ready to accept journals that publish the results of mythological inquiry.

The evolutionary approach to inquiry considers the psychic activity as an integral aspect of the evolutionary forces that are active in the world. It has the sense of participation in the evolutionary process, that is, psychic activity makes evolution happen and gives it direction. The evolutionary mode justifies the creativity that comes from within us.

The altruistic cooperation and sharing that is characteristic of the evolutionary mode of inquiry is still a long way off from dominating any significant part of our society. In *Design for Evolution*, Erich Jantsch has done great service by putting the evolutionary mode of inquiry on par with the mythological and the rational. As with lateral and vertical thinking, where one should not be used to the exclusion of the other, so it may be said that, on suitable occasions, any or all three of the modes may be useful. Jantsch has noted that the fragmented world of scientific disciplines is of great value for the holistic, mythological world of integral qualities. If we use the systems approach or the dialectic approach, either of these can provide methods for elevating the knowledge from the rational to be applied to the mythological. This, in fact, is implicit in the meaning of interdisciplinarity: the transition from the rational to the mythological. The transition from the mythological to the evolutionary, has not yet found a valid methodology.

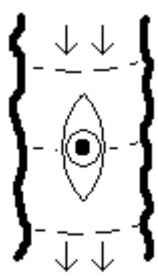
There is one additional image that Jantsch uses to differentiate the three modes of inquiry – the image of the life stream (see below). With the rational approach you are standing on the bank of the stream watching the water go by. You do not get wet (you are uninvolved) and you take no side as to what is happening (since science is value-free).

Observer is on a bank
of the stream



With the mythological approach you are in a boat in the stream. You try to steer the boat as it is buffeted about by the current. You have no sense of direction except that you are drifting downstream, and you try to use information from either bank. You are definitely involved (you get wet).

Observer is in a boat
in the stream



With the evolutionary approach you are not watching from the bank, you are not in a boat in the stream, YOU *ARE* THE STREAM! You are the source, the current, the flow, the carrier of boats and the carried, the whole stream and at the same time only a wee holographic part of it.

Observer is the stream

The rational approach does no centering whatever; the mythological tries to center between the opposites; the evolutionary tries to center the process itself.

We can learn much from these three modes, but “enemies” are encountered on the way to learning. The first enemy is fear. There is such a complicated mass of knowledge to comprehend, sometimes leading to holistic paralysis, the dread disease of interdisciplinarians. If things are made clear, the fear is lessened. But clarity is the second enemy. One becomes content with the simplified, static model of what one thinks is true. Clarity is overcome by attempting to put the knowledge into action. By forcing the clarified knowledge to work (implementation) one tends to lose the clarity and gain power. We all know the many ways in which power is an enemy. Finally, as told by Don Juan in Castenada’s books, we get to the last enemy: Old age. Does anyone know of a way to overcome old age? Let me know.

BEYOND TRANSDISCIPLINARITY

Let’s review some of the themes that run through Ecosystemology. A prominent one is evolution.

In his book *Holism and Evolution* Jan Christiaan Smuts wrote about the three great evolutionary leaps that were made here on earth. He called them the “phenomena” of *matter*, *life*, and *mind*. Smuts observed that these phenomena appear to be genetically related and gave rise to each other in a series of stages of evolution. In disciplinary terms he put them into physical, biological, and psychical (mental) categories. Then Smuts asked, “What will be the next great leap, one that would be of the same magnitude of difference from mind as mind is from life or life is from matter?” We may ask in turn whether our collective mind is capable of predicting a novelty of such magnitude, yet Smuts gave it a try. He suggested “beauty.” Well, we already know a lot about beauty today. I posed the same question to students in the Ecosystemology classes. The most frequent answer by individuals was *spirituality* and this was also the consensus answer.

