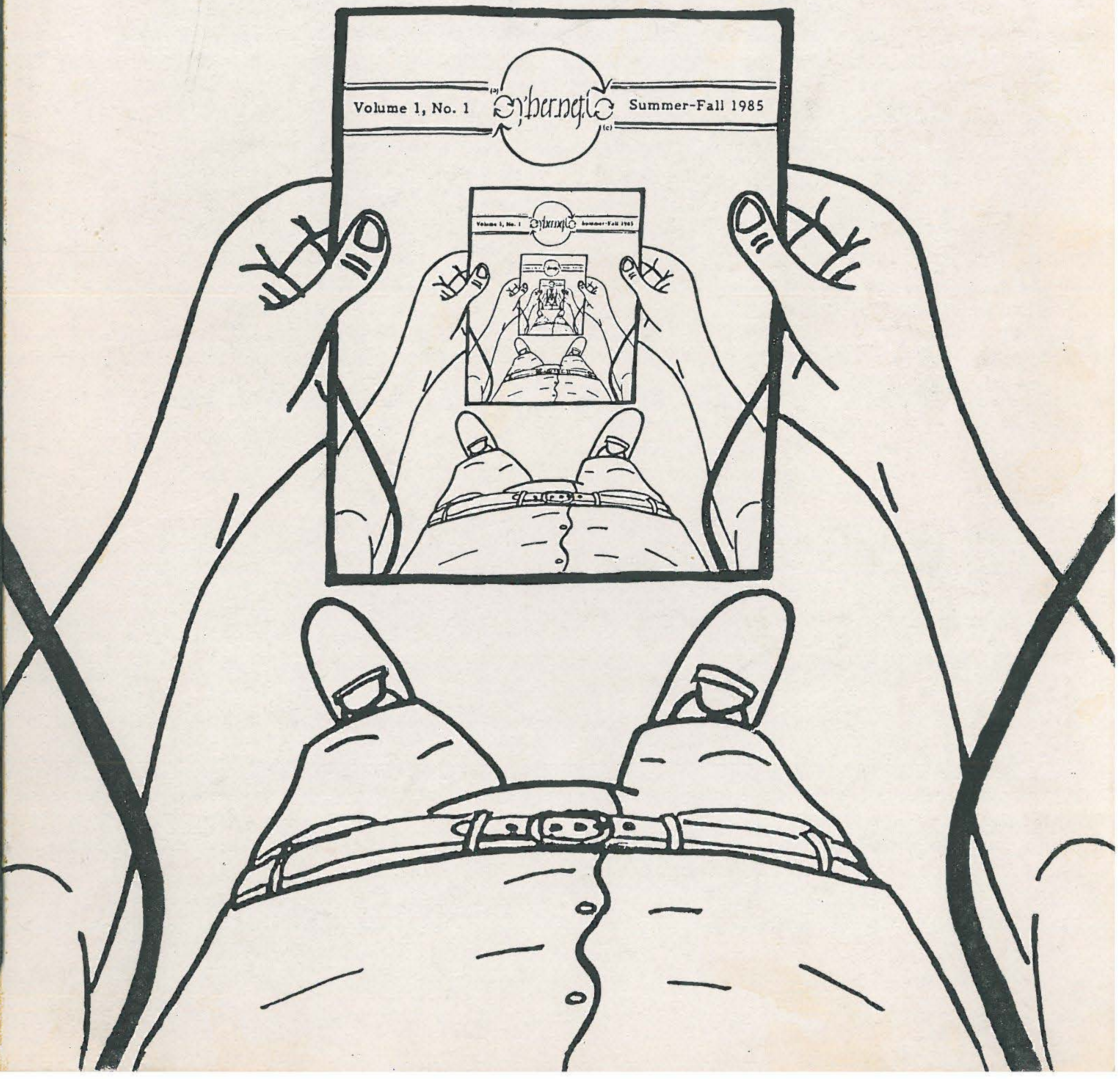
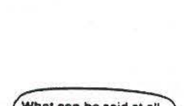
Volume 1, No. 1

Cybernetic

Summer-Fall 1985




What can be said at all
can be said clearly.
Wittgenstein

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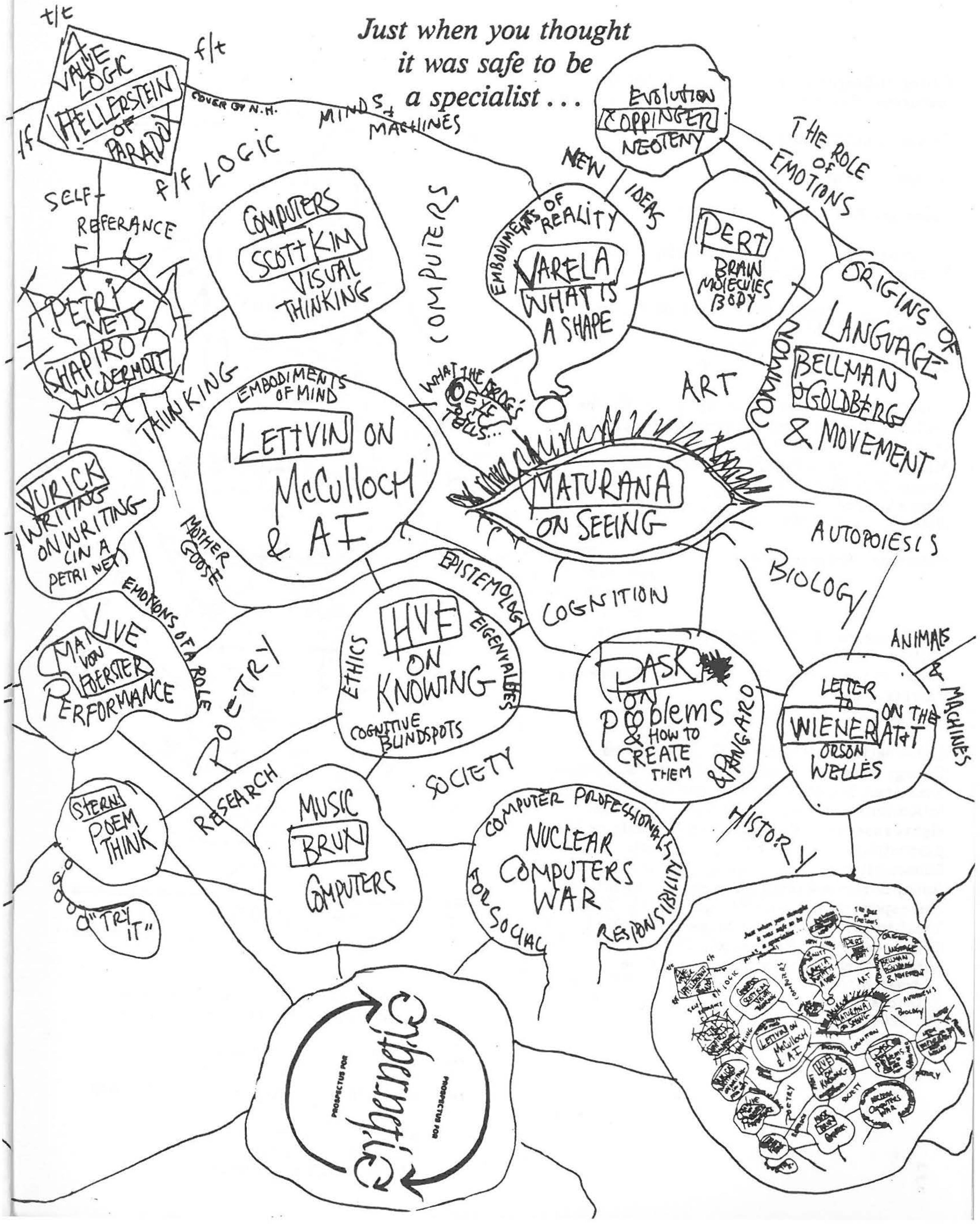
Just when you thought it was safe to be a specialist . . .



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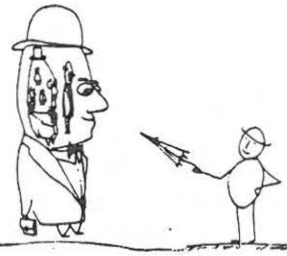
EDITORIAL



This first issue of Cybernetic is almost a reality as I write, after a marathon layout session that has gone on for four days and nights in a loft, an office, a van, various Chinese restaurants and donut shops, an Irish pub, an airport, and other locations now lost to memory, as we moved recurrently in creative loops, carrying manuscripts and type books and even our light table with us. We also carried a piano keyboard with us. Designer Bruce McIntosh explained that we were going to Xerox it. The process of constructing the magazine had decidedly self-organizing characteristics, as anyone who came near us seemed drawn to become part of us. One of our authors, who caught up with us to correct his proofs, stayed on to invent the cover.

All this was taking place around Cambridge, Mass., not far from where Norbert Wiener conceived of cybernetics. While Wiener and cybernetics are usually associated with MIT, one of his colleagues recently recalled the real beginnings of this new science as taking place in a local Chinese restaurant where Wiener hosted his wartime colleagues at boisterous interdisciplinary dinners, which may explain the origin of the term "feedback" for that fundamental principle of communication and control.

In its early days, cybernetics put science in a broadly human context, and this magazine is an attempt to revive and continue that tradition. We hope the diversity of articles will stimulate readers to make new connections, perhaps unexpected ones, among many different ways of understanding the world. Unexpected ways of thinking were certainly a part of the process of putting this magazine together. In the last hours of laying it out, we really did Xerox the piano (see page 42), and by then it even seemed to make sense.

Paul Trachtman

Warren McCulloch and the Origins of AI

by J. Y. Lettvin

At the start of the 20th century in the United States, psychology reflected none of the epistemological problems outlined in the 19th century, none of the metaphysical questions raised by the existence of these problems, and certainly no clue as to how to go from structure to function in the case of the nervous system.

Let me illustrate the point. If one were to get a book on the kidney that never once mentioned urine or the production of urine, one would feel cheated. Or if one had a long essay on muscle which never mentioned contraction, one would certainly turn the essay back. Yet one could publish long treatises on the anatomy and physiology of nerve, on the diagnostic criteria for nervous disease, and never once consider mental process. Against this background, not particularly rich, the background of William James, or the English philosophers - Russell included, there was no possible approach to a theory of nervous action, since a theory would imply: things are this way for such and such a reason. But the notion of reason, as we now see, was read out of a natural science by the English philosophers.

To this day that rather dreadful state of affairs has prevented neurosciences from exhibiting any theory whatsoever. As the data in the field grow to the point where no man can read it all, much less comprehend it, there is no background, no backbone, no structure or theory against which to understand the details. To my knowledge, the McCulloch-Pitts theory of the brain is the only one that has ever been issued, and it, itself, was issued more or less to the indifference of those who most needed it.

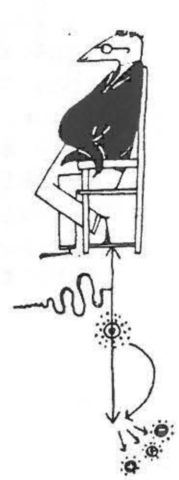
It does not matter so much whether theory is right or wrong, just so that there be a theory, not simply a vague hypothesis. The McCulloch-Pitts theory of nervous action remains to date the only available for nervous action. It is certainly wrong, but in its wrongness, just as Bohr's wrongness in his view of the atom, it contains the seeds of new theory.

At present, the McCulloch-Pitts theory, in one way or another, becomes the foundation for the field called Artificial Intelligence, which itself is an embattled attempt to provide a theory relating brain and mind.

Let me dwell a little on the philosophical posture that was held by the sciences of the nervous system between 1900 and 1943. To do this, consider the history of that posture. The rules of natural science laid down in the 17th century from the time of Galileo to the time of Leibnitz and Newton were that the external world is given in terms of magnitudes, figures (or, if you wish, arrangements) and motions or changes. So that what was available to the observer were not the objects of his perception but things that could be interpreted by the observer to be objects and their negotiations through a world. The function of science was to relate the measurements made on observables to each other such that given a set of measures one could write out the laws by which observables changed. So far as the

Verse by Frederick Winsor

Illustrations by Marian Parry



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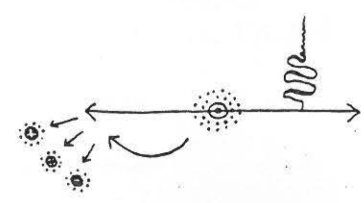

observer goes, he has perceptions, knowledge, memories, things of this sort, which are not measureable under any circumstances because they are private and inaccessible. To relate measured observables to those things which are not measurable is impossible.

