In Context

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The Newsletter of **The Nature Institute**

Dear Readers,

Defining events such as those of September 11 demand a reckoning from all of us, no matter how remote we may be from "ground zero." In any such reckoning we do well to avoid the two extremes, neither elevating the significance of our own responses relative to those who acted so fatefully or suffered so terribly, nor denying the numerous threads that weave our individual lives into the social whole and help to make that whole what it is, with all its pathologies and hope.

The Nature Institute does not deal directly with social and political affairs — we are a nonprofit scientific research organization. But the threads linking the Institute's concerns to the social conditions of the day are much more than casual. We are inclined to think they are fundamental.

One truth that has emerged with increasing clarity over the past several decades is the interlinked fate of nations. No country is an island. The flow of knowledge, drugs, capital, illegal immigrants, political conviction, masses of refugees — these make it impossible for any nation to isolate itself from the larger community of nations and call itself secure.

And now we see this truth in its most extreme form: in an era of megatechnologies and suicidal determination, not even the twisted psyche of a single individual in a remote haven can be a matter of indifference to the most powerful nations. We're all in it together; we have no choice but to recognize that our own fate is intertwined with that of our fellows around the world.

In other words, the understanding demanded of us today is an ecological understanding. Everything can, potentially, affect everything else. The sensitivities we must develop are not unlike those required for studying the organism in its environment. The relation of individual to society is, after all, the relation of organism to environment raised to its most multi-dimensioned complexity.

The struggle to develop a new, qualitative science that can reckon with the relations of part and whole is primarily a struggle for new, more imaginative capacities of thought and feeling. It is hardly surprising that our ability to weave a coherent and harmonious whole from the fragmented social realities currently besetting us should depend on the development of these same imaginative capacities.

So perhaps you can see why the recent events have increased our sense of urgency about the work of The Nature Institute. We invite you to share in this work by perusing the following articles and reflecting critically upon them. If you wish to share your reflections with us, we would welcome any word from you. This give and take of words and ideas is vitally important throughout society; only when the process breaks down do the words degenerate, finally becoming desperate acts that speak only of loneliness, alienation — even terror. We are all engaged together in the struggle for a more hopeful conversation.

Craig Holdrege *Steve Talbott*

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The Nature Institute

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The Trouble with Qualities

If you are pursuing a qualitative science, sooner or later someone is bound to ask, "Can you define 'quality' for me?" It can be a little embarrassing, since no satisfactory answer is close at hand. True, part of the problem lies, as we will see, in the contradictory nature of the request itself. But there's much more to be said. If you are like me, you may suspect that our difficulty in saying what a quality is reflects a striking cognitive deficit in ourselves.

This is That (So What?)

Recognizing the deficit may be the most difficult thing. Personally, I always assumed (without much reflection) that qualities were obvious, even if science, beginning with Galileo, had explicitly decided to leave them out of consideration. But things left out of consideration tend eventually to be lost from view, and this seems to be what has happened with qualities. If we fail to attend to something long enough, we forfeit the ability even to experience it. My own fear is that humanity today risks losing the qualitative world altogether, as it disappears behind a veil of abstractions.

"But," you may ask, "where is the problem? Surely we have no difficulty recognizing qualities such as green, coolness, the fragrance of a rose, the peculiar roughness of a surface, the taste of salt, the timbre of a musical instrument!" True enough. Yet bare recognition, it turns out, does not carry us very far. Yes, I recognize that a green leaf is green, but what does my recognition consist of beyond the assertion, "This is the same as that" — this color is identical to that other one I've already experienced? Have I grasped the *content* of the sameness? What is it, exactly, that I am calling "the same" both here and there? We can all too easily classify without having much of a sense for the expressed qualities we are classifying. We just say repeatedly, "the same," and are done with it, which amounts to little more than counting. Counting, of course, is what science embraced when it ruled qualities out of consideration.

One indication of the extremity of our loss is the not-uncommon conviction within the cognitive sciences that qualities simply don't exist in any fundamental sense. We may *speak* of them as given realities, but they are actually a kind of mirage, purely subjective in nature, thrown up by the computational apparatus of our brains. As cognitive scientist Paul Churchland puts it, our senses betray us by not revealing things as they really are, and the qualitative presentation of the senses is therefore a kind of deception:

> The red surface of an apple does not *look* like a matrix of molecules reflecting photons at certain critical wavelengths, but that is what it is. The sound of a flute does not *sound* like a sinusoidal compression wave train in the atmosphere, but that is what it is. The warmth of the summer air does not *feel* like the mean kinetic energy of millions of tiny molecules, but that is what it is. (*Matter and Consciousness*, MIT Press, 1988, p. 15)

While this statement appears to me hopelessly confused, it is not my intention to address the confusion here. More important, as a starting point, is to realize how natural such a view becomes once we have lost any vivid experience of qualitative content. Take away qualities and we are left with the kind of abstraction that presents us with molecules, wavelengths, and kinetic energies, as if these were the sole valid content of experience.

Our abstracting capabilities are crucial to our efforts at understanding, but when the sophisticated pursuit of abstraction becomes one-sided, we lose the world. Abstractions, and especially mathematical abstractions, give us clearly outlined, narrowly defined, precise concepts serving our need for accuracy and clarity. But the more we move in this direction alone, the more we lose significant content, which is always qualitative. We become more and more precise about less and less, until finally we become perfectly precise about nothing much at all. We begin with stars and planets and landscapes, and we end with featureless particles moving in the void. We begin with a living, breathing, behaving organism, and we end with millions of genetic "code" fragments that are, in and of themselves, meaningless.

So perhaps we can, to begin with, think of qualities as the content without which our precise formulations are not *about* anything — certainly not about anything significant or meaningful.

Logic and Image

But concern with qualities is not a luxury reserved for poets straining after meaning. Science itself cannot do without qualities. Look at a tree and subtract all the qualities from what you see, and there is no longer anything —

anything at all — there. Nothing remains from which to abstract our desired quantities, nor is anything left for such quantities to refer to. So we can't even count without qualities. Qualities are what give us the possibility for an empirical, sense-based science. Without them we lose the world of experience we initially set out to understand. The fact that science relies so profoundly on qualities while refusing a disciplined reckoning with them can only be seen as a grave vulnerability.

Qualities are problematic for science because their existence in the world and their existence in us seem to be one and the same existence. This flies in the face of the radical diremption of matter from consciousness upon which science was founded. Yet the same problem applies even to conventional scientific knowledge. Does the law of gravity reside within human consciousness, or in the world? Some favor one answer and some the other. But the more profound answer may be: "Both" — because human consciousness is at the same time the interior of the world. This conclusion, which once would have been taken for granted, is, of course, terribly perplexing for us today. But it may be exactly the perplexity we need to wrestle with.

This, in any case, is the sort of conundrum raised by qualities. More directly, and out of our own experience, perhaps we can say: a quality is always the expressive shape of some inner gesture, a gesture of consciousness. To ask about a quality is to ask about an expression; it is to ask what something is *saying*. We are in the realm of the word, in its broadest sense. Presumably, we can enter the world of qualities in a disciplined way only through concentrated and trained attention to these inner, word-like gestures, something our culture at large does not encourage.

Image and Definition

The fact that qualities *express*, and that we find ourselves speaking of the *shape* of an inner *gesture*, suggests that qualities also have an imaginal character. Owen Barfield contrasts images with the discrete, sharp-edged concepts of logic this way:

> It is characteristic of images that they interpenetrate one another .... That is just what the terms of logic, and the notions we employ in logical or would-be logical thinking, must *not* do. *There*, interpenetration becomes the slovenly confusion of one determinate meaning with another determinate meaning, and there, its proper name is not interpenetration, but equivocation....

To take just one element of images: colors, considered qualitatively, can blend together and modify each other in a way that defies the either-or imperatives of logic. Add a little yellow to some red. Does the result still have the quality of red? Well then, does it *not* have the quality of red? We can, of course, start thinking of numerical wavelengths, which work quite well in the formulations of mathematical logic; but color as particular, qualitative content is no longer present in the numbers.