Smuts did not seem to wonder about the front end of the series, namely “what came before matter?” or “matter was a great leap from what?” (He apparently was satisfied with Genesis author’s command: “Let there be matter.”) Years after the 1925 publication of *Holism and Evolution*, the famous Stanley Miller-Harold Urey experiment and Melvin Calvin’s research (Chapter 10) described inorganic evolution, leading from simple molecules to very complex ones, including organic compounds which preceded life. Research clearly supports Smuts’ observation that the three “phenomena” are genetically related and gave rise to each other. The transition from matter to life has occupied scientific investigation for centuries and is fairly well documented. The study of the transition from life to mind has been underway since about 1970. The work to date is told by Edward O. Wilson in his book *Consilience: The*

Unity of Knowledge.[5]

The Big Bang happened four and a half billion years ago. The first sign of primeval life is dated at three billion years ago. The first sign of brain expansion (in *Homo habilis*) is dated at 2.5 billion years ago and in *Homo erectus* 1.8 billion years ago. Thus, matter building up to life took 1.5 billion years and life up to mind from 0.5 to 1.2 billion years. Organic evolution has been a very slow process. In fifty years brain scientists working with fast computers can traverse the equivalent of hundreds of years of organic evolution. Let's say that the work described by Wilson brings us completely up to date on what we know about the mind. What about the **beyond**? Will artificial intelligence help us to predict what the next "great leap" will be? Or do we have it already? Will Artificial Intelligence tell us that it will be *superbeauty*? I can't wait.

Not too long ago, most scientists thought that *mind* as a concept should be left to philosophers, but now the issue has been joined where it belongs, at the juncture of biology and psychology.

Another theme that has been prevalent throughout this entire book is education. The underlined part of the sentence above, especially the work *juncture*, is what this chapter is mainly about. Many students major in biology, others major in psychology, chemistry, physics, etc. but how many choose to major in the junctures between these fields? In 1986 I read an article by Frederick Turner in the September issue of *Harper's Monthly* magazine. "The Design for a New Academy" is subtitled "An End to Division by Department." It happens that Turner is a poet. He describes the contemporary

[5] New York: Vintage, 1998

university metaphorically as a broad pasture divided into separate fields by departmental fences. The model emphasizes the high degree of specialty that exists within each field and because society condones it and thinks it is good, the managers can not bring themselves to change it. A closer examination reveals growing evidence that if the fences were removed, the fodder in each field would show only slight differences at the edges. In fact, suggests the poet, the model should look more like a pyramid.

Recall Erich Jantsch's pyramidal diagram of the transdisciplinary institution. The empirical "fields" at the base are integrated into pragmatic disciplines, and these again are integrated at a purposive level. These steps up the pyramid connote coordination of the lower levels from the higher, not the other way around. This is what Jantsch calls the essence of interdisciplinarity. "It has to be understood as a teleological as well as a normative concept, which means asking *interdisciplinary to what end*? Another way to say this is that a sense of purpose is introduced when the common axiomatics for a group of related disciplines is defined at the next hierarchical level."[6] So within the hierarchy, purpose is given to each level by the level immediately above.

In the Complexity chapter we explored the rationale for hierarchical versus relational ordering. Jantsch connects the levels through what he calls the vertical organizing languages, namely logic, cybernetics, planning, and purpose. The idea of an educational institution organized in this way made much sense to me. In fact, during one of the repeated reorganization attempts made by the College of Natural Resources at Berkeley,

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[6] From "Inter- and Transdisciplinary University: A Systems Approach to Education and Innovation." Ekistics, 32: 430-437. 1971.

I proposed a modified version of the transdisciplinary university á la Jantsch, but it didn't even pass the first stage of consideration by the committee in charge. The British systems philosopher Stafford Beer once said, "For any organization or idea, the highest point of its value comes at the moment of its conception, and it's all downhill from there." Today transdisciplinarity is a concept that has much merit, but there are too many obstacles to overcome on the road to implementation. Perhaps we should jump over it. That's why I have called this section "Beyond Transdisciplinarity." I think what I have been looking for is something deeper than the juxtaposition of disciplines according to vertical organizing languages. Which brings me back to Frederick Turner, the poet.

Frederick Turner's "Design for a New Academy" comes close to what I mean. Turner says that our education misses the sense of cognitive unity which imparts meaning to the world. He explains that in the last several hundred years great advances have been made – especially in the sciences but in other disciplines as well – that have torn down the barriers between disciplines, but alas, all that has happened at our colleges and universities is further fragmentation and specialization. It is clear that Turner knows science better than most scientists know poetry. He describes the vertical unity – from mathematics to chemistry to biology to anthropology to the arts, then to religion – which is denied by those fundamental metaphors as "fields of study," "departments," or "specialties." His picture of the hierarchy of the universe resembles Jantsch's transdisciplinary model, religion at the top, but it emphasizes more the horizontal unity of the empirical sciences at the bottom. Turner's conclusion goes, "This is the call for a change in the fundamental paradigms of study, and in the nature and function of the academy itself – a change as great, perhaps, as that which marked the end of medieval scholasticism and the beginning of the Renaissance humanist university." We have in our own time a project that requires a full mutual engagement of all fields of study, physics as well as poetry, and a hint of a warrant for its success. And if not now, when? If not here, where?