In a sense, a theory of mind could not be a theory in natural science. Yet, from Aristotle on, and very much regarded by Newton as well as by the Continental philosophers, was the tradition that nothing could be had in the knowledge of the observer in terms of content, empirical content, that was not initially in the senses. This, of course, is the point which is made by Leibnitz, and then by Kant. Were the observer not so bound to observables science itself would be impossible, since an observation would have no strict basis. What relates that which is observed to the processes in the observer must be something akin to information rather than to the energetics of the world, and, although Leibnitz had made an attempt at it, information had not yet been clearly defined. If one were given axioms by which sense data, which still are physical, could somehow or other be related to the state of mind in the observer, then and only then would a theory of observation or a theory of knowledge be possible, having at least one foot in the natural sciences.

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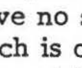
That lay in the Theory Jack built.



From The Space Child's Mother Goose, Simon and Schuster New York 1958

It is one thing to say that all the source of empirical knowledge lies in the senses, and another to take the consequences of that. Curiously enough an American engineer/ scientist, J. Willard Gibbs, uttered what is to be regarded as the fundamental epistemological law by which it might be possible to go from physiology to mind.

Gibbs was one of McCulloch's heroes. He was one of the few native American philosopher/scientists; unfortunately not sufficiently well regarded by the Americans themselves. Gibb's phase rule issued at a time when it was supposed to apply only to thermodynamics, had an epistemological significance which was noted at that time by Gibb's European colleagues, but was ignored back home. The principle laid down by Gibbs in his famous rule describes what one can say by virtue of the information given, and it lays an important constraint upon what can be perceived given the sense data. It does not tell you specifically what can be perceived but what it is impossible to perceive given those data. An additional principle, corollary to the phase rule, and only expressed clearly by the time Shannon (and implicit in a good deal of work up to the time of Shannon) is that information which is lost in process is forever lost and cannot be supplied to later parts of a process by such things as revelation. Nobody has ever bothered to make such rules as Gibbs' rule and the information loss rule axiomatic in such a way as to make it possible to proceed, if not directly to perception, at least to the statements of what perception cannot be.

In the heritage of McCulloch and Pitts, there was an additional factor. Leibnitz in the 17th century had designed, although he had not been able to build, the first logical machine. This was not known until the 1950's, when interest in logical machines began again. Leibnitz had said of such a machine that in the future when philosophers disagree they will not fight with each other but say to each other, "let us sit down and compute."

Gibbs' phase rule brings into natural science the formal notion that if a system is to be defined in terms of a state, every one of the ways in which that system can vary from that state must be constrained. In short, if I have a system defined by n variables, there must be n-independent equations needed to provide a specific solution to those equations for each of the variables.

The history of computing machines is reasonably well known from the time of Babbage on, that is for a century and a half after Leibnitz. The possibility of logical machines, namely, devices that would be able to compute any computable number, was very much in the air as nearly as the nineteen forties. At that time Turing's paper on general treatment of all logical machines was available more or less as a curiosity in mathematical circles and relatively unknown in the biological community. Quite independently, McCulloch and Pitts set about looking at the nervous system itself as a logical machine in the sense that if, indeed, one could take the firings of a nerve fiber as digital encoding of information, then the operation of nerve fibers on each other could be looked at in an arithmetical sense as a computer for combining and transforming sensory information.

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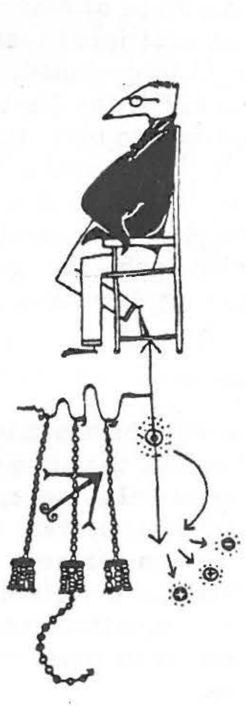

There was a good deal of reason for their notion. First, nerve impulses were all-or-none in character; that is, at any instant there would be a pulse or no pulse in a particular place along a nerve fiber. Second, the rules for combination had already been explored in part so that it was known that one could prevent firing of cells by afferent pulses from other cells and one could also promote firing by other afferent pulses.

The concepts of inhibition and excitation in the nervous system go back to the 19th century and reach their English fruition in The Integrative Action of the Nervous System by Sherrington, written in 1911. In the forties, inhibition and excitation on a monosynaptic basis had already been established by the remarkable work of David Lloyd. This profoundly impressed McCulloch. It was, in fact, the examination of the consequences that led McCulloch and Pitts to the supposition that one could apply such principles to advantage elsewhere in the nervous system. And so they set about laying out the structure of the nervous system as if it were a network of gates, exactly as in current computers, in order to compute particular functions from sense data.

Implicit in the McCulloch-Pitts design were the two notions mentioned earlier; first, that all of the data on which the content of knowledge is founded is provided by the senses and is given form by the structure of the system acting as the embodiment of the synthetic a priori, the processor; second, that any information lost in the process is permanently lost. This is given in the nature of the design of the neurons such that they can only operate on information received in the same layer.

Because this theory is, as I say, the only extant theory, however wrong it may be, of the relation of brain to mind, it is very useful to trace the precursors of that theory as it developed in the mind of McCulloch.

Early in his life, McCulloch became interested in the metaphysics of Emmanuel Kant, and in particular was very much taken with the problem of understanding the notion of the synthetic a priori. That kind of knowledge, which itself was not informative, gave form to the data or, if you wish, processed the sense impressions which are the connections with the external world. The notion that the synthetic a priori was a kind of processor was already implicit in the way Kant expressed it. The notion of giving form to that program became an obsession with McCulloch. It is one thing to utter a kind of general principle underlying a process in terms of what a mechanism can provide. For Warren, in a much more explicit way than for almost any other of his contemporaries, the brain was strictly a mechanism. It was not something that would ultimately remain mysterious, but would have to operate by virtue of rules. And he was going to find those rules somehow or other. But no matter how one regarded the problem of the brain/mind relation, perceptions, knowledge, memory, all of these mental functions remained so undefined that it was impossible to say what kind of structure would lead to them in a believable way. It occurred to Warren and Walter working together that one of the ways by which data can be manipulated and given form is to encode them, which subjects them to logical operations in a machine.

Walter Pitts, who was companion, protege and friend to Warren, had, for a long time, been convinced that the only way of understanding nature was by logic and logic alone. Up to the early forties,McCulloch's thinking was rather vague, as it had to be before the actual issues took shape. He knew that he wanted a kind of nervous operation that would do useful things, but the fundamental question remained; what was it that a neuron could do? Although he knew his logic thoroughly, he did not regard it in the same impassioned way as did Pitts. And although he knew of the work of Boole and knew very well that the Boolean logic could be applied to some mental processes, the notion of embedding that logic in a neuronal structure occurred only after the collaboration began. That was because Pitts had committed himself to logic as the key to the structure of the world in a way that no other person that I know had ever done.

When you try to think of alternative manners of handling data, except by programs, you are hard put to it to imagine them. The general rules laid down by Kant about the synthetic a priori are not specific about either data from the outside world, the empirical synthetic aspect, or about the program that handles those data. Since logic is the only successful method we know to handle data in general, and since all natural historical theory can, in one way or another, be reduced to logical manipulation, it was inevitable that the representations that McCulloch and Pitts both wanted and were successful in obtaining were representations in terms of a logical machine. In fact, what they had done in 1943 was to achieve ahead of time a kind of program for handling data before computers even existed. Strongly in the minds of both McCulloch and Pitts were the notions of Russell as contained in his essays on mind, the notions of Peirce, and to a great extent the notions of Whitehead, in particular as regards the structure of mind and experience. It was inevitable, therefore, that they should deal with brain as a logical machine. But certain personal experiences of McCulloch made this an even stronger image than he could have professed on logical grounds alone. His

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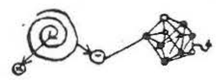

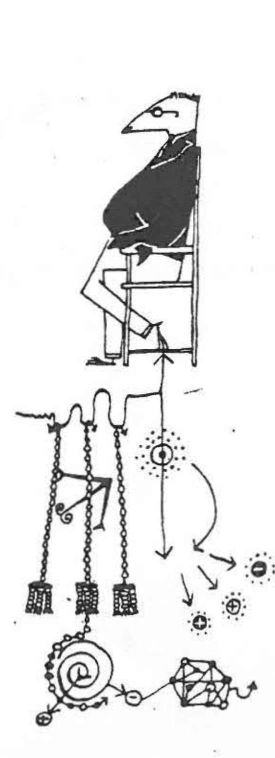

experimental researches with Dusser de Barenne on the strychnine localizations in the brain, and his own vast reading of the work done in the control of motor system, led him to the notion of a structure that must, in its internal working, be logical.

Let us regard, for example, the work done following the lines laid down by Dusser de Barenne. On strychninizing a single patch of cortex, he was able to show that the lines of communications, that is, the axonal structures leaving that portion of cortex, led to very specific other cortical points. And the way he was able to tell this was by the production of a massive, single synchronous volley occurring in the place strychninized and proceeding as a recordable volley to other points in the way that pulses would go down telegraph lines. Since the only thing that could travel down those lines were the pulses that originated in the strychninized region, then these pulses carry the information that would issue from that region to other regions. And so he had a vast account of what happened behaviorally when different portions of the brain were strychninized so that impulses proceeded from there to elsewhere. And he would give vivid accounts of cats with strychnine applied to a particular part of the brain turning and biting and scratching at particular regions of their bodies there represented, indicating that something of a sensation was set up by these synchronous pulses. Similarly he would observe, in common with his other physiological colleagues, that if one stimulated a particular nerve or a particular portion of the brain, the stimulus there,

This is the Constant K
That saved the Summary
Based on the Mummery
Hiding the Flaw
That lay in the Theory Jack built.

although electrical in nature, not coming from the external world but set up in the substance of the brain itself, would be attended by definite and very vivid kinds of experience. This kind of thinking was profoundly reinforced by Penfield's observations of particular, definite percepts attained from electrical stimulation of one area of cortex. Similar were the observations of Percival Bailey, who was one of McCulloch's very good friends. So too were the observations made by a variety of students on specific auras connected with epileptic seizures. So that, although on no account would Warren subscribe to a jukebox theory of the brain (for which he parodied Walsh, the British neurologist), nevertheless there was no question in his mind that the pulses that moved down pre-existing paths from one place to another, acting inhibitorily or excitatorily, were responsible for all kinds of perception, thinking and memory that we enjoy. If these pulses could be expressed as all-or-none entities, then one might consider that the language with which the brain talks to itself consists of strings of zeroes and ones exactly as one would have in a digital computing device built on a binary system. So, it was inevitable that one should take the easiest and most perspicuous way of devising a computer as a model of the brain.

A second feature of his work with Dusser de Barenne also played a strong part. That was the notion of the irreversibility of the synapse. That is to say, information could proceed in only one direction given a system in which synapses were the copulae. So that while it is possible that one can always build a cell that is self-excitatory or self-inhibitory by having axonal branches ending back on itself, these exotic kinds of elements, useful in a formal way, only make more poignant the specific idea that information goes in only one direction through a nervous net.

It would be impossible to devise a logical system in which the connections were reversible: that is, active informationally in both directions. So, to McCulloch's mind, the existence of a single direction in the nervous system for information reinforced the idea of an essentially logical device.

Yet, early in their thinking, both he and Pitts, looking at the material, conceived the notion that two-valued logic is not sufficient. In a word, while their machines worked on a relatively low level, the contingent aspect of experience and perception was not something that they could afford to ignore. Shortly after the paper on the logical calculus, McCulloch produced another dealing with the heterarchy of values in a nervous system. The hierarchical structure implied by the machine that he and Pitts had devised did not seem adequate to experience. In that paper, "The Heterarchy of Values," he explored the contingent aspect of perceptions by dealing with circularities of preference. This one paper by itself set him to thinking of systems of logic in which one did not have a simple yes-no, one-zero kind of element - the common gate- but, instead, one in which whether an element occupied one state or the other was contingent not only on the immediate information coming to it but on stored information as well. He sought some way to bring memory into play in a way that would not be so exaggerated as to be unrealizable, which would be the case if he pursued memory by a kind of logical net structure. The notion of many-valued logic was already given by a variety of writers in the field, although it never entered biology, but it was a proposed way of handling some formal propositions in the field of logic itself.