One other thing. A definition, as Barfield points out — so far as it is not given by metaphor or example — is the attempt to grasp a thing in the most clearly delineated, abstract, logical terms we can manage. So the definitional stands at the opposite pole from the qualitative — which is why there's something contradictory about asking for a definition of "quality." Unlike perfectly definable terms, qualities cannot be precisely conveyed to a passive recipient, but can only be suggested. If a quality is the shape of an inner gesture of consciousness, it stands to reason that it cannot be received passively; the recipient must participate in the gesture in order to experience "what it is like" or "what it is saying."

These are just a few brief reflections intended to highlight the problem of quality. Take them more as fodder for rumination than as clear, definitive statements. Better yet, consider your own experience and write us with your own additions and amendments to these preliminary thoughts. "The trouble with qualities" may become an ongoing theme for *In Context.* *SLT*

Drawing by Martina Müller

The Great Green Hype

In August, a public radio station in Urbana, Illinois, asked me for an interview after a staff person had read Steve's and my article on genetic engineering and agriculture in *Sierra*.* The station had previously interviewed a proponent of genetic engineering and now they wanted to hear the other side. It was a call-in show and became especially engaged when an Illinois farmer called in who felt that anti-biotech activists (among whom he counted me) were out to ruin farmers. He said, in effect, "Tell me what to do. I grow a thousand acres of soybeans and plant Roundup Ready soybeans [genetically engineered, herbicide-resistant soybeans sold by Monsanto, which also produces the herbicide "Roundup"]. I can't grow a thousand acres of soybeans without herbicide; that wouldn't work. But I use less herbicide than I have previously, which is good for the environment. And I save money. What's wrong with that? I'm demonized for doing this by you activists. You tell me what to do."

I couldn't help sympathizing with the farmer. He was genuine in his frustration, feeling as he did that his industrial agricultural practices were less environmentally harmful, and all he gets is criticism from environmentalists. He felt "damned if I do and damned if I don't." Nonetheless I couldn't agree with his reading of the situation. I suggested that he was more a victim of prevailing agricultural economics – driven by the unhealthy pairing of the biotech industry with the government – than he was of activists. I'm not convinced he heard or believed what I said.

I'd just been reading studies that indicate the amount of herbicides farmers are spraying is, overall, not declining and is in many cases rising (Benbrook 2001). One reason may be, as agricultural consultant Charles Benbrook states, that "intense herbicide price competition, triggered by the commercial success of Roudup Ready soybeans, has reduced the average cost of today's popular herbicides by close to fifty percent since the introduction of Roundup Ready soybeans. In response farmers are applying more active ingredients at generally higher rates" (Benbrook, 2001, p. 3). (Most industrial farmers like a "clean field.") A similar case is Bt-Corn, which is genetically modified to produce its own insecticide. Although between twenty and thirty percent of all corn grown in the United States is Bt-Corn, there has been no overall drop in the amount of insecticides sprayed on cornfields since 1996, when Bt-Corn was introduced (Obrycki 2001). This certainly doesn't look environmentally friendly to me, especially, since we have to add to these amounts the pesticides that the plants themselves are producing. As Steve and I pointed out in our *Sierra* article, this plant-derived increase in the use of poisons is never added into the standard calculations.

There are other problems with genetically modified crops. Benbrook points out that Roundup Ready soybeans produce five to ten percent fewer bushels per acre compared to traditional varieties grown under comparable conditions. This so-called yield drag is at least in part due to a weakening of the roots and nitrogen fixation in Roundup Ready soybeans, which makes them especially susceptible to drought. There is also evidence of weaker plant defense against pests. In Canada a wholly different kind of problem is surfacing: farmers are complaining about genetically modified, herbicide-resistant Canola, which is spreading as a weed in the fields of other crops like wheat; their favorite herbicide—Roundup —won't kill it!

Of course, individual farmers, like the one who called in, may be well satisfied with their product (at least for the time being). But they have become indoctrinated into the industrial agriculture paradigm, which says bigger and more uniform is always better, as long as it appears more profitable. That's why the farmer couldn't imagine growing soybeans organically. He'd probably have to give up his monoculture and plant different varieties, and give attention to building up soil rather than sterilizing it with poisons. He'd probably also lose government subsidies. This farmer was not willing to entertain such a possibility. His answer: it just won't work —the standard answer we give when we're afraid of revolutionary developments.

In preparing for this interview I came across a quote that spoke volumes. Dan Glickman, the Agriculture Department Secretary under Clinton and a vocal proponent of genetically modified crops and food, was reflecting back on his time as Secretary. He stated, "[Government] regulators even viewed themselves as cheerleaders for biotechnology. It was viewed as science marching forward, and anyone who wasn't marching forward was a luddite." In other words, the biotech industry was running the government regulation (or, rather, the nonregulation) of genetically modified crops and foods. The reporter who interviewed Glickman summarizes, "Looking back now, he regrets that industry was allowed to take the lead, as regulators ceded their watchdog role" (*Los Angeles Times,* July 1, 2001).

* A somewhat longer version of "Sowing Technology," which appeared in *Sierra*, has now been published in our own *NetFuture* online newsletter: www.netfuture.org/2001/OCT0901_123.html.

And we're living with the consequences. Seventy-five percent of food in the supermarket today contains genetically modified products. There has been almost no government regulation — as opposed to cheerleading — and no policy to require labeling, which would at least acknowledge the right of consumers to know where their food comes from. Both the biotech industry and government scientists have duped farmers into thinking that biotech farming is not only profitable ("profitable for whom?" we ask, since most industrial farmers rely on government subsidies), but also good for the environment and necessary for feeding the world.

The genuine vexation of my farmer-interrogator is a good measure of the educational challenge The Nature Institute has taken on. *CH*

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2. Obrycki, John J. et al. (2001). "Transgenic Insecticidal Corn: Beyond Insecticidal Toxicity to Ecological Complexity." *Bioscience* 5: 353-361.

Science and Belief

We introduce Ronald Brady in our News from the Institute section below. The Nature Institute is now in the process of making many of Brady's papers available on our website, www.natureinstitute.org. Some of these papers, dealing with evolutionary theory and morphology, make for difficult and intense reading, but the rewards to persevering readers are great. Ron brings an extraordinarily penetrating intellect to the elaboration and defense of a phenomenological approach to science.

To begin with, we have posted the following two papers on our website (www.natureinstitute.org):

"Dogma and Doubt." The theory of natural selection has often been accused of tautological emptiness. (A tautological explanation pretends to explain something by merely repeating what is to be explained.) As biologist C.H. Waddington once summarized the accusation, natural selection states that "the fittest individuals in a population (defined as those which leave the most offspring) will leave the most offspring." If this is all the theory of natural selection means — if it cannot provide an independent definition of fitness — then it gives us only the vacuous statement that "the individuals that leave the most offspring will leave the most offspring."

Brady points out that the charge of tautology is substantially unfounded. Darwin did not define fitness in terms of offspring, but rather in terms of heritable traits analogous to the ones human breeders try to select for. These hypothesized traits lending fitness would tend toward the preservation of the individual organism.

The real problem, Brady argues, is not tautology but something else that is often confused with tautology. Biologists have not come up with a definition of fitness that can be *tested*. George Gaylord Simpson, a leading evolutionary theorist, has written that "the fallibility of personal judgment as to the adaptive [or fitness] value of particular characters, most especially when these occur in animals quite unlike any now living, is notorious." And Theodosius Dobzhansky was even more emphatic: *no* biologist "can judge reliably which characters are neutral, useful, or harmful in a given species." The critic Tom Bethell illustrates the problem this way:

> A mutation that allows a wolf to run faster than the pack only allows the wolf to survive better if it does, in fact, survive better. But such a mutation could also result in the wolf outrunning the pack a couple of times and getting first crack at the food, then abruptly dropping dead of a heart attack because the extra power in its legs placed an extra strain upon its heart.

"The contributions of individual traits," Brady adds, "must be summed in the whole before we know how useful any one actually is." But biology today has no approach to the organism as a whole.