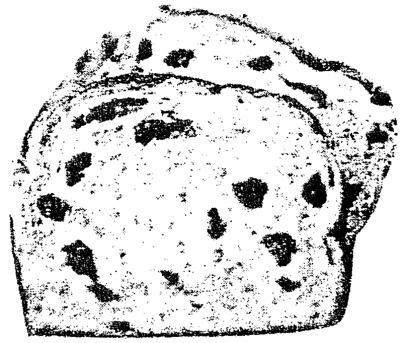
While I appreciated reading Turner's appraisal of the "state of the academy" from a poet's holistic point of view, and fully expected the perspective to appear as such, I did not expect to hear the same conclusions from an extreme reductionist. Browsing in a bookstore a few years ago I spied the book *Consilience* by Edward O. Wilson. I bought it, took it home and began to read it. But first I looked up "consilience" in my dictionary. The word wasn't there, but I also have an old Century dictionary printed in 1898 which did have the word, and with this definition: *the concurrence of generalizations from separate classes of facts in logical inductions so that one set of inductive laws is found to be in accord with another set of distinct derivation*. After assuring myself that this definition was not written by Buckminster Fuller, I began to see that it referred (profoundly) to the subtitle of Wilson's book: *The Unity of Knowledge*.

Now I must tell you about my relationship with Edward Wilson. I have read only a few of his earlier books (actually, I completed only one) because he is the most uncompromising reductionist I have ever read. Reductionism is fair enough, but he can't stand even to print the word "holism." For example, consider this sentence from the last chapter of *Consilience*: "As the century closes the focus of the natural sciences has begun to shift away from the search for new fundamental laws and toward new kinds of synthesis – 'holism,' if you prefer – in order to understand complex systems." So, in the context of the thesis developing in this section called Beyond Transdisciplinarity, I was surprised to find Wilson coming to the same conclusion as Turner about how to "fix the academy." From the mind to culture to the social sciences to art to ethics and religion, chapter to chapter, Wilson discusses the deep connections. His conclusion in the chapter "To What End?" summarizes this connection, although he still remains a biologist, albeit an environmentally aware biologist.

Another fairly recent book develops a similar theme. Fritjof Capra's *The Web of Life* (1996) ties together such topics as self-organization, dissipative structures, chaos and complexity, and other aspects of what I call the "system sciences." Instead of asking, "To what end?" Capra ends with "Bringing Forth a World." In Ecosystemology, we need to learn how to **go beyond** in education – but how? Polyverse is our proposal.

RAISIN BREAD

Ingredients:



1 package active dry yeast
2 Tablespoons honey
½ Cup warm water
¼ Cup butter cut in small pieces
1 ¾ Cup warm milk
5 to 6 ½ Cups all-purpose flour
1 ½ teaspoons salt
1 teaspoon cinnamon
½ Cup raisins (or more) (better if soaked in water or cognac for an hour or so)
½ Cup chopped nuts (walnuts, pecans, almonds, or all three)
melted butter

Dissolve the yeast in warm water with honey and allow to proof… Warm the butter in the milk, then add to the yeast mixture… Stir in the flour, mixed with the salt and cinnamon, one cup at a time, beating well with a wooden spoon after each addition… When the dough is too stiff to stir, turn out on a floured board… Knead, adding small quantities of flour until the dough is soft, velvety, and elastic… Shape this dough into a ball and place it into a buttered bowl, rolling it around to coat with butter on all sides… Cover tightly and let rise in a warm, draft-free place until doubled in size… Punch the dough down and turn out onto a floured board and let rise for five minutes, then knead in raisins and nuts… when the raisins and nuts are thoroughly integrated in the dough, cut in half and shape into two loaves… Place in two well-buttered 9 x 5 x 3-inch bread pans, and allow to rise again until doubled (or above the top of the pans).