Yet a third influence played upon the development of the logical calculus, and that was the extreme regularity, however complex it appeared in the sketching, that was noticed by Ramon y Cajal in the descriptions of the neurons of a particular region. While to the uninitiated it seems as if the nervous system, as shown by Golgi stain, is complex beyond any reason, there is a certain repetitive order in structure that is not trivial. Indeed, the way Ramon y Cajal drew his illustrations makes the point. Ramon y Cajal never drew cells directly by looking at them through the microscope. What he did was to look at a particular region of the brain for several weeks, if necessary, day after day, element after element, and then one day he would close up his instruments, sit down and draw what he had seen, thus abstracting what might be called the visible invariants of the tissue without giving any specific cell or specific connection a hegemony, unless it were so often repeated that he could not use it. These invariant structures inside a particular portion of the brain, and for that portion of the brain invariant over all of the animals of that species, led McCulloch and Pitts to the notion that the structure of the brain dictated the logic. And it is a point that to this day is not easily controverted. It is a synthetic, indeed an esthetic task to take such an assemblage of neurons, complexity interconnected but of repetitive structure, and read into the design a function; a very dangerous step but a most useful one and certainly better than a professed ignorance.

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Cloaking Constant K
That saved the Summary
Based on the Mummery
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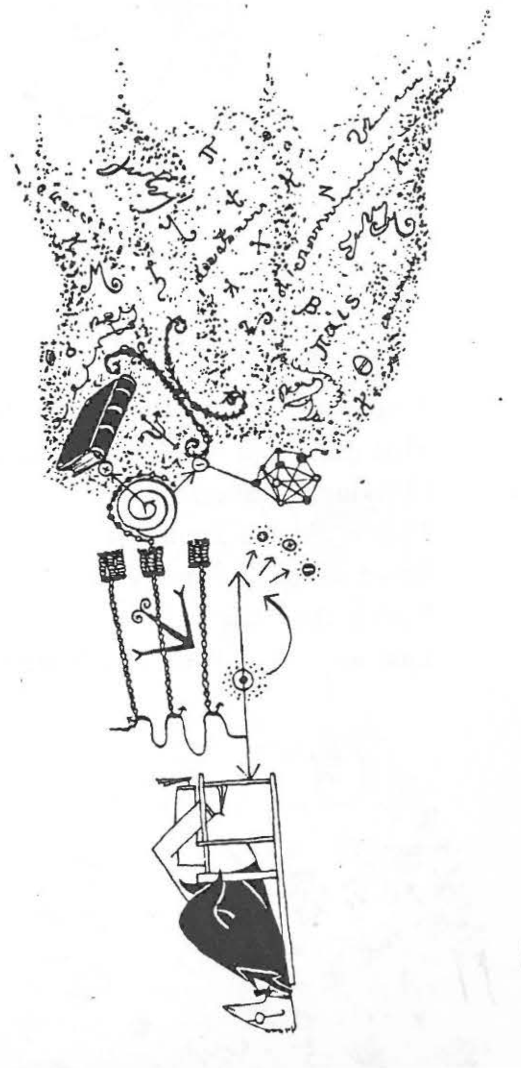
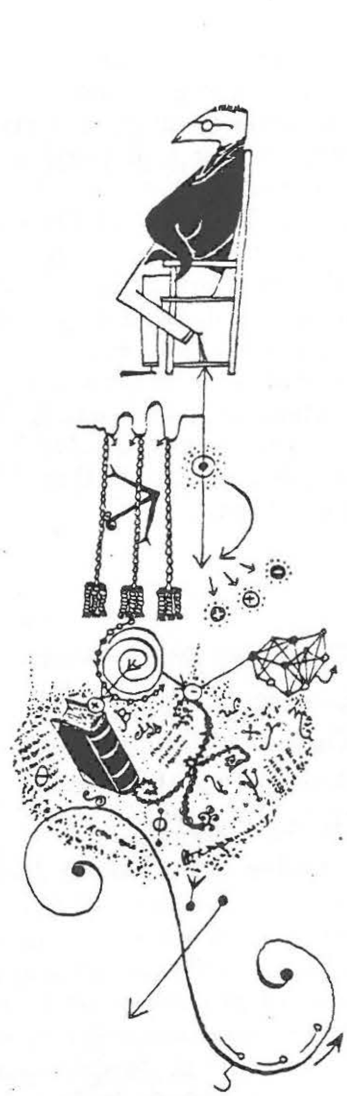
That lay in the Theory Jack built.





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That thickened the Erudite Verbal Haze
Cloaking Constant K
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The attitude of McCulloch and Pitts to the complexity, at which others turned up their hands and backed away, is perhaps best given by an anecdote which does not concern either one of them. In the 19th century there was a neuro-physiologist by the name of Dubois Raymond who would travel the lecture circuits of Berlin (for this was before television) with a nicely prepared lecture about the nervous system and its functions. He ended with the ringing motto: ignoramus et ignorabimus, "we don't know and we won't know." So incensed was the mathematician Hilbert by this horrible motto that he caused inscribed on his tombstone, Wir mussen wissen, und wir werden wissen, "we must know and we will know." And it is delightful to note that McCulloch and Pitts in this respect were on Hilbert's side.

The influence that played on McCulloch and Pitts for the construction of their paper have been recounted. But what confirmed them in their belief that the notions they had were not irrelevant was the move by von Neumann into the construction of a logical machine electronically run realizing the dreams of Babbage. Once such a machine was possible, and this occurred in only a few years after the appearance of their paper, the great temptation was to suppose that now, by means of such a machine, one finally would be able to model the brain. This certainly was McCulloch's hope. But Pitts, at this point, began to dissent. In 1949 von Neumann brought out an essay: "The Natural and Logical Theory of Automata," at the Hixson Symposium, in which after paying due tribute to the McCulloch-Pitts "logical Calculus," and recognizing it as a theory, he nevertheless takes it to task as insufficient to account for experience. According to von Neumann's criticism, the categories of experience cannot be such as those to which known logic applies. The paper is interesting because it not only deals with the McCulloch-Pitts theory of the brain, but also deals with the notion of self-replication of such systems and announces, three years prior to the discovery of the DNA basis for genetics, what the structure of genetics must be. McCulloch and Pitts took the paper seriously but could not respond to the criticism any more than von Neumann himself could show a way out. Von Neumann was of the opinion that the logical design of his computer would indeed make all sorts of computation possible, but only under the specification that you knew exactly what you wanted; that is, it could compute any computable number in exactly the same way as could the McCulloch-Pitts nerve set. The question that von Neumann raised not only about his machine but about the McCulloch-Pitts model was whether or not this was the essence of perception, thinking, memory and the like; that you were computing specific computable numbers or something that could be mapped onto them.

Later on Minsky, who took his doctorate under von Neumann, was to say that this was an aberration of von Neumann's. That is to say, it was a confession of weakness on von Neumann's part, because he had not enough faith in the structure that he had built. But this, I think, is a way of avoiding the issue raised by von Neumann as much against himself as against the McCulloch-Pitts theorem.

One would assume, I think, that the presence of a theory, however strange, in a field in which no theory had previously existed, would have been a spur to the imagination of neuro-biologists, if I may use so horrid a term. But this did not occur at all! The whole field of neurology and neurobiology ignored the structure, the message, and the form of McCulloch's and Pitt's theory. Instead, those who were inspired by it were those who were destined to become the aficionados of a new venture, now called Artificial Intelligence, which proposed to realize in a programmatic way the ideas generated by the theory. In no sense was Artificial Intelligence going to resemble or explain natural intelligence. Instead, it would show that monsters that could, in fact, act like humans or like animals could be built and, therefore, could be used as representations of the original. This field, Artificial Intelligence, so peculiarly engendered by McCulloch, was one, for some reason, McCulloch himself avoided. In retrospect, it is hard to say why. Minsky's work was not inconsiderable. Minsky and Papert between them had already begun designs on game-playing machines - task-oriented machines that were to become in the short period of a decade or two more impressive. Not that they ever realized anything so simple as a perception, but they did tasks that were formerly thought to be peculiarly human. For example, they played chess, they piled blocks on each other, they did what two or three year old children are said to have to learn to do, and in a way represented exactly the sort of caricature necessary before one begins a filling-in job.

This is Chaotic Confusion and Bluff
That hung on the Turn of a Plausible Phrase
That thickened the Erudite Verbal Haze
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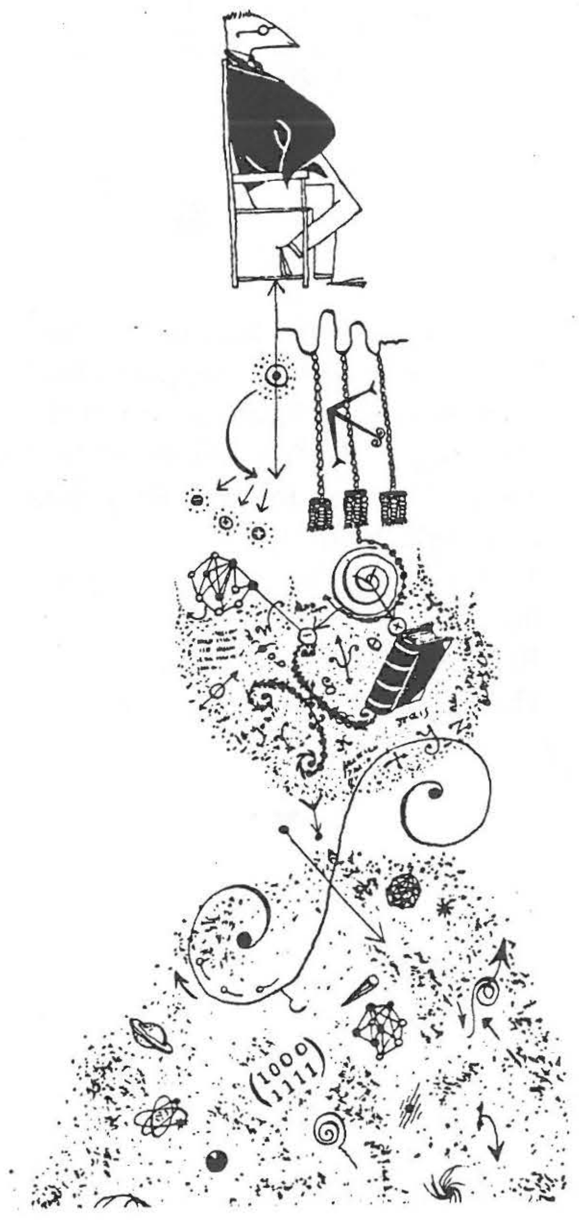
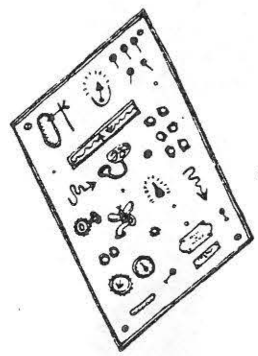
Hiding the Flaw
That lay in the Theory Jack built.



This is the Cybernetics and Stuff
That covered Chaotic Confusion and Bluff
That hung on the Turn of a Plausible Phrase
And thickened the Erudite Verbal Haze
Cloaking Constant K
That saved the Summary
Based on the Mummery
Hiding the Flaw
That lay in the Theory Jack built.



This is the Button to Start the Machine
To make with the Cybernetics and Stuff
To cover Chaotic Confusion and Bluff
That hung on the Turn of a Plausible Phrase
And thickened the Erudite Verbal Haze
Cloaking Constant K
That saved the Summary
Based on the Mummery
Hiding the Flaw
That lay in the Theory Jack built.