Without a definition of fitness that can be tested, the theory of natural selection rests on faith or belief. Such belief tends to cripple the imagination. Other approaches to morphological diversity — for example, those rooted in the evolutionary potential of the organism's *type*, as Goethe conceived it — go unexplored. These alternatives are not the subject of Brady's paper, but he does note that the absence of empirical, evidential concerns regarding natural selection "has produced a premature closure of inquiry in several branches of biology."

"Dogma and Doubt" was published in the *Biological Journal of the Linnean Society*, vol. 17 (1982), pp. 79-96.

The Global Patterns of Life: A New Empiricism in Biogeography." Biogeography is the study of the distribution of the ranges of plants and animals. Many species have discontinuous ranges, inhabiting two or more distinct regions separated by oceans or other natural barriers. This made difficulty for Darwin, who believed that each species must have had a single point of geographic origin and who also saw geographic isolation as going hand in hand with morphological diversity. To solve the problem, he proposed that the discontinuous ranges resulted from a combination of migrations and local extinctions. He suggested that we should be able to trace the migrations from existing distributions.

Little evidence for the necessary migrations turned up and, as Brady summarizes it, "the centers of origin proved remarkably difficult to fix." Eventually, the evidence for continental drift provided an entirely different explanation for most of the discontinuous ranges. But a century of work by numerous investigators had gone into the search for the hypothesized "centers of origin" and the subsequent routes of migration — all to little avail. As the biologist, S.A. Cain (who was himself engaged in the search for centers of origin) remarked in 1943:

> The sciences of geobotany ... carry a heavy burden of hypothesis and assumptions which has resulted from an overemployment of deductive reasoning....In many instances the assumptions arising from deductive reasoning have so thoroughly permeated the science of geography and have so long been part of its warp and woof that students of the field can only with difficulty distinguish fact from fiction.

Brady's aim in this paper is to disentangle two different modes of explanation as a basis for scientific work. One relies at least in part on what he calls "pseudo-phenomenal events" — events that *as yet* possess no evidential basis, such as ocean-circumventing migrations and speciation at centers of origin. The other restricts itself to a kind of conceptual elucidation that remains *at the level of description*. This elucidation can be understood as pattern seeking. (See box.)

As Brady notes, Darwin actually had available to him the data revealing one particularly remarkable pattern demanding explanation — namely, the pattern whereby numerous species and other groupings share the same discontinuous ranges. But he did not see this pattern because he was focused on pseudo-phenomenal events that became for several generations of biologists a matter of faith.

"The Global Patterns of Life" appeared in *Gaia and Evolution*, published by the Wadebridge Ecological Centre, Worthyvale Manor, Camelford, Cornwall, UK, 1989.

SLT

Pattern and Explanation

When, in the mid-twentieth century, Leon Croizat plotted the discontinuous ranges of various animal and plant groups, he found that many of these groups share the *same* discontinuous ranges. Here was a regularity, or pattern, needing explanation.

As Ronald Brady points out (see accompanying article), Darwin failed to note this pattern even though he had the necessary information at hand. It is not so much, Brady says, that Croizat was guided by a better *theory* than Darwin, but rather that Croizat saw the patterns "*in spite* of his theoretical preference, or even due to an *absence* of explanatory theory." He was just looking for meaningful patterns, not for the justification of a theory. And while meaningful patterns already embody conceptual commitments, these commitments need not go beyond the task of properly formulating the observations themselves. They need not include, as in Darwin's case, reference to hypothetical, unobserved phenomena, such as ocean-circumventing migrations, which he employed to explain the discontinuous ranges of animal and plant groups.

Brady cites Goethe, who proposed a science that "nur darstellen und nicht erklären will"—a science that would only portray and not explain. The goal is an "interpretive portrayal"—a phrase recognizing that we cannot see anything at all except by virtue of the conceptual relations through which we accomplish the seeing, but also suggesting that these conceptual relations (or "theory," or "explanation") need not be something *distinct* from description.

Brady notes that when we restrict ourselves to articulating relations between observed phenomena, the latter act as a control on our interpretations. How well the interpretation "works" is determinable from the process of observation itself. But when, as in Darwin's case, unobserved "phenomena" are also supplied by the mind, the controlling function of observation is lost.

As for Croizat's patterns, they gained a further significance when juxtaposed with the new patterns observed by continental drift theorists. These new patterns meshed with and helped to explain the ones Croizat was studying—all without need for resort to hypothetical migrations for which there was no observational evidence. It was the land itself that "migrated." *SLT*

New Affiliations

As part of its expanding program, The Nature Institute has invited three individuals to become Affiliate Researchers. We already have collegial relations with each of the three, and now that they have accepted our invitation we are looking forward to an intensification of our common work. Here is a very brief introduction to these new Institute colleagues. You will doubtless find more about them in future issues.

Ronald Brady has, throughout his professional life, concerned himself with the philosophical foundations and practice of Goethean science. A professor of philosophy at New Jersey's Ramapo College since 1972, he has made important contributions to the study of evolutionary morphology, while also pursuing fundamental issues in epistemology. One of his more recent contributions is the chapter, "The Idea in Nature: Rereading Goethe's Organics," in *Goethe's Way of Science: A Phenomenology of Nature*, edited by David Seamon and Arthur Zajonc (Albany NY: SUNY Press, 1998, pp. 83-111).

Ron tells this story about his undergraduate days:

> When I began college as a chemistry major my enthusiasm for science was somewhat dampened by meeting a professor of chemistry who pointed out the difference between my own goals and those he, as an experienced professional, would call mature. My passion, he noted, was entirely focused on direct experience — my sense of chemical change was invested in sensible qualities: in smells, colors, the effervescence of liquids, the appearance of precipitates, the light and violence of flame, etc. But, he countered, this was probably closer to medieval alchemy than to chemistry. The latter is really a matter of molecular and atomic events of which we can have only a theoretical grasp, and the sensible experience on which my excitement centered was secondary … I was reminded of him when I spoke to a morphologist at Berkeley about my interest in Goethe's attempt to approach science by keeping to direct experience. The morphologist responded: "*You* are interested in this approach because you are a *Nature appreciator*, while *I* am a *productive scientist*." It is always nice to see where one stands.

We think Ron would agree that much of his career has been devoted to understanding the cognitive blind spots of those college mentors. For more about his work, see the Notes and Reviews section above.

Michael D'Aleo is a founding member of the Saratoga Experiential Natural Science Research Institute (SENSRI) in Saratoga Springs, New York. He was a co-founder of that city's Spring Hill Waldorf High School, where he teaches physical science and mathematics. With a Mechanical Engineering degree from Rutgers University and a Masters degree in education from Sunbridge College, he is co-author of *Sensible Physics Teaching*, a guide for sixth, seventh, and eighth grade educators.

Michael worked for several years in design and development for Lutron Electronics, where he was awarded several patents and promoted to the position of Engineering Project Leader in charge of new product development. His primary interest is to find artistic solutions to technical problems based on processes in the natural world. His highly original paper on "Water, Energy, and Global Warming," co-authored with Stephen Edelglass, is available on The Nature Institute's website, at www.natureinstitue.org.

Johannes Wirz is a molecular biologist on the staff of the Research Laboratory at the Goetheanum in Dornach, Switzerland. He edits the journal, *Elemente der Naturwissenschaft*, and several years ago joined colleagues around Europe to found Ifgene, a scholarly network exploring the presuppositions, consequences, and moral implications of genetic engineering. (For information about Ifgene, see www.anth.org/ifgene.) His current research projects include a qualitative assessment of genetically modified potatoes; a study of butterflies with a view toward the land management policies necessary for their preservation; and an effort to develop criteria for beekeeping that do not include chemical attacks against the varroa mite, which is proving so devastating to honey bees worldwide.

Johannes recalls two "silly" thoughts that redirected his interests while he was working toward his Ph.D. in molecular biology at the University of Basel. In the laboratory of Walter Gehring he "discovered" that fruit flies anesthetized for observation under a compound microscope do not exhibit their most important traits, namely, behavior, movement, and flight. He began to wonder what the tiny flies did in their natural habitat, and how this might be described.