Bake in a preheated 400° oven 25 to 35 minutes, or until loaves sound hollow when tapped on the bottom… brush with melted butter and place on racks to cool before slicing…

CHAPTER 14 : POLYVERSE

"And now that we've found out there is more than one universe, everything's changing!"
– Arnold Schultz

Hello
This is not the end
This is just the beginning
Remember to learn some
To **think** some
To draw and paint some
To sing and dance some
To play some
To work some
and to **think** some more
and act to make the world
a better place to live in.

This is the end, beginning and continuation of thoughtful observation, mindful living, and positive action. The words of this book are examples, a glimpse of the whole, some perspectives, tools for the taking, a little inspiration for your bag of tricks.
It is some truth.
A path.
But not nearly as beautifully revolutionary as your own.
There is a polyverse of possibility for us all to bring a world forward that the seventh generation will be proud to call
home.

This book provides a piece of vision towards that future. Enjoy reading these words or go find your own. Or just go outside
and do something.

Stop reading
The whole universe is trying to tell us something
Stop reading
And make something
Stop reading
Sit with the wind
and act
Ecosystemologize
and do it now!

Imagine what you're told not to
Design what you've never seen
Build something
Look people in the eye and see yourself in them
Seek the true dimensionality of your experience
Share your stories
Get uncomfortable
Become native to a place
Be fearless in the face of authority
Discover what has been present all along
Make spontaneous music
Get dirty
Cry with the ravens, the street cars and the sirens
Listen to the rumbling fault lines, the clouds, and children
Call for revolution
Find the river that runs inside you
Ride your truth, your beauty
Weave your voice into the whole

Get through these words
and do it now!

PARADIGMS and PARADIGM SHIFTS

Oftentimes our paradigms must undergo transitions,
Which means that we no longer see our world in stale traditions.
For most of us, Copernicus switched earth and sun around
And told the Pope there's not much hope to find a common ground,
Lest he agreed to drop his creed for paradigms more sound.
The pontiff said, "Your head instead will drop, not my belief.
The Church will stand on Holy land, and you will come to grief."

Our knowledge that our world is flat was finally put to rest
When it was found it's really round, as ships sailed east to west.
Then when we learned Sir Isaac turned his thoughts to natural laws,
He'd gravitate and then create reductionistic flaws.
But Newton knew his new World View would prove those old Greeks wrong.
Experiments made much more sense—he knew it all along.

In Eden's park and Noah's ark, all species known to man
Arrived one day, Creation's way, the way we all began.
But little finches, inch by inches, started to evolve
And left it up to the Beagle pup the quandary to resolve.
How we began, from ape to man, Charles Darwin made the call.
It's not like this in Genesis where there's no Neanderthal.

In Century 20, new thoughts aplenty; and Einstein leads the changes.
Atomic bombs and other qualms this physicist arranges:
How E has fared as MC-squared, new theories, and inventions.
His greatest gift: the brilliant shift from three to four dimensions!

What's coming next in World View text? We won't wait long to see:
Every day a brand new way to think, to dream, to be.
A stable view will never do, our texts will change each day.
So, will our brain remain the same when Cyber leads the way?

AMS

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APPENDIX 1

LEFT BRAIN RIGHT BRAIN PUZZLE SOLUTION

FOR CHAPTER 7 : THINKING

1 P	2 A	R	3 T	4 P	A	5 L	C	6 R	E	7 P	R	8 O	9 D
10 T	E	11 K	N	A	12 L	B	13 P	E	14 N	A	15 N	C	E
B	D	16 R	E	Y	A	L	17 E	N	O	Z	O	C	R
O	18 I	A	19 L	E	I	20 F	21 S	E	I	22 D	N	A	C
23 A	24 G	M	A	25 E	C	I	V	T	26 K	A	27 R	M	A
28 T	I	E	29 T	30 S	E	R	O	F	N	I	A	R	S
31 M	A	D	32 A	E	P	33 S	H	O	E	L	E	34 S	35 S
36 G	N	I	R	P	S	T	N	37 E	L	I	38 S	39 M	L
40 I	N	T	R	O	41 E	42 T	E	H	T	43 S	E	A	E
44 D	I	45 V	A	46 I	47 F	48 R	E	T	49 A	I	L	E	D
50 A	N	I	51 Y	L	L	A	R	E	T	A	L	R	O
52 R	I	P	53 E	54 L	E	D	G	E	R	55 L	E	D	M
A	56 R	E	C	A	S	E	57 E	S	I	A	R	P	58 A
59 P	A	R	A	C	H	U	T	E	60 A	C	C	E	M