Yet, with all of this promise held forth by AI, McCulloch could not himself take it as seriously as he might have, and that was because he felt that a logical machine by itself, however cleverly programmed, would come to naught. It was very hard to find out from him why this was the case. He staunchly supported Minsky and Papert in their endeavors, and indeed they readily agree that they took inspiration from McCulloch. Yet something lay in McCulloch's mind, saying this is not the case; that is, there must be another kind of model that should be more suitable. And he began playing with all manner of logic. I mentioned the three-valued logic which arose from the paper A Heterarchy of Values. He also played with probabilistic logics. He played with all manner of strange notations to try to find one that would appear to him consonant with what it was he felt neurons could do. It is hard not to sympathize with him, because it is better to be Don Quixote than Sancho Panza in any view of the world. That is, it is better to go with a lance after a dream than to accept the status quo, however profound the status quo may seem.

And so, for a while he went back to the philosophers who initially had informed him, and again he restudied Leibnitz, Kant, Peirce, the various schools which they set up and others set up after them, and I well remember his revulsion when he came to Hegel reconsidered. There was no nonsense to his tongue-in-cheek view of their considerations of epistemology. He never seemed to be able to find a philosopher to whom he could accord an insight into the nature of the problem that he was attacking. One line of thought he found immensely attractive. In his reaction against Freud, seeing in Freud the simple repetition of what was in Plato's Republic, the notion occurred to him of a command structure in the nervous system, almost military, certainly governmental, possibly naval in structure; a system of command and control by which experience as much as intention and all those other aspects of epistemology could be formed. He had investigated the reticular formation in the brain stem, together with his colleagues Magoun and Snider at Northwestern University. This region anatomically described by Paul Yakovlev as "the original beast," the fundamental animal structure of the brain, seemed to Warren to be not necessarily the place of the ego, but certainly the place whence all of the rest of the brain was organized in some instructional way. He was delighted when Percival Bailey, touching the opening of the aqueduct from the third ventricle, showed that a patient instantly went to sleep, and called the region "the center of unconsciousness," which is a delightful parody. In almost all the instances of encephalitis, wherein the circum-aqueductal structure was involved, there was profound disorder in thought, in consciousness, and in ability to perform in spite of the fact that the number of cells in this lining of the aqueduct and ventricles is relatively small compared to the number of cells in the rest of the nervous system. It was important that Magoun was able to show that he could either activate an animal - that is, arouse an animal from sleep - or put an animal to sleep by stimulating in different portions of the reticular formation. In those parts of the reticular formation called the magno-cellular groups, there lies the capacity of either inhibiting or exciting the whole sphere of action via long tracts to the spinal cord. I remember how excited he was when Oliver Selfridge and I one night showed that, in an animal intoxicated with a fatal dose of strychnine, we could prevent all strychnine convulsions by continuous stimulation of the bulbo-reticular inhibitory tract. It seemed to him, as it seemed to Paul Yakovlev, and as it seemed to Magoun and his cohorts, that the control of the whole nervous system lay in this innominately connected reticulum around the central canal of the brain and spinal cord. He switched, therefore, from examining the input and how it was to be processed to examining the control system that ordered the processing. While it would be difficult to say exactly how the reticular formation as a biological structure would engage the whole brain, throwing it into one state or another, that it did so seemed to be unarguable to McCulloch, and certainly in many respects seemed to follow from the physiological experiments themselves.

Accordingly he transferred his attention from the relatively intractable problems of dealing with perception and memory to dealing with control processes, or the control of processes that themselves were the synthetic a priori needed by Kant. In this way, which represented a kind of impossible dream by his own account, he was joined by a variety of

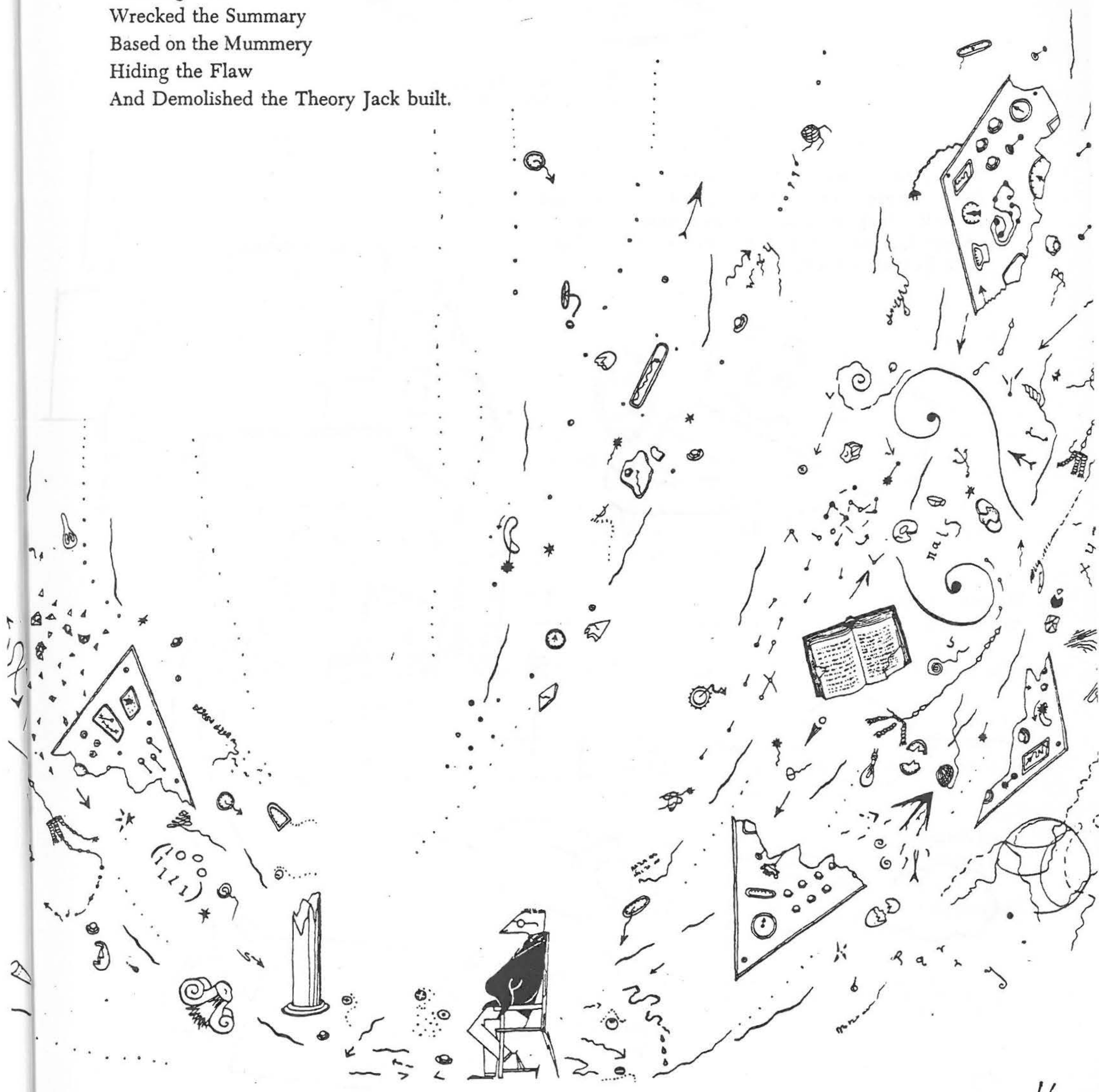
other researchers. Here the data were not to be had, and it was not that states of the reticular formation could be represented in such a way as to be experimentally accessible. It was a set of gedanken experiments entirely devised to give a kind of eminence grise that chose between synthetic a prioristic programs. This is the first time that McCulloch departed from a base in empirics. He was going to try to devise the system completely divorced from the possibility of any measurement, and devise it in such a way that the logic used could be applied to any control system. It was an ambitious program and one that is very hard to understand.

The notion of a control system somewhat independent of what was to be controlled is like a Cheshire cat's smile. Yet, in a way, the experience of Magoun and Snider in which Warren also collaborted, could not help but give the impression that such a system must exist. And accordingly, Warren set about how to envisage an optimum naval command as a way of looking at the fundamental governing structures of nervous activity. Not wishing to give the notion that he was designing for military purposes, I mean only that he was looking at general principles involved in an hierarchical structure of command.

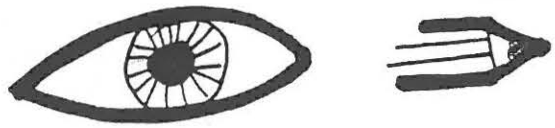
Even in this, however, he was to be frustrated, because the handling of such a system as he wanted required minimax operations of a kind which had not yet been realized. One of the difficulties in dealing with representations of systems is that singularities which are, in fact, an important part of a theory of control in the real world are very difficult to represent formally. The notion of a general mode of handling such singlarities, therefore, was Quixotic in the extreme. And yet, as Walter Pitts once remarked, there are only two kinds of problems: trivial and insoluble, and an insoluble problem becomes trivial once you have solved it. It was certainly in McCulloch's character that the more insoluble a problem seemed the more he was likely to attack it.

J. Y. Lettvin is Professor of Communications Physiology in the Department of Electrical Engineering and Biology at MIT, and a Lecturer in Neurology at Boston University.
This article was written as an introduction to the collected works of Warren McCulloch, edited by Rook McCulloch, as yet unpublished.

This is the Space Child with Brow Serene
Who pushed the Button to Start the Machine
That made with the Cybernetics and Stuff
Without Confusion, exposing the Bluff
That hung on the Turn of a Plausible Phrase
And, shredding the Erudite Verbal Haze
Cloaking Constant K
Wrecked the Summary
Based on the Mummery
Hiding the Flaw
And Demolished the Theory Jack built.

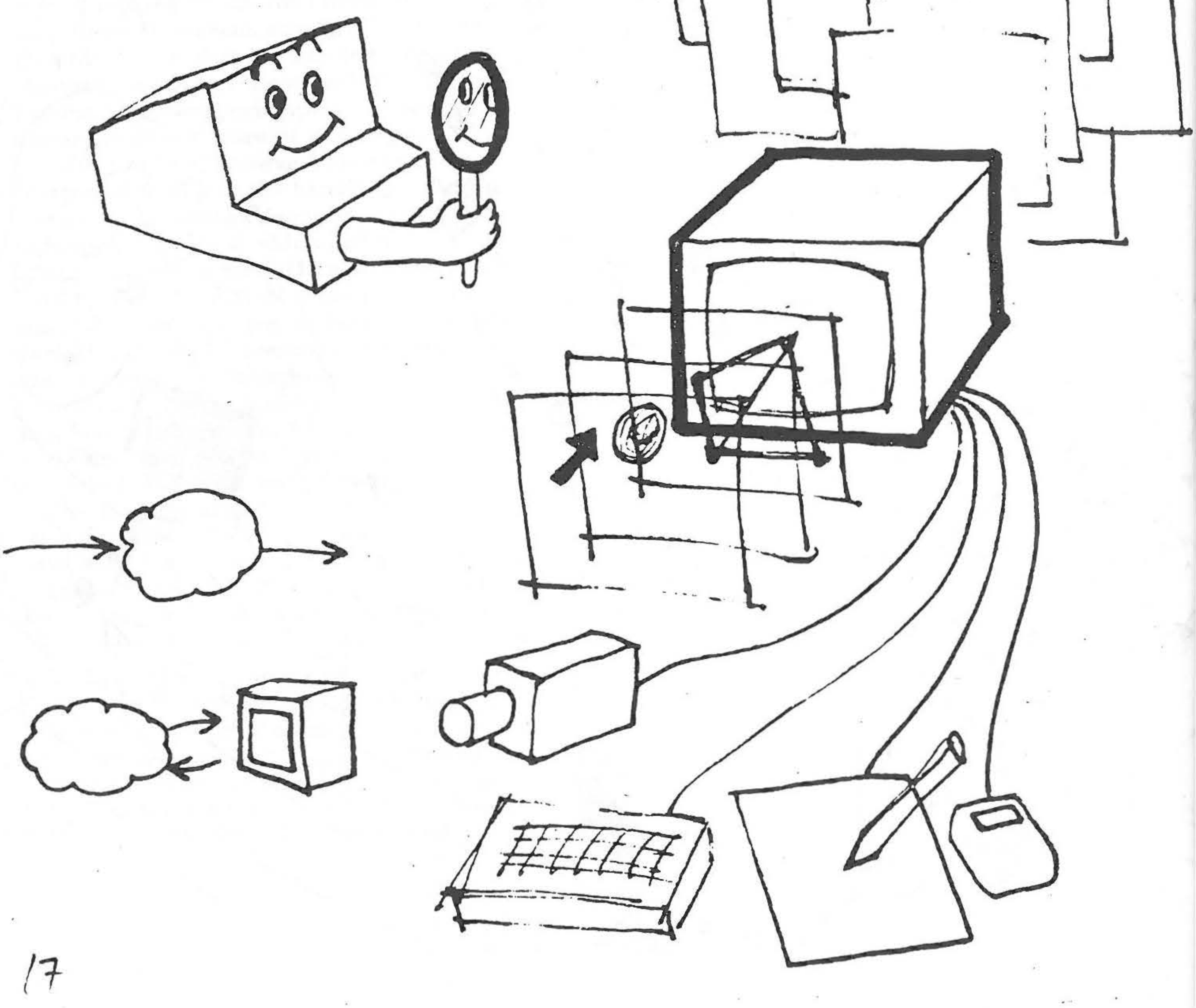


Viewpoint



Scott Kim

This article is adapted from my thesis proposal for an interdisciplinary Ph.D. in computers and graphic design at Stanford University. The research is currently being done at Xerox Palo Alto Research Center.