His second thought arose from work on the embryonic development of these same fruit flies. The embryos employed for laboratory analysis were believed to show their essential properties at minus 70 degrees C — yet no one would use material from such frozen flies for genetic modification. Only living and maximally healthy flies were used for modification experiments. Why is this so, he asked himself, since according to theory the deep-frozen embryos were like live ones in every regard, except for the fact that they were dead?

These ruminations led him to focus on two questions: What is life, and how can the "true" habitat of an animal properly be described? *SLT*

Nature Institute Courses

Often we've been asked: when are you going to start giving courses? We could only say, "not yet." Trying to build up the Institute in an organic way, we didn't want to tackle all tasks at once. But now the time seems ripe for developing this new branch of our work. As part of a program we are calling *Inside Nature,* we will soon start offering courses for the interested public, held at The Nature Institute in Ghent, New York. In these courses our aim will be to introduce the practice of a qualitative, Goethean approach to science. We want to help people learn to see and grasp nature as a world of connections and meaning, a world in which we can participate.

- In the winter, we will offer an evening course (one evening per week over several weeks) on "The Wisdom of the Animal World."
- In the spring, we will offer a course on successive Saturdays exploring "The Botany of Local Wildflowers."
- In the summer, we will offer a week-long intensive course that will include talks, observational work, and artistic activities. The precise theme of the week will be announced later. Tentative date: June 30 to July 6, 2002. We will send out detailed information early in 2002.

Welcome to New Board Members

Last spring the Institute's founding Board of Directors decided it was time to enlarge the Board. Not that strength lies only in numbers, but we saw the need for a larger group of people to help us carry the concerns of the Institute and to be active in its further development. We had our first board meeting with the new members in June. There was lots of energy and good will toward the work. We'd like to welcome the new board members and thank them sincerely for taking on this responsibility.

DAN HALDEMAN is a senior insurance examiner for New York State and is the Institute's new Treasurer. He lives a stone's throw from the Institute and has followed its development with great interest.

JIM KOTZ is a physicist who worked in the high-tech industry for many years. He has a long-time interest in phenomenological science and recently began teaching science. He is the editor of the Newsletter of the Society for the Evolution of Science.

NINA MIHAYCHUK is an endodontist and has her own healing arts practice. She has also practiced the sensitive crystallization method of assessing blood quality. She is active in the Science and Medical Sections of the School for Spiritual Science.

CHRISTINE SLOAN is the General Manager of Hungry Hollow Food Coop in Spring Valley, NY. She has a keen interest in furthering the cause of organic food and farming, while critically questioning the development of genetically modified foods.

DOUGLAS SLOAN is Emeritus Professor of History and Education at Columbia University. As the Director of the Center for the Study of the Spiritual Foundations of Education, he has hosted many important conferences on education, science, and technology.

Along Fern Row

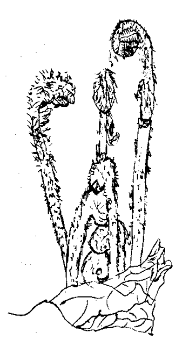
In the spring of 2001 Heather Thoma studied at The Nature Institute. Heather, who has a Masters Degree in holistic science from Schumacher College in England, wanted to deepen her understanding of the Goethean approach to plants and nature. One part of her work for us was an independent project studying the wetland in the nature preserve of which we are stewards. Heather also helped Henrike Holdrege and a group of ninth graders build a new, 2000-foot-long trail around the perimeter of the wetland. The trail leads through a variety of wetland and forest habitats, each of which can be a study in itself. We've selected Heather's descriptions and sketches of ferns to give you a taste of her work.

An old logging road comes down from the hillside to the southeast edge of the wetlands, intersecting our property at the end of the boardwalk built last year. This is where we began to build the extension to the perimeter trail with the students this spring. Because the new path followed the edge of the logging road for a hundred yards, there was less clearing to do on this first stretch of the trail than elsewhere in the wetlands and forest. Following the new path to the northeast, I move slightly away from the wetland edge and into a grove of ferns that grows on both sides of the trail.

The ferns have a distinctive growth process that has been astounding to watch, day by day, week by week. Early in the season they push their heads up through the packed soil, breaking the surface of the earth with their rising force. One by one, the plants appear, and they form a circular cluster of fiddleheads, each tightly coiled inward, like vertical centipedes, heads just barely lifted. As they grow upward, they unroll their stalks, and then the leaflets, known as "pinnae", become visible one by one. The different fern stalks in the cluster rise slightly one after the other, so they create a progression, almost musical somehow, in their reaching upward.

At first the leaves remain folded, and if we continue the centipede image, they would be hugging their dozens of arms to their bodies. They are covered almost completely with fuzz at this stage. Then gradually, they rise upward little by little, stretching more vertically. The leaves become exposed more fully and expand out to the sides. The fuzz falls off, and the stalks become stronger. More and more the different fronds seem quite related to each other in the circle, rather than appearing to rise as independent entities. Each stalk is oriented inward toward the others. They create a full circle, but are still constantly changing and growing, rising and expanding. As they reach almost full height, each frond begins to arch backward a bit, opening slightly to the sky. By late spring the fronds are tall and full, lush green feathering forms spreading and expanding out, but holding their circular whole!ness as a group. There are dozens and dozens of these circles densely covering many yards of forest floor.

Interrupted ferns and cinnamon ferns seem to grow intermingled in this area along the old logging road, though each circular cluster is composed only of one species or the other. The two species look very similar, the differences being most apparent in their spore cases. While the cinnamon ferns have entire fronds that are composed of dried-looking, cinnamon-colored spore cases, the interrupted ferns have spore cases in the place of just a few leaflets in the middle of one or two fronds in a cluster (therefore the name, "interrupted" fern).



When these plants were just coming up in April, I remembered that it is possible to eat them, so I picked a few from different clusters, hoping to sauté them to taste. As I picked them, I hesitated. Which ones would be best? Are they all edible? How should they be picked? Are there specific ways? Specific times? I thought about people who *knew* these things and grew up practicing this type of food gathering. Many questions arose in me, and I wanted to learn more. Perhaps this would be a project for a future season.

Brambles grow quite thickly along the old logging road amidst the ferns. Small saplings of oak, maple, and witch hazel had to be removed as we created the path, but not a lot of other vegetation grows where the roadway used to be. This openness in the ground cover allowed me to see a new friend as I was drawing the ferns one day. I had been sitting very still for almost an hour observing and drawing, and as I rose to leave, I sensed a motion next to me. I looked, and saw nothing. Looked again, and just sensed motion, ever so slight, but still saw nothing. Finally I realized what was there. Camouflaged, nearly invisible, a wood frog, with exactly the same colors as last year's leaves, sitting on the ground, about four inches long, beige, rust-colored with a golden tint, and a dark brown swath below his big, staring black eyes. He sat, so still, and waited for me to leave. Or just waited...or just sat. So still.

Heather Thoma

Thank You!

We would like to extend special thanks to the following persons who have contributed money, goods, or services to The Nature Institute (or its online publication, NetFuture) between April **and the end of September, 2001.** If we have inadvertently omitted your name, we'd like to hear about it!

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We Still Need Your Help!

As subscribers to *In Context* learned through a letter and membership appeal some weeks ago, The Nature Institute has received a challenge: A group of European foundations, recognizing our need for increased funding, will give us $90,000 a year for three years, if we can raise an equal amount from American sources. We are well on our way for 2001, and only need another $17,000 to reach that goal. As *In Context* goes to press the first donations in answer to the appeal are coming in. Our warmest thanks to all our "Friends of The Nature Institute" for helping make our work possible. If you haven't yet become a supporting Friend and would like to help us meet the matching challenge, please send us your contribution in the enclosed envelope. Thank You!

What Forms an Animal?

Craig Holdrege

What forms an animal? A likely answer these days is "genes." Or perhaps: "genes and environment." Such high-level abstractions reveal how little we actually know and tend to discourage further inquiry. When I hear "genes and environment" I yearn for something more concrete, something I can mentally take hold of. And the only way I know to develop such saturated concepts is to get back to the things themselves – to look carefully at what nature presents and inch my way toward a more full-toned understanding.

Wild and Captive Lions

A few years ago I came across a remarkable article written in 1917 by N. Hollister, then superintendent of the National Zoo in Washington, DC.* He was studying the lion specimen collection at the National Museum, which encompassed over 100 lion skulls and skins. Hollister noticed marked differences between wild-killed specimens and those that had lived for a number of years at the Washington zoo. He proceeded to make a more detailed comparative study.

Since lions from different areas of the world and also different regions of Africa differ substantially from one another, Hollister focused on one subspecies – the Masai lion (*Panthera leo masaica*) from East Africa. Five of the zoo-reared animals were Masai lions and had been captured as small cubs near Nairobi, Kenya. Hollister compared these specimens with wild-killed lions from the same area. He thus had animals from the same subspecies and one regional population. He knew, in other words, that he was comparing fairly close relatives and not genetically and geographically distinct populations.

When the five lions were brought from Kenya to the Washington zoo, they already stood out through their very pale, grayish buff-colored fur. This is the typical coloration of wild-living Masai lions, but contrasted starkly with the much more darkly colored lions at the Washington zoo. Over a period of years the fur of these imported animals darkened considerably, becoming like that of the other lions at the zoo. Moreover, the captive male lions grew much longer manes than wild Masai lions and they also had longer and fuller hair tufts at their elbows.

Immediately we ask, "Why?" But an easy answer is not forthcoming. Hollister was cautious. He believed the higher humidity and precipitation in Washington might have played a role in fur darkening, since humidity has been correlated with darkening of fur, and also feathers in birds. But he also recognized that the quality of light as well as metabolic changes due to the abnormal life and diet in the zoo might have contributed to the differences.

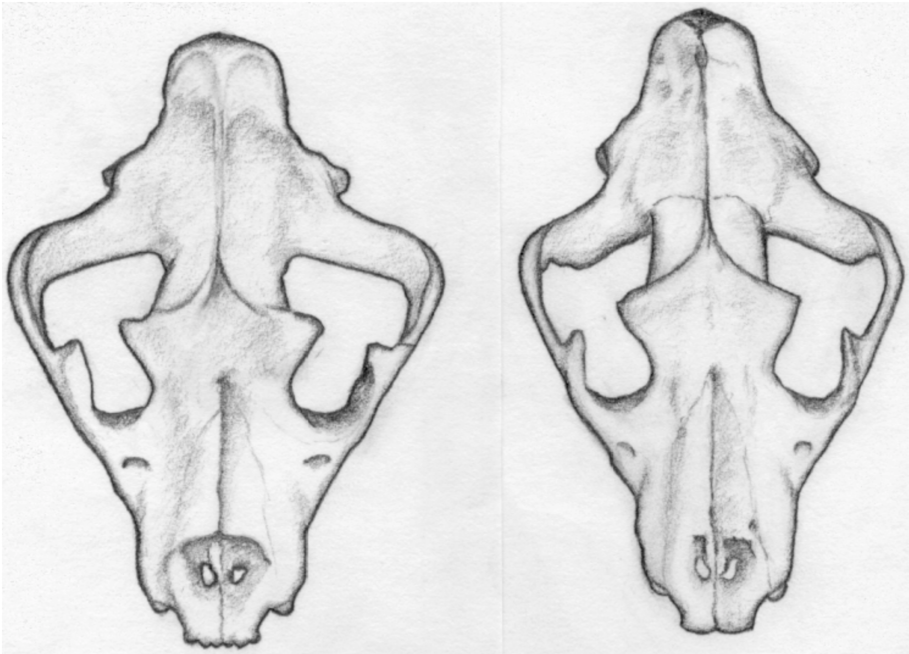
The Skulls of Wild and Captive Lions

Since an animal's fur is in direct contact with the external environment, we can imagine that it might somehow change in relation to changing environmental conditions. But the solid and complexly formed skull, hidden from the world by skin and muscles, is another matter. And yet, surprisingly, the most striking differences between the wild and zoo-reared animals were in their skulls (see Figures 1, 2 and 3).

The skulls from the zoo-reared animals are much shorter and broader than in the wild animals. They appear compact compared to the more sleek skulls of the wild lions. When I first saw the photographs of the skulls, I thought they had been incorrectly labeled, expecting the more stocky, massive skull to have belonged to a wild animal. But they were correctly labeled and I needed to consider the matter more closely. (A good exercise in overcoming prejudice!)

The skulls from the zoo-reared animals – whether male or female – are not only broad but also thicker-boned. One can see this in the prominent cheekbones (zygomatic arches, see Figure 1). The arch sweeps out further to the sides and consists of much thicker and more rounded bone. Figure 2 shows a cross section through the bone of the zygomatic arch in a zoo-reared and a wild animal. The difference is glaring. The zoo-reared animal's bone is triangular in cross section with convex surfaces and rounded corners. It consists largely of porous bone material (spongiosa). In contrast, the wild animal's arch is narrower and has one concave and one convex surface that meet at the top of the arch, forming a sharp ridge. The arch has little porous bone, consisting mainly of the outer layer of strong compact bone.

* Hollister, N. 1917. Some effects of environment and habit on captive lions. *Proceedings U.S. National Museum* 53: 177-193.



zoo-reared lion wild-killed lion

Figure 1. Top view of a zoo-reared and a wild-killed lion; both adult males. Drawn to same scale. (Drawings by Christina Holdrege. After Hollister 1917)

Similar differences are visible at the rear of the skull (see Figure 3). Not only is the skull of the zoo-reared animal much broader, the surfaces and forms are more rounded with gradual transitions from convex to concave. The skull of the wild-reared lion has much sharper, more defined edges and angles.

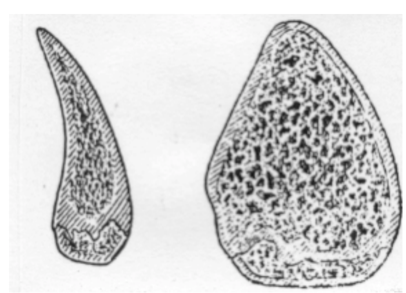
One further interesting contrast between the skulls pertains to the braincase (see Figure 1). Measured externally, the braincase in the skull of a wild lion is smaller than in the zoo-reared lion. When, however, one measures the internal cranial capacity — which is a direct indicator of brain size — the wild lion skull is considerably larger (40 to 50 cubic centimeters greater in size). This apparent paradox is resolved when one considers bone thickness. As in the other parts of the skull, the bones of the braincase are substantially thicker in the skull of the zoo-reared animal. Therefore the braincase appears externally larger but internally leaves less room for the brain. The larger brain of wild lions is covered by thinner, but solid, compact bone.

Hollister writes that even an untrained observer would group the skulls into wild and zoo-reared specimens, so apparent and uniform are the differences. He suggests that if one were dealing with only specimens from wild animals (or fossils), a biologist or paleontologist would think that he or she was viewing specimens of different species (a remark that makes one wonder about the accuracy of fossil classifications). Where does this contrast come from?

Activity that Sculpts

A primary activity missing from the life of a captive lion is the hunt and kill. A hungry lion in Africa's savannah crouches in the grass, all muscles tensed and its senses focused on the movement of a herd of antelopes or zebras. It stalks slowly and silently toward the herd and then suddenly, in a forceful burst of speed, sprints toward an animal, leaps, grabs onto the neck, and pierces through blood vessels and the wind pipe with its long, pointed canines. It pulls the prey down – using head and paws – and holds it until it dies. If the lion is a female with young cubs, she may drag the prey, locked into her jaws, toward the place where she's hidden them.