1. Introduction

As more and more people throughout society learn to use computers, the quality of the human-computer interface is becoming an increasingly important factor in the design of computer systems. Manufacturers are turning to graphics in particular to give the computer user a better picture of what's going on.

In fact, we are just beginning to discover the full potential of computer-aided graphic communication. The "desktop" may be a useful metaphor, but it is only one small point in a sea of possibilities. Computers have been and still are visually impoverished when compared to the full range of human visual experience.

The problem has to do with imagination, not hardware. Computer scientists simply aren't trained to think in terms of visual communication, and therefore don't know what questions to ask. Graphic designers and other visual communicators, on the other hand, have not had the time or motivation to fully appreciate the capabilities of the computer medium, and so are ill-equipped to find answers. What is needed is an interdisciplinary approach that recognizes the capabilities of both computers and graphic design.

The purpose of Viewpoint is to explore the consequences of a particular user interface design principle: The computer should be able to see everything the user can see. I will build a series of small interactive programs that maintain the condition that the computer can at any time reconstruct the entire state of the system by "looking" at the screen (i.e. reading the contents of the frame buffer*). In other words, what you see is not only what you get, it is also what the computer gets.

The purpose of this proposal is to define my research goal, place it in the context of current thought, show that it is worthy of research, and show that it is feasible as a project. Since the topic is somewhat unusual, this proposal goes rather far towards imagining a solution.

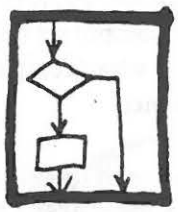
* "Frame buffer" here actually refers to more than one screenful. Just as one must scroll through a text file (extended text buffer) to read beyond the current screenful, so one must flip through many pages of a graphics file (extended frame buffer) to see beyond the current screenful.

2. Background

Here are some thoughts I have pondered while formulating Viewpoint.

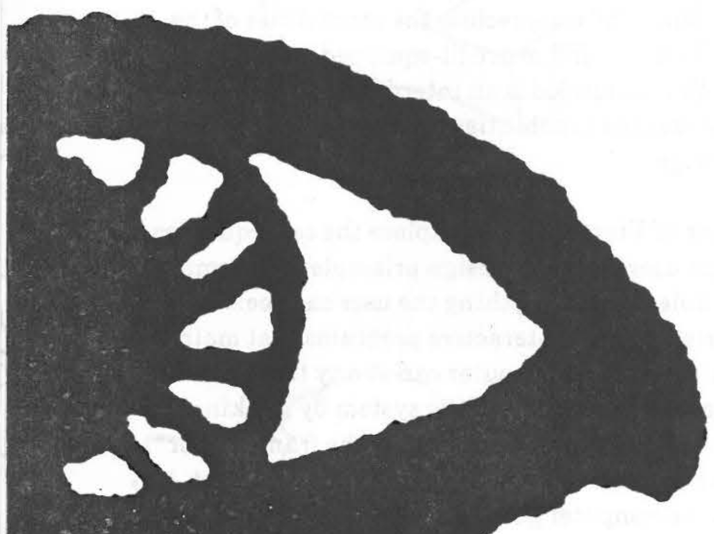
Computers and Graphic Design

Computer-Aided Design is computers in support of design, either 2 or 3-dimensional. The flip side of CAD is DAC: Design-Aided Computation, or design in support of computation.



What is a Programming Language?

From the moment I learned my first programming language, I have been curious to probe the more philosophical aspects of language. I expected to find the sort of systematic axiomatic discussions one finds in mathematics. What I found instead were shallow territorial arguments that were of no help in clarifying the structure of the space of possible programming languages. I found the most broadminded discussions in historical books such as *History of Programming Languages* [Wexelblat].



After many discussions, I have concluded that programming languages are but one point on a continuum of possible human-computer interactions that include commands, editing, and simulation. My goal as a user is less to design better programming languages, and more to eliminate the need for programming in the first place.

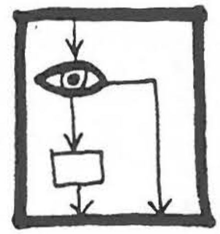
What is Visual Thinking?

We live in a society that systematically rewards verbal skills, and devalues visual skills. Admission to college is on the basis of mathematics and English skills. Visual and spatial reasoning are relegated to "IQ" or "aptitude" tests, the implication being that these skills are innate, not teachable. Indeed, many people cannot comprehend what it means to "think in pictures".

My dream is a computer for visual thinkers. I am motivated by a belief that the current verbal bias of computer science is not inherent in computers, but instead reflects current societal tendencies.

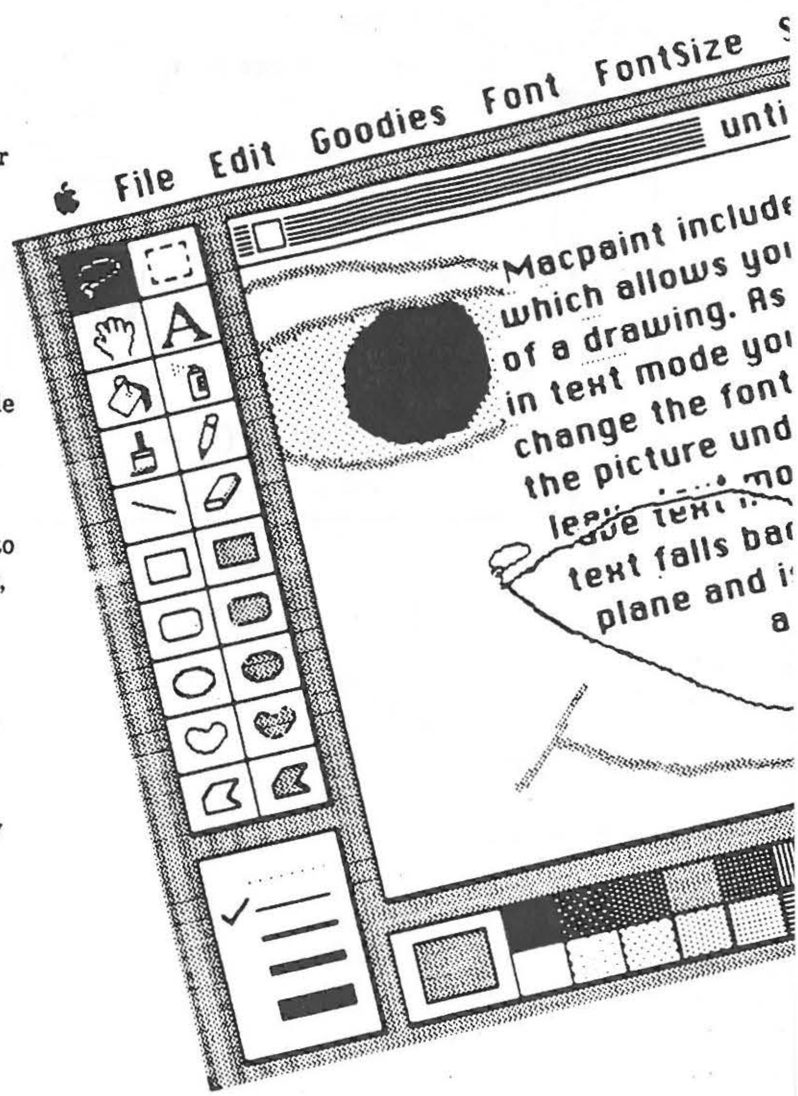
Visual Programming

It is tantalizing to imagine an entire programming language in which programs were represented as pictures or diagrams, instead of as strings of text. Consider this analogy: A text editor is to a programming language as a painting system is to what? It should be possible to find the missing analogy -- and yet every attempt I have ever seen falls frustratingly short of the mark.



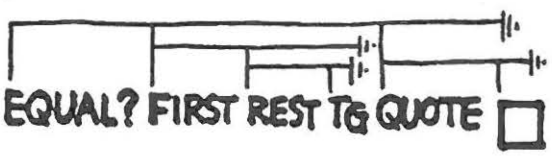
For the past three years I have studied visual programming languages. I decided reluctantly to give up the idea of constructing a visual programming language when I realized that I had a good idea of what wouldn't work -- but not much idea of what would. Too many fundamental issues remain cloudy.

Here are some of the approaches that have been tried. For discussion of general issues, see [MacDonald] and [Narasimhan].



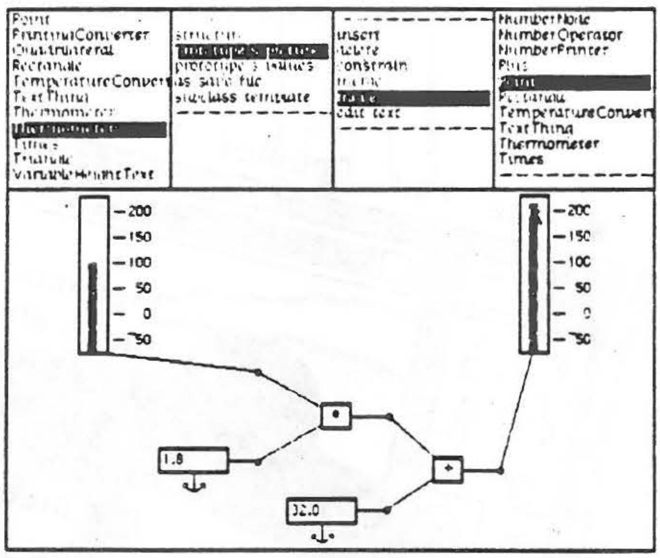
Flowcharts are the best known diagrammatic form of programs. Many attempts have been made to automate the conversion of code into flowcharts. The other direction, the automatic conversion of flowcharts into code has also received some attention. Ephraim Glinert's system *Pict* [Glinert] is a particularly thorough implementation of a totally iconic programming system that uses flowcharts. I find the flowchart metaphor easy to learn, but not very satisfactory for large programs. *Boxer*, by Andy diSessa [diSessa] , uses nested boxes to show program structure.

Dataflow. Flow diagrams are particularly well-suited to highly parallel systems such as circuits and data-flow languages. Dataflow programming languages that actually use flow diagrams as source code include *GPL* by Alan Davis [Davis].



Trees are an alternate way to diagram program structure. Fred Lakin's *VennLisp* [Lakin] uses trees to visualize the structure of the programming language Lisp.

Programming by Example represents flow of control implicitly by sequences of actions by the user, instead of using explicit connecting arrows. In many such systems the "program" is never seen all at once. Programming-by-example systems include *Pygmalion* by David Canfield Smith [Smith75], *Programming by Rehearsal* by Laura Gould and Bill Finzer [Gould], *Tinker* by Henry Lieberman [Lieberman], and *Smallstar* by Dan Halbert [Halbert].