All this activity is missing from the life of a captive lion. And this activity forms the skull. The lion uses powerful muscles to grip, bite into and hold the prey in its jaws. The masseter muscle is especially important for the gripping power exercised in using the incisors and canines to pierce and hold the prey. This muscle attaches to the zygomatic arch and to the mandible (lower jaw). A powerful muscle must be rooted in strong bones. As the lion exercises its muscles, they not only grow but also put tension and stress on the bones. Although we tend to think of bones as inert structural elements of the body, they are, in fact, alive and adaptive. With an increase in stress and tension the bones



a b

Figure 2. Cross section through the zygomatic arch of a wild-killed (a) and a zoo-reared lion (b). Adult males of same age; natural size (From Hollister 1917)

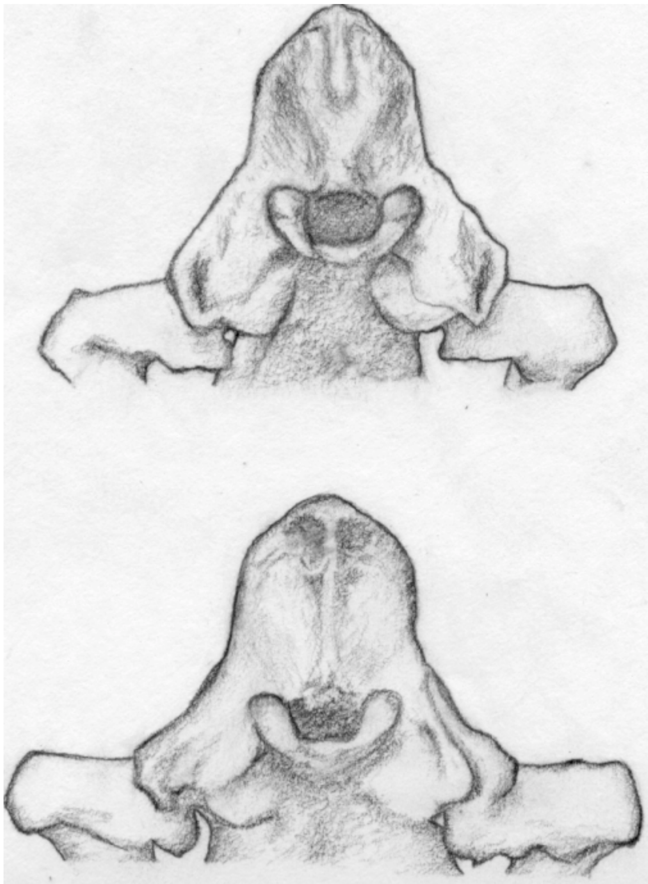


Figure 3. View from the rear of a wild-killed (top) and a zoo- reared (bottom) lion, both adult males. Drawn to same scale. (Drawings by Christina Holdrege. After Hollister, 1917)

change form and structure to meet the demands of the activity. The zygomatic arch remolds to form a sharp ridge of compact bone as the ideal attachment for the masseter muscle. In the same way the mandible forms thinner, more compact bone with ridges and rougher surfaces for the strong muscles attached to it. In contrast, the rounded, smooth zygomatic arch and mandible in the zoo-reared lions reveals a lack of activity. The bones grow and billow out, being hardly influenced by muscular stress and strain. Hollister notes their juvenile appearance, which reflects the lack of change due to inactivity.

Likewise, the sculpting of the rear of the wild lion's skull discloses activity. The wild lion uses its neck muscles in holding, pulling, lifting, shaking, and dragging prey. At least seven different neck muscles attach to the rear of the skull and every contraction sculpts the bones these muscles are rooted in. As in the jaw, the rear of the skull forms defined ridges and rough surfaces where the muscles attach. The little-used neck muscles of the captive lion leave the rear of the skull largely unaltered; the bones become more rounded and have smoother surfaces.

The Formative World

In the life of an animal, activity is a key formative factor. The active, hunting lion takes on a modified form compared to the inactive zoo lion. The muscle-orchestrated movement of the lion shapes the bones. This movement, in turn, is stimulated internally by the animal's drives (hunger) and externally by the perception of the antelope or the zebra. In this sense the antelope and the zebra form the lion. A remarkable thought. We all know that the flesh of these animals nourish the lion, but now we can recognize that the activity these animals call forth in the lion sculpts the lion's very bones. We can go even further and say that the savannah — its soil, light, warmth and moisture, its grasses and trees, its other animals — forms the lion. But it becomes increasing difficult to say precisely *how* this larger world influences the lion.

The outer world that forms the lion points us to the lion. By "lion" I mean the specific way-of-being that, for example, is open to and reacts to antelopes and zebras in a particular way. A lion doesn't see the grass it's crouching in as something to feed on, as does the antelope. Grass is something to hide in and move through. In this sense the lion is a specific world, a way to be and behave. This aspect of the lion is centered in the bodily form it is born with. This form is given through inheritance and then molded by activity. The hereditarily given model is something dynamic and plastic, waiting to be filled and formed by the animal's activity. This is what we should be picturing when we speak of a "genetic background" or genes, not some fixed plan.

The vast and rich ecology of the savannah stimulates the lion to activity. In a sense it brings forth the lion and allows it to unfold its life. This stimulation influences the whole metabolic activity of the animal, not only the muscles and the bones. Every sense perception forms nerve activity and influences the formation and function of the brain. The zoo lion lives in a world that calls forth little activity. Its bones grow large and thick, expressing the weight and inertia of its existence, while muscles and nerves receive little stimulation. One can sense the responsibility one takes on in having captive animals — knowing that we are cutting them off from part of the world that enlivens and forms them. How can we create a surrogate environment that at least to a degree is appropriate to their needs?

So when you hear that an animal is a product of its genes and its environment, think of the lion. Think of the most solid part of the body — bone — being molded by the animal's activity. In activity, the lion's specific anatomical and behavioral readiness takes hold of a world without — the kill at a watering hole at dusk. The antelope shapes — and so is part of —the lion.

The Lure of Complexity

Steve Talbott

IN April, 1999, the prestigious journal, *Science*, informed its readers that "shortfalls in reductionism are increasingly apparent .... The much-used axiom that scientists 'know more and more about less and less' may have an element of truth .... Another problem is oversimplification. Witness the 'gene-for' syndrome (as in 'gene for intelligence' or 'gene for sexual preference'), in which genes that contribute to human traits are instead taken to specify that trait" (Gallagher and Appenzeller 1999, p. 79).

These remarks occur in a special issue of *Science* devoted to *complex systems*. A news article in that issue carries the point about genes further:

> "The expression of individual genes is not being regulated by one, two, or five proteins but by dozens," says Shirley Tilghman, a molecular biologist at Princeton University. Some regulate specific genes; others work more broadly. Some sit on DNA all the time, while others bind temporarily. "The complexity is becoming mind numbing," says Tilghman.

"When we get to a certain network complexity," adds Adam Arkin, a physical chemist at Lawrence Berkeley National Laboratory, "we completely fail to understand how it works" (Service 1999, p. 81).

In recent years the study of complex systems, or complexity, has been widely proclaimed a scientific revolution. The revolution lends new currency to the idea of holism, and has popularized terms such as "self-organization," "complexity," and "chaos." Many might take the aspirations of the complexity theorists as a fulfillment of the hope, often expressed in our Nature Institute publications, for a new and revitalized science. But it is a live question whether the current developments are indeed a renewal of science or instead represent a retrenchment and strengthening of the most serious limitations of traditional science.

In any case, we think readers of *In Context* will want to know something about this ongoing "revolution." Unfortunately, a summary is not easy. There is no consensus definition of complexity studies, and its researchers seem to understand what they are doing more in terms of a style of theorizing than a specific subject matter. Indeed, the subject matter is often taken to be scarcely distinguishable from "everything," which is perhaps why the disciplines at issue have so far yielded a richer harvest in vague hunches than concrete results.

Vagueness, however, has not made for shyness. Rarely, if ever, have the advocates of a new science been so effective at advertising the fundamental, "paradigm-shifting" importance of their own work before they had much to show for it. In addition to a new holism, the advertisements promise a rejection of reductionism, the discovery of almost mystical-sounding "emergent" and "self-organizing" properties of physical systems, and the overcoming of narrow specialization.

Here I present a brief sketch of the new work, with this caveat: In what follows you will find a strange mixture of high aspirations and the crassest dismissal of nature you could possibly imagine. I try to present a sympathetic description, but you should not think that the views summarized here are those of the researchers at The Nature Institute. These views are, however, powerfully symptomatic of the scientific thinking of our day, and we would all do well to come to terms with such thinking.

First, then, three "classic" pictures invoked in many complexity studies:

First Picture. If you drop grains of sand onto the middle of a table, you will eventually form a pile reaching all the way to the table's edges. As you continue dropping the grains, some of the avalanches they provoke will send little sand cascades off the table. But, over time (and up to a point), the pile will continue to grow, with the sides getting steeper, and with some of the avalanches getting larger and larger. During the later stages the pile becomes susceptible to catastrophic collapse; as far as you can know, the next grain of sand may (and likely will) have only a tiny, local effect – but it may also trigger an avalanche that sends much of the pile cascading onto the floor. Nothing about the local collection of grains near the point of the next grain's impact can tell you whether a catastrophic shift will occur. The necessary information is distributed throughout the pile as a whole.

Second Picture. You and an acquaintance are in prison, being separately interrogated about a crime the two of you may or may not have committed. The prosecutor gives you this choice: if you deny the crime and your acquaintance implicates you, you will get life in prison and he will go free.

If you both deny the crime, you will receive a minimum sentence. If you both confess, you will receive a medium sentence. The same choice is offered to your acquaintance, so if he denies the crime and you implicate him, he will be the one sentenced to life and you will go free.

This is known as the Prisoner's Dilemma. The scenario is truly devilish, for even if you and your partner previously agreed to maintain silence (therefore assuring yourselves of a light sentence), you both also know that the other may be tempted to get off scott-free by confessing. So holding to your agreement could very possibly land you in prison for life. Can you risk that? Wouldn't it be better to confess, knowing that you just might gain your freedom, while at worst you would be slapped with a medium sentence? And one further question: is evolution an iterative playing of the Prisoner's Dilemma game, through which one organism continually seeks an advantage over the others?

Third Picture. Imagine a pot with numerous "symbol strings" floating around in it. A symbol string is, in the simplest case, just an ordered group of zeroes and ones — for example, here are three strings:

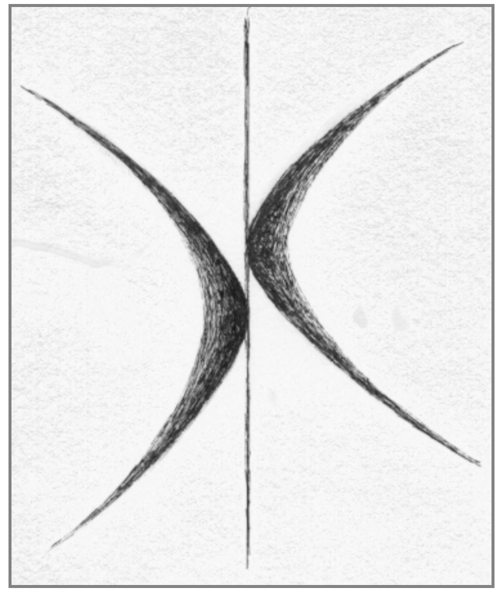
011
101011
11100

Imagine further that these strings randomly "collide" with one another and that some of the collisions result, according to a set of "grammar rules," in the transformation of one of the strings. For example, a rule might say:

If part of one colliding string consists of 011, and if part of the other string is 100, then the latter sequence of digits is changed to 11010.

You may, if you like, think of the first string as an "enzyme" that facilitates, or catalyzes, the transformation of the second string. The assumption is that the pot contains an adequate provision of zeroes and ones to supply any additional digits required for a catalytic reaction.

It is easy to simulate a given initial pot of strings and a given set of grammar rules by using a computer. The program simply selects pairs of strings at random and "collides" them by applying the grammar rules. In this way, the pot of strings can evolve. For example, given the right initial conditions, you might find that you get an "autocatalytic set" — that is, a set of symbol strings that proves stable, continually producing more of the very same strings it itself consists of. Such a set is self-regenerating, and is thought by some to provide crucial insight into life's development from a primordial "soup pot" containing molecular "strings" of atoms.


Martina Müller

Complex Themes

Each of these "pictures" has figured in the work of complexity theorists over the past few decades. We can use them to help us grasp several fundamental characteristics of the new work, as it is seen by its practitioners:

Unprecedented Generality. "The convergence of chemistry, physics, biology, and engineering is upon us," according to Stanford University biologist, Lucy Shapiro (quoted in Service 1999, p. 80). Complexity theorists are looking for the underlying laws governing such diverse phenomena as the fragile edge along the crest of a sand dune, the collective action of networks of neurons in the brain, ecologies of living organisms, and the behavior of financial markets. These theorists commonly express a yearning for "deep" truths – deep because possessed of the greatest possible generality.

For example, the Santa Fe Institute's Stuart Kauffman is intrigued by the similarities between an *E. coli* bacterium and the IBM corporation. "Organisms, artifacts, and organizations are all evolved structures .... What are the laws governing the emergence and coevolution of such structures?" (Kauffman 1995, p. 246). Referring to the pot of symbol strings and their "grammars," Kauffman reflects,

> Somehow the string images we have discussed press themselves on me. The swirl of transformations of ideologies, fashions begetting fashions begetting fashions, cuisines begetting cuisines, legal codes and precedents begetting the further creation of law, seem similar in as yet unclear ways to model grammar worlds .... (Kauffman 1995, p. 298)

Similarly reaching across disparate domains, the influential philosopher Daniel Dennett asks why trees in the forest expend so much energy growing tall. He answers: "For the very same reason that huge arrays of garish signs compete for our attention along commercial strips .... Each tree is looking out for itself and trying to get as much sunlight as possible." Invoking the Prisoner's Dilemma, he goes on:

> If only those redwoods could get together and agree on some sensible zoning restrictions and stop competing with each other for sunlight, they could avoid the trouble of building those ridiculous and expensive trunks, stay low and thrifty shrubs, and get just as much sunlight as before!

But, like the prisoners, the trees cannot get together, and therefore "defection from any cooperative 'agreement' is bound to pay off if ever or whenever it occurs." Such agreements would be "evolutionarily unenforceable" (Dennett 1995, pp. 253-55).

This drive toward generality – toward principles that can be applied to the development of cuisines and laws and brains and redwoods and commercial street signs – leads, as we will see, to most of the other key themes in complexity theory.

Maximum Abstraction. "A general theory of complex systems," says Danish scientist Per Bak, "must necessarily be *abstract*." Bak, who pioneered the investigation of sandpile models, believes that a general theory of life "cannot have any specific reference to actual species. The model may, perhaps, not even refer to basic chemical processes, or to the DNA molecules that are integral parts of any life form that we know." After all, he wonders, what might life forms on Mars be like?

> We must learn to free ourselves from seeing things the way they are! A radical scientific view indeed! If, following traditional scientific methods, we concentrate on an accurate description of the details, we lose perspective. A theory of life is likely to be a theory of process, not a detailed account of utterly accidental details of that process, such as the emergence of humans. (Bak 1996, p. 10)

The demand for abstraction is a demand for sharp-edged, unambiguous, precise terms, ridded as far as possible of qualitative or phenomenal content. Numbers and the terms of logic are perhaps the primary abstractions, and Bak observes further that theories "must be *statistical*" — like the laws governing sandpile avalanches. John Holland, the University of Michigan theorist and "father of genetic algorithms," speaks a great deal about the necessity for the scientist to "strip away details," noting that "numbers go about as far as we can go in shearing away detail."

> When we talk of numbers, nothing is left of shape, or color, or mass, or anything else that identifies an object, except the very fact of its existence. (Holland 1998, pp. 23-24).

The quest for generality dictates this resort to abstraction. To arrive at generalizations regarding phenomena, we have to strip away all the differences between the phenomena, looking only for what they have in common. This stripping away makes it possible to assign different things to the same class (for example, street signs and redwoods), and once we have done this we can, without ambiguity, count and measure the members of the classes we have formed and reason mathematically about them (for example, formulating laws about their height).

Holism. As mentioned above, no information about local regions of the sandpile can tell you whether the next grain added to the pile will trigger a catastrophic collapse. The necessary information is distributed throughout the whole of the pile. It is a matter of the interlinked balances of force upon every grain in the pile, the shape of every grain, and so on. Therefore, the theorists of complexity say, understanding must proceed on a holistic basis.