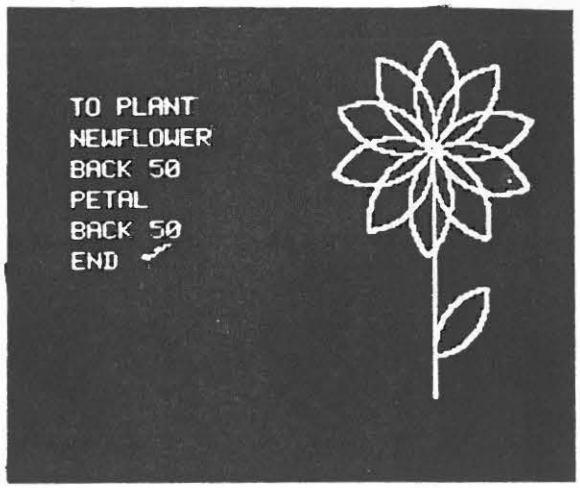
Constraints provide an interesting way to specify structure in a geometric figure. Constraint-based drawing systems include Ivan Sutherland's early system *Sketchpad* [Sutherland], Alan Borning's *Thinglab* [Borning], Greg Nelson's *Juno* [GregNelson], and most recently James Gosling's *Magritte* [Gosling].

Kits. The most satisfactory examples of visual programming simplify their task by restricting the domain. "Kit" is Alan Kay's word [Kay84] for a system that is particularly prone to learning by sticking things together to see what happens. *VisiCalc* by Daniel Bricklin and Robert Frankston [Bricklin] is the single most successful example of a kit. Another popular kit is *Think Tank* by David Weiner [Weiner]. I like to call these "single metaphor systems". The trick is to find a single organizational metaphor with a very simple behavior that can be exploited to cover a wide range of applications. Other kits that aspire towards programming include *Pinball Construction Set* by Bill Budge [Budge], *Rocky's Boots* by Warren Robinett [Robinett], and its sequel *Robot Odyssey* by Mike Williams [Williams].

Program visualization takes the idea of a visual programming language in an entirely different direction. Three strikingly original efforts to visualize the workings of a running program include *Algorithm Animation* by Marc Brown and Robert Sedgewick [Brown], *MacPascal* [MacPascal], and *Typography for Computer Programs* by Aaron Marcus and Ronald Baecker [Marcus].

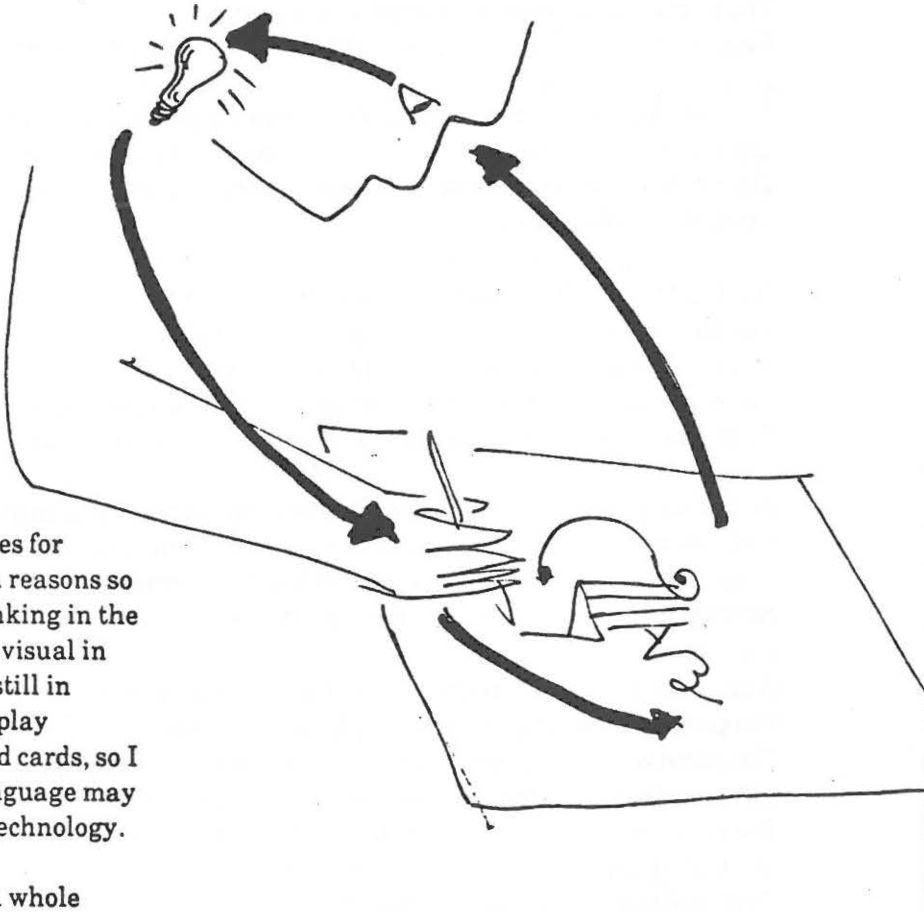
Logo, by Seymour Papert [Papert], is a programming language often associated with graphics. While the output of a Logo program is frequently graphical, the programs themselves are still conventional text, so Logo does not qualify as a visual programming language.

(On the other hand, text *is* visual in the sense of being something you look at, so in an extreme sense Logo (and every other programming language) can perhaps be considered a visual programming language.)



Mumble by Leo Guibas [Guibas] also does not qualify as a visual programming language -- the source code is still textual. It does, however, treat the raster as a fundamental data type, and considers the computational implications of raster-oriented operations.

Mandala by Jaron Lanier is an ambitious effort to combine many different programming metaphors in a single visual programming language. The visual style is iconic, and can mimic many different notations. The most unusual aspects of Mandala are its ability to keep up with real-time simulation, and the importance given to style and "playability".



3. The Idea

After pondering visual programming languages for several years, I concluded that one of the main reasons so many people got stuck was that they were thinking in the wrong medium. The programs may have been visual in form, but the thinking behind the scenes was still in words. Just as it is difficult to conceive of a display oriented text editor when you're using punched cards, so I imagined that a truly visual programming language may be beyond difficult to imagine within today's technology.

So I turned my attention away from building a whole programming language to building a medium that would support such investigations. My goal was to imagine what computers would be like if pictures (as opposed to numbers or text) were treated as the primary representation of information in a computer.

Here is the thread of reasoning I discovered.

Four Views of Computers

My research fits best under the heading "user interface design". It is very useful to understand how the concerns of this new field differ from those of other aspects of computer science -- my research makes little sense within more traditional attitudes.

Attitude #1. The computer as reality.

The purpose of a program is to control a computer.
First build the computer, then figure out how to program it.

In the earliest days, the main problem was to make sure that the machine kept running. This view is embodied machine language programming.

Attitude #2. The program as reality.

The purpose of a computer is to implement programs.
The purpose of a program is to get an answer.
First write the algorithm, then build a computer to implement it.

As computers became more reliable, it became possible to treat the computer as a black box and concentrate on idealized "device-independent" algorithms. This view is embodied in the analysis of algorithms and the mathematical theory of computation. The transition from computer to program is described in [Dijkstra].

Attitude #3. The software system as reality.

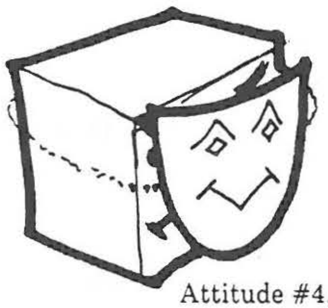
The purpose of a computer is to implement programs.
The purpose of a program is to implement part of a larger system.
The purpose of a system is to simulate a process, part of which involves getting answers.
First plan the system, then write the individual modules that implement it.

As software systems became larger, it became necessary to shift attention from isolated software modules to the integrity of the connections between modules. This view is embodied in structured programming. Previous views ignored the importance of maintaining consistency in the face of complexity. The transition from program to system is described in [Winograd].

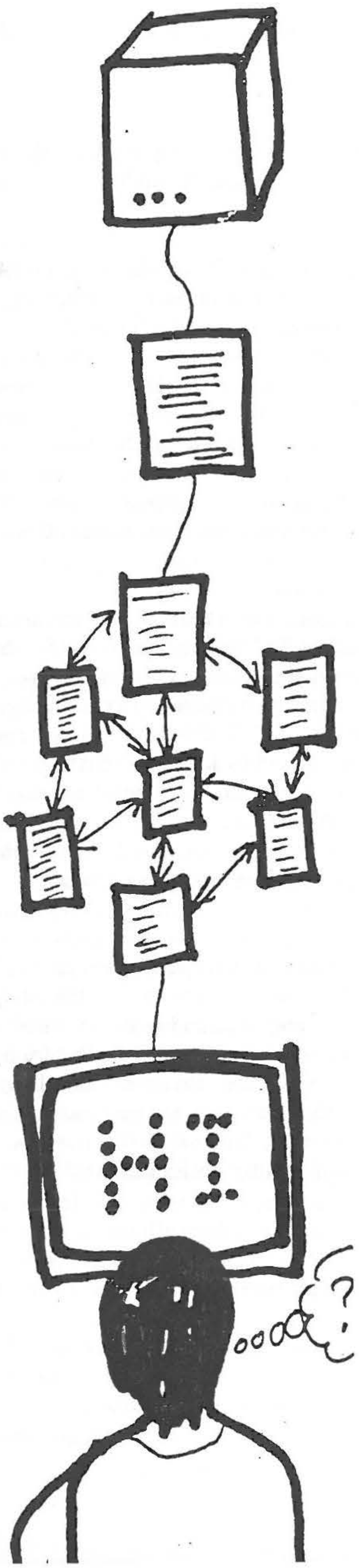
Attitude #4. The human-computer interface as reality.

The purpose of a computer is to implement programs.
The purpose of a program is to implement part of a larger system.
The purpose of a system is to implement an interface.
The purpose of an interface is to support human-computer communication, part of which involves simulating processes and getting answers.
First design the interface, then plan the system that implements it.

As computer hardware became cheaper and the audience for software became larger and less specialized, it became economically both possible and necessary to devote more of the resources of the computer to the user interface. This view is embodied in video games, word processors, and bit-mapped displays. Previous views ignored the role of the user in the design of a computer system. The transition from system to interface is described in [Smith82].



Beyond "User-Friendly"



Attitude #4, the interface as reality, is just now beginning to be accepted. The ACM has finally formed a special interest group in "Human-Computer Interaction" [SIGCHI]. Computer manufacturers are now hiring graphic designers, writers and other nonprogrammers to design interfaces before the software is written.

The field is immature, however. Design is imitative, heavily influenced by obsolete technologies. Interface design by computer scientists is further hampered by lack of knowledge of basic communication techniques.

Paul Heckel in his book *The Art of Friendly Software Design* [Heckel] argues that "writing friendly software is a communications task, and to do it effectively you must apply the techniques of effective communication, techniques that are little different from those developed by writers, filmmakers..." Unfortunately, Heckel's recommendations are too vague to design from. User interface design has yet to evolve beyond banner waving.

Text editor design, the quintessential interface design problem, has yet to take its place next to compiler design in the computer science curriculum. There are still no books written on the principles of text editor design. Interface design is treated like a token art class in an engineering school, if indeed it is treated at all.

Research in the psychology of human-computer communication has concentrated almost exclusively on textual interaction [Card]. It is too early to evaluate the effectiveness graphic interaction techniques -- far too few ideas have been attempted, let alone analyzed. In general, communication, psychology and linguistics are better equipped to cope with linear textual communication than they are with visual communication.

We need simple experiments that systematically explore possible graphic interface paradigms, fueled by precisely stated interface design principles. Unfortunately, interface design principles are usually vague -- "user-friendly" is hardly objective. Xerox's Star [Smith82], one of the few systems developed according to interface design principles, is too complex to be a conclusive experiment.

The Display as Reality

OBJECTIVITY IS
THE DELUSION
THAT IT IS NOT
A DELUSION.

IT IS THE COGNITIVE
VERSION OF THE
PHYSIOLOGICAL
BLINDSPOT:

WE DO NOT SEE
THAT
WE DO NOT SEE.