"The whole is greater than the sum of its parts," says Kauffman, repeating a common refrain (Kauffman 1995, p. 24). As a news item in *Science* reports, "understanding how parts of a biological system — genes or molecules — interact is just as important as understanding the parts themselves. It's a realization that's beginning to spread" (Service 1999, p. 80). The editors of *Science*, in their special issue devoted to complexity, note that "we have taken a 'complex system' to be one whose properties are not fully explained by an understanding of its component parts" (Gallagher and Appenzeller 1999). In the same spirit, Kauffman complains that

> we have lost an earlier image of cells and organisms as self-creating wholes. The entire explanatory burden is placed on the "genetic instructions" in DNA – master molecule of life — which in turn is crafted by natural selection. From there it is a short step to the notion of organisms as arbitrary, tinkered-together contraptions.

He adds: "Life has, I think, an inalienable wholeness" (Kauffman 1995, pp. 274-75).

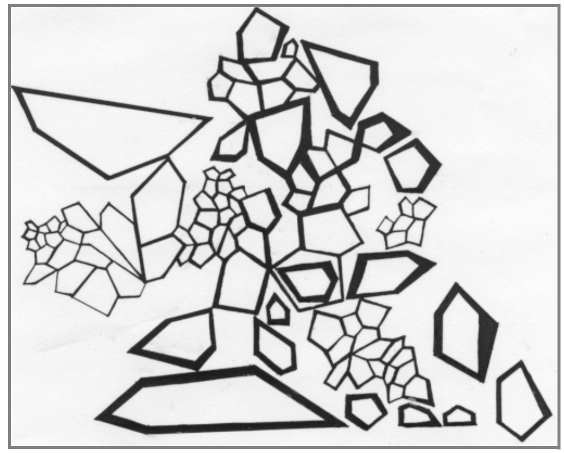
Emergence. The difficult and rather obscure notion of emergence is close companion to holism. If the whole is greater than the sum of its parts, then (as these theorists seem to view the matter) somewhere along the way from parts to whole something *in addition to* the parts must have emerged. Holland tells us that emergence "occurs only when the activities of the parts do *not* simply sum to give activity of the whole." He also says that "the hallmark of emergence is this sense of much coming from little."

Holland's examples of emergent phenomena may help to explain this. He speaks of ant colonies where, "despite the limited repertoire of the individual agents — the ants — the colony exhibits a remarkable flexibility in probing and exploiting its surroundings. Somehow the simple laws of the agents generate an emergent behavior far beyond their individual capacities. It is noteworthy that this emergent behavior occurs without direction by a central executive."

In the same way, he speaks of collections of neurons, the immune system, the Internet, and the global economy as systems where the emergent "behavior of the whole is much more complex than the behavior of the parts." Likewise, the complex dynamics of the solar system and galaxy would hardly have been foreseeable if we had merely been given Newton's laws of motion to contemplate, and are therefore emergent (Holland 1998, pp. 1-12). In a similar vein, Bak remarks that "the emergence of the [complex avalanche dynamics] of the sandpile could not have been anticipated from the properties of the individual grains" (Bak 1996, p. 51).

All this makes clear that the holism we spoke of above does not refer to wholes independent of, or antecedent to, the parts. The term "emergence" testifies to a bottom-up conception of the whole: it is not that the whole generates, and manifests itself through, its parts, but rather that the parts, by interacting, generate the complex behavior of the whole that "emerges." It is hardly clear, from the current literature, what this emergent whole is thought to be, beyond the sum of its parts.

Non-Reductionism. *Science* magazine introduced its special issue on complex systems with the heading, "Beyond Reductionism." The claim to have escaped reductionism is common (though not universal) among investigators concerned with complexity. The idea is that if higher-level properties really do emerge in complex systems, yielding wholes that are more than the sum of their parts, then explanations of these systems must refer to the higher-level properties. Everything cannot be "reduced" to descriptions of lower-level parts. As Bak puts it, when the growing sandpile reaches the state where it is subject to catastrophic collapse, the pile itself "is the functional unit, not the single grains of sand. No reductionist approach makes sense." To predict a catastrophic avalanche in traditional, reductionist terms,



Martina Müller

> one would have to measure everything everywhere [in the pile] with absolute accuracy, which is impossible. Then one would have to perform an accurate computation based on this information, which is equally impossible. (Bak 1996, pp. 60-61)

These researchers therefore accept, for example, that there can be a legitimate science of economics, whose explanations need not be reducible — certainly not in any practical sense — to the motions of atoms. Humans and societies and commercial activities have all emerged in the course of evolution, and in order to understand them we have to speak directly of their emergent features — things like rational agents, markets, prices, interest rates, and so on — not just the lower-level entities from which they emerged. Depending on what we are trying to explain, we must resort to different *levels of explanation, or description* — to use a phrase that often turns up.

Self-organization. References to self-organization abound in the literature on complex systems. The sandpile, says Bak, has "organized itself" into the "critical state" where it is susceptible to unpredictable avalanches of all sizes. Kauffman's pot of grammar-obeying symbol strings spontaneously organizes itself into a self-regenerating "autocatalytic set," suggesting to him that an oceanic soup of primordial molecules could do the same — and this principle of self-organization, he believes, underwrites the entire evolutionary drama:

> I propose that much of the order in organisms may not be the result of selection at all, but of the spontaneous order of self-organized systems. Order, vast and generative, not fought for against the entropic tides but freely available, undergirds all subsequent biological evolution. (Kauffman 1995, p. 25)

Kauffman has practically made a mantra out of the phrase, "order for free." Others are more modest; they do not say "for free" but only "somehow." Speaking of the "spontaneous self-organization" through which individuals form economies, cells form organisms, birds form flocks, and atoms form molecules, Mitchell Waldrop observes:

> In every case, groups of agents seeking mutual accommodation and self-consistency somehow manage to transcend themselves, acquiring collective properties such as life, thought, and purpose that they might never have possessed individually. (Waldrop 1992, p. 11)

Again, this notion of self-organization is integral to the others we have discussed. If a new and coherent whole emerges bottom-up from interacting parts, then, *somehow*, it appears that the parts have transcended themselves and "self-organized" so as to produce the whole.

Reliance on Models and Algorithms. The drive toward simplicity dictating the goals of generality and abstraction is also evident in an extreme reliance upon models. Holland (1998, p. 24) observes that "shearing away detail is the very essence of model building. Whatever else we require, a model *must* be simpler than the thing modeled." We are a long way here from Goethe's contention that the phenomenon, rightly and fully understood, *is* the theory, and that there is no need for an intervening model. Similarly, Bak writes,

> The beauty of the model can be measured as the range between its own simplicity and the complexity of the phenomena that it describes, that is, by the degree to which it has allowed us to condense our descriptions of the real world. (Bak 1996, p. 44)

The model offering this condensed description is, of course, a mechanical one, and today this means more and more that the description is algorithmic, or recipe-like, in the way that computer programs are algorithmic. More likely than not, in fact, the model just *is* a computer simulation. Daniel Dennett sees three key features in all algorithmic explanations:

> *Substrate neutrality*. It doesn't matter what sort of material apparatus executes the algorithm as long as the logical structure of the recipe is preserved.
>
> *Underlying mindlessness*. A dumb mechanism can do the job.
>
> *Guaranteed results*. Follow the recipe and the result is assured.

You can think of these three principles as representing the movements toward abstraction, mechanism, and logical purity, respectively — which are actually a single movement (Talbott 2000).

Looking Ahead

Those are some of the key themes and intellectual commitments guiding the work on complex systems, as voiced by a number of the pioneers in the field. In the next issue of *In Context* I will attempt an assessment of these themes and commitments. Here I would like merely to suggest one question that seems to me fundamental for any such assessment:

Are the rather obscure appeals to "emergence," "self-organization," and "holism" simply the result of reintroducing, magically and without sufficient justification, some of the richness of the original phenomena – richness that was "sheared away" in the drive toward generality and abstraction? After all, if the complexity theorist's explanations are to explain real phenomena, then *somehow* the qualitative phenomena that were sacrificed to abstraction and mechanical modeling have to be regained at the end of the explanatory process. But is saying that they just happened to "emerge" a satisfactory way to get them back into the picture? Or should we instead pursue a qualitative science that refuses to sacrifice the phenomena to abstraction in the first place?

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