HEINZ VON FOERSTER

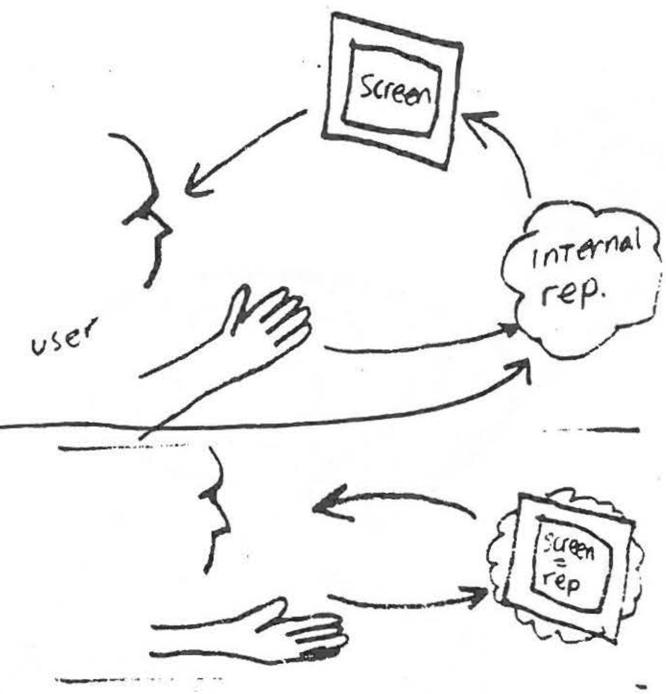
A subtle thing happens when everything is visible: the display becomes reality. -- David Canfield Smith [Smith82]

Ben Shneiderman, in his article *Direct Manipulation: A Step Beyond Programming Languages,* [Shneiderman] reports that "certain interactive systems generate glowing enthusiasm among users -- in marked contrast with the more common reaction of grudging acceptance or outright hostility". He cites as examples word processors, VisiCalc, Nicholas Negroponte's Spatial Database Management system [Herot], video games, and computer-aided design and manufacturing. All these systems display a continuous graphic model of the state of the system.

The key to direct manipulation is that *the user can act as if the display were reality.* Ted Nelson has a name for this phenomenon. "By the virtuality of a thing I mean the *seeming* of it, as distinct from its more concrete 'reality,' which may not be important." [TedNelson] The user need not know or care about 1s and 0s dancing about the silicon. The internal and external representations may in fact be very different. All that matters is that the display provide everything the user needs to know for a particular application. Alan Kay calls this "the user illusion" [Kay84].

The "user illusion" comes as a surprise to many in computer science. It has much more to do with the misty world of expectations, perceptions and misunderstandings than it does the black and white world of bits. But from the point of view of the naive user, the screen has always been reality. Faced with a black box, the user has no choice but to trust the screen. The real question is how was computer science able to not notice this fact?

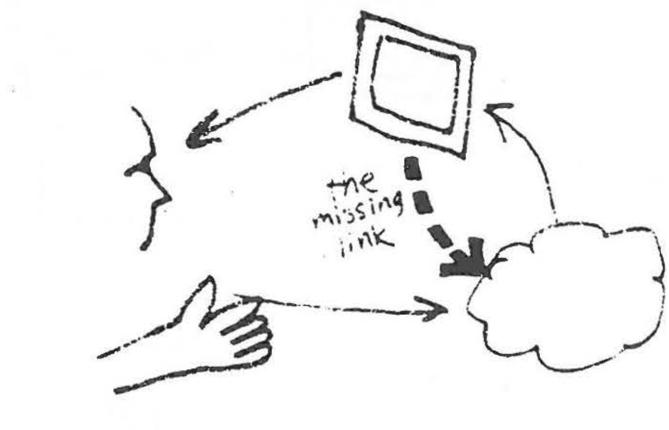
Visual Modelessness



Here is a diagram of a human-computer dialog featuring a bit-mapped screen. The user types on a keyboard, which affects an internal data structure. The computer, in term, displays a response by writing it to the frame buffer, which is isomorphic to the screen the user sees.

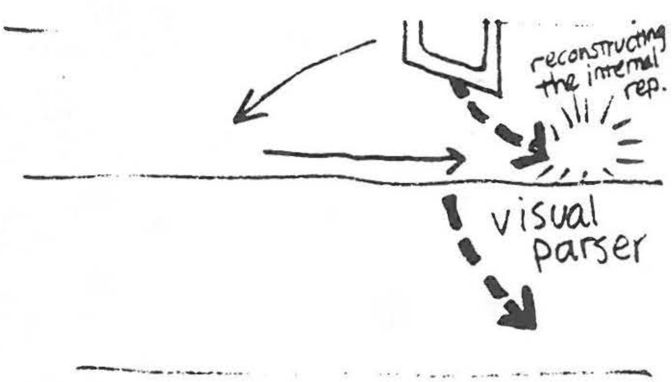
Direct manipulation occurs when the user can act as if the bitmap were the same as the internal representation. In this case the three-part loop collapses to a two-part exchange in which both the user and the computer are working from the same assumptions.

The thing to notice in this picture is that from the point of view of the computer, the screen is a second class citizen. The real work happens in the internal representation, invisible to the user. Only then does the computer deign to inform the user of the results. Nothing guarantees that the screen image is in fact an accurate picture. The user depends on the screen for accurate feedback; the computer has no such dependency.



What if the screen were a first class citizen? Selfridge's principle [Selfridge] says that the computer ought to be able to do anything the user can do. Applied to graphics, this leads to a computer that can see its own screen. In order for the screen image to be a first class citizen, we need to fill in a missing link. I call this operation of converting a screen image into an internal representation "parsing the bitmap".

Definition: A computer system is "visually modeless" if at the end of each operation it is possible to completely reconstruct the entire internal state solely from the information in the screen image.



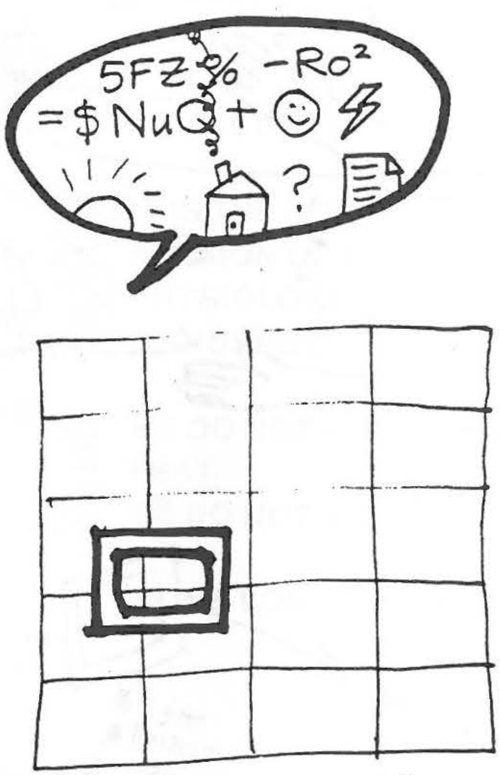
Of course it may be wasteful to actually throw out the internal state after each operation. Nevertheless, if the system is visually modeless, it shouldn't matter. The test of visual modelessness is to write an explicit visual parser that can rebuild the internal state from the screen image.

My thesis is that a variety of useful interactive systems can be built that adhere strictly to this principle. I intend to show how this can be done, and show when it is advantageous.

This hard principle has several soft aspects.

1. "At the end of each operation" implies that the cycle time for operations is relatively short. Visual modelessness is intended to be applied to interactive systems, in which typical operations take less than a second.

2. "The entire internal state" need include only what is relevant to the user's application.



3. Information must be legible, not merely visible. For instance, a raw core dump is not enough. Another way to violate the spirit of visual modelessness is to burden the image with every possible caption and explanation. Again, this is not in the spirit of the principle. A concurrent goal to visual modelessness is clear communication with the user.

4. Only very small systems can keep the entire state of the system on a single screen. When I say that it is possible to reconstruct the internal state solely from the information in the screen image, I allow the screen image to include much more than can be actually displayed at once. This means that one way to achieve visual modelessness is to sweep all the state information under the rug, so to speak, into an off-display screen. Clearly this is not in the spirit of the principle, but it is difficult to disallow. Offscreen information is allowed to be used in the reconstruction only if it is locatable based on the onscreen information, and relatively easily accessible:

5. Visual modelessness was inspired by "what you see is what you get", a principle designed to make things clearer to the user. However, visual modelessness by itself does not guarantee clarity any more than structured programming guarantees good programming style. Nor does a program have to be visually modeless to be good. It is merely one of many possible design constraints. I should add that visual modelessness and conventional modelessness are quite different constraints. One does not imply the other. (I need a better name for "visual modelessness"!)

Why Do You Want to Deal With Bitmaps?!?

I'm glad you asked that question. The general idea of "direct manipulation" may seem okay, but groveling in the bits strikes many people as going a bit too far. At least it struck me that way the first time the idea occurred to me. Here are some of the more common objections I've heard.

Objection #1. What you see is all you've got. The whole point of using a computer is the ability to abstract. By forcing everything to the lowest common denominator, you lose the whole point of using a computer.

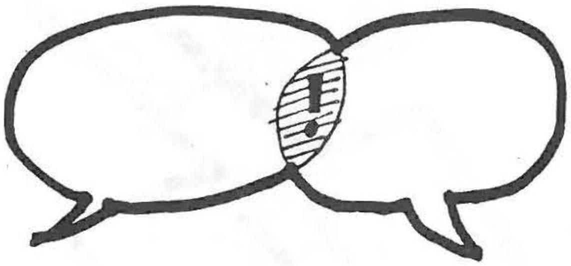
Answer #1. All you've got may be quite a lot, if you've chosen your visual language well. The lowest common denominator in fact has the great advantage that you never paint yourself into a corner. Consider the lowly string of text. The uniformity of text makes it very easy to do everything you want in a text editor with a very simple set of commands. Yet compilers and interpreters make it possible to turn text strings into much more structured objects.

Objection #2. You're going to have to solve the whole vision problem! At best it will be several lifetimes of work, at worst it will be impossible to cope with the ambiguities and subtleties of human vision.

Answer #2. No, I don't intend to go that far. In fact I intend to sidestep entirely any aspect of pattern recognition that has any element of chance or uncertainty. Instead I will simplify the vision problem by restricting the visual syntax to simple unambiguous shapes.

Here's an analogy I've found tremendously helpful in understanding this point. In 1953 Captain Grace Hopper was trying to sell the idea of high-level programming languages to the military. In those days programs still looked like social security numbers. It was in that setting that her

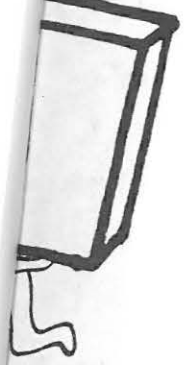
> ...December 1953 report proposed to management that mathematical programs should be written in mathematical notation, data processing programs should be written in English statements, and we would be delighted to supply the two corresponding compilers to translate to machine code. I was promptly told that I could not do that. And this time the reason was that computers couldn't understand English words. [Wexelblat]



Viewpoint need not solve the vision problem any more than Fortran need solve the language problem. The trick is to meet half way, to devise a syntax that is both helpful to the user and unambiguously parsible by the interpreter. Vision research is interesting, but it is not the subject of this project.

Objection #3. I said it once and I'll say it again. The whole idea is to get away from the bit-level representation.

Answer #3. That's only partially true. The formal power of a language derives from its ability to represent abstract structures. But the communicative power of an interface derives from its ability to make ideas concrete. Both abstraction and concretion are important in computer systems. It's true that resolution independent outlines are more readily adapted to a variety of output devices. But anyone who wants to get the best out of a particular device must also confront the problems of device dependency, in this case the bit-level representation. Finally, the bit-level representation is better able to sustain ambiguity. Smalltalk gets great leverage by delaying the interpretation of messages, keeping them as raw strings.



Objection #4. Why put yourself under such severe design constraints?

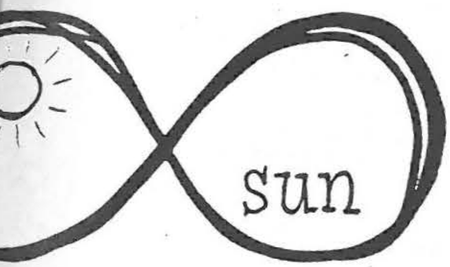
Answer #4. To see what breaks. Until I know what fails, I won't know where the limits are. I am deliberately taking an extreme position in order to see what happens.

And it may not, in fact, be that extreme. I like to think of visual modelessness as similar to program modularity. In both cases you gain confidence that there will be no unexpected side effects by adopting a strict discipline that maintains certain invariant conditions. The only difference is that structured programming deals with the interface between program modules, where visual modelessness deals with the interface between people and computers.

Objection #5. Parsing the bitmap at every step will be extremely slow and take excessive amounts of memory.

Answer #5. I have no objections to using auxiliary data structures to gain efficiency. Visual modelessness says only that they are not logically necessary. On the other hand, speed is not the main goal of this project. Yes it will take rather large amounts of memory, though I have no objection to data compression.

Objection #6. What can you do that's new?



Answer #6. Truly integrated text and graphics. I imagine a system in which there are just bits on the screen. If you want to treat some bunch of bits as text, you temporarily lift it out of the bit plane into a text plane. But once you are done, it becomes bits again. "Integrated" implies that the elements were once separate; a better term is "homogeneous" software. The final justification is "because it's there". No one, to the best of my knowledge, has tried this approach yet.

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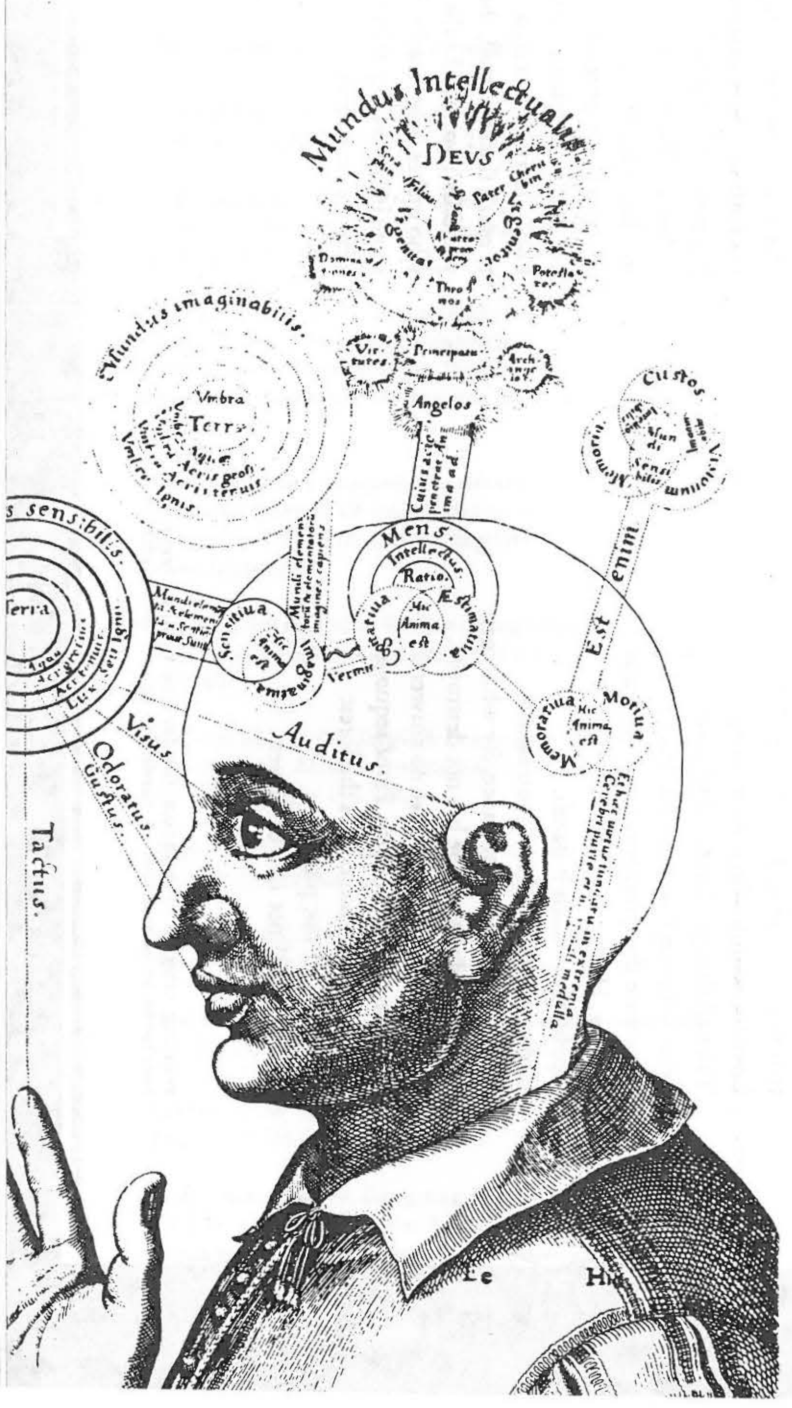
Manifesto: The Mad Farmer Liberation Front

By Wendell Berry

Love the quick profit, the annual raise,
vacation with pay. Want more
of everything ready made. Be afraid
to know your neighbors and to die.
And you will have a window in your head.
Not even your future will be a mystery
any more, Your mind will be punched in a
card
and shut away in a little drawer.
When they want you to buy something
they will call you. When they want you
to die for profit they will let you know.
So, friends, every day do something
that won't compute. Love the Lord.
Love the world. Work for nothing.
Take all that you have and be poor.
Love someone who does not deserve it.
Denounce the government and embrace
the flag. Hope to live in that free
republic for which it stands.
Give your approval to all you cannot
understand. Praise ignorance, for what man
has not encountered he has not destroyed.
Ask the questions that have no answers.
Invest in the millennium. Plant sequoias.
Say that your main crop is the forest
that you did not plant,
that you will not live to harvest.
Say that the leaves are harvested
when they have rotted into the mold.
Call that profit. Prophesy such returns.
Put your faith in the two inches of humus
that will build under the trees
every thousand years.
Listen to carrion—put your ear
close, and hear the faint chattering
of the songs that are to come.
Expect the end of the world. Laugh.
Laughter is immeasurable. Be joyful
though you have considered all the facts.
So long as women do not go cheap
for power, please women more than men.
Ask yourself: Will this satisfy
a woman satisfied to bear a child?
Will this disturb the sleep
of a woman near to giving birth?
Go with your love to the fields.
Lie easy in the shade. Rest your head
in her lap. Swear allegiance
to what is nighest your thoughts.
As soon as the generals and the politicos
can predict the motions of your mind,
lose it. Leave it as a sign
to mark the false trail, the way
you didn't go. Be like the fox
who makes more tracks than necessary,
some in the wrong direction.
Practice resurrection.

NEUROPEPTIDES, RECEPTORS



While some scientists might consider the study of emotions in the metaphysical realm, the biologist Charles Darwin thought it a worthy topic for a major work entitled The Expression of the Emotions in Man and Animals. Recent discoveries about the localization of "neuropeptides" and their receptors suggest that these short signal peptides constitute the biochemical basis of the emotions, the physiological correlate Darwin sought.

What makes the neuropeptides most interesting in this regard is the fact that several of them have been demonstrated to bind to brain receptors as they mimic the psychological effects produced by the psychoactive drugs whose receptors they share, such as the opiates, valium (1), and phencyclidine (PCP) (2). We have devised methods for studying precise brain distributions of neuropeptides (3) and their receptors (4); we have learned that even those neuropeptides which lack alkaloid analogs and thus have unappreciated mood-altering effects (e.g. bombesin) (5), share common areas of brain enrichment at "nodes" previously implicated in mediating emotion. In addition to classical "limbic system" areas such as the amygdala and hypothalamus, these nodes include such structures as the habenula and periaqueductal grey which set thresholds for sexual arousal and somatosensory (pain) arousal, respectively.

Coupled with these developments is the growing realization that the division between the endocrine, immune, and nervous systems may be more historical than actual. "Neuropeptides" of similar structure and receptor function are found concomitantly in the periphery and in the brain, sometimes in cells like macrophages, capable of changing shape and location. While insulin was recognized first as a hormone secreted by the pancreas onto receptors in fat cells and other peripheral cells, it can now be demonstrated that the brain has similar receptors localized discretely in limbic areas like other typical neuropeptides (6). Opiate peptides not only have been shown to be secreted by some cells of the immune system (7), but also have been shown to function in modulating the immune system (for a review see ref. 8). For example, a

AND EMOTION Candace B. Pert

recent study demonstrates that opiate receptors on human monocytes mediate chemotaxis toward very low concentrations of opiate peptides, an effect reversed entirely and stereospecifically by naloxone on neuropeptides (9). Many other examples of this rapidly emerging literature on neuropeptides and the immune system are referenced by Ruff and Pert (1984) (10); this paper coins the term "psychoimmunoendocrine network" to express the notion that functional integration of cells of the immune system with cells of the nervous and endocrine systems through networks of neuropeptides and their receptors might mediate the psychosomatic aspects of disease.

Does the individual network for each neuropeptide operate by increasing secretion at all nodal points within the brain and body so that a predominant "tone" with a typical mood state for each neuropeptide might be presumed? Are opiate peptides equivalent to pleasure, for example, and substance P equivalent to pain? While these are currently questions without answers, the notion that mind-body integration via neuropeptides and their receptors is scientifically approachable is an exciting one. I suspect that rigorous evidence for this concept will come from invertebrate preparations such as the leech in which neurochemistry, function, and anatomical precision can be attained simultaneously. To the extent that it has been studied (B. Zipser, personal communication) the leech shares many examples of analogous neuropeptide organization with mammals. The fact that neuropeptides have been a stable feature mediating intercellular communication throughout evolution (11) is also consistent with their theorized role as mediators of emotion. It is clear from classical evolutionary theory that emotions must exist in even the most primitive organisms in order to bias behaviors toward those with the greatest survival value.

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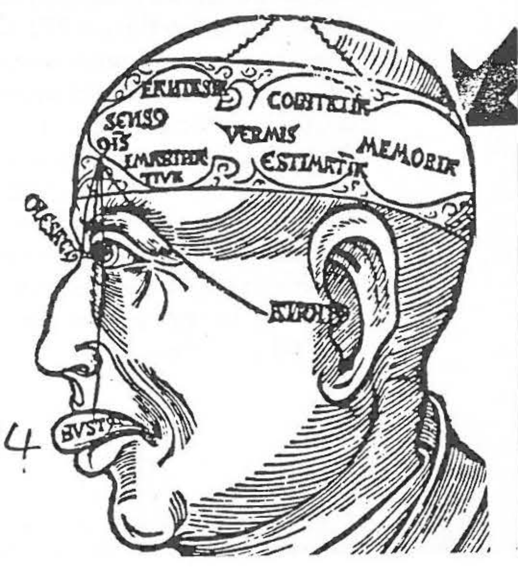


Neotenic Evolution And the Origin of Human Nature An Abstract

By Raymond P. Coppinger and Charles Kay Smith

The conventional scenario for human evolution, unchallenged until recently, is that Ramapithecus, whose fossils have been found in a wide area from about 15 Million years ago until about 7 Million years ago, was a direct ancestor of humans necessitating a divergent human evolution separate from the apes for perhaps the past 15-20 million years. But there is now growing evidence that Ramapithecus may be ancestral to orangutans (Pilbeam 1984) rather than a direct ancestor of humans. The last decade of work by immunologists, geneticists and anthropologists, such as Goodman (1963), Sarich and Wilson (1967), King and Wilson (1975), have investigated the startling similarities and relatively few differences among the genomes in humans, chimpanzees and gorillas. They make it increasingly difficult to doubt the existence of a very recent (perhaps only about 5 million years ago) common ancestor. (See Figure 1). In any case, biochemically speaking, we are very close to chimpanzees and gorillas and share 99% of our genetic material with them. Thus we are more like their sibling species rather than distant cousins. It is not easy to see how we could have evolved so fast and in ways decidedly different (considering language and culture) from other primates yet have done so with very few genetic mutations. King and Wilson (1975) and Gould (1977) have pointed toward a possible answer with their suggestion that a relatively small number of regulatory gene mutations could account for many of the large differences of physique and social and cultural behavior between humans and apes, whereas all these changes if they were made by structural gene mutations one at a time would have required the selection of a huge number of genetic mutations over a much longer period of time.

Following Kollmann in 1884 and Louis Bolk's 1926 argument, many authors (e.g., Garstang 1922; Haldane 1932; Montagu 1962, 1982; Mason 1968; Schultz 1969; Le Gros Clark 1971; Campbell 1974; Gould 1977; Geist 1978; Gribben and Cherfas 1982) during this century have suggested that humans (indeed the whole primate order, see Figure 2) evolved by a process called neoteny in which the regulatory system retarded ancestral developmental rates so that by the time neotenates are reproductively mature they still look and act, relative to the ancestral stock, like juveniles (see Figure 3). During evolution, selection of mutations of regulatory system genes could occur as easily as the selection of any other genes, provided the genetic changes in structure and behavior effected by such a regulatory gene mutation provided an adaptive advantage for the animals of a population. The difference between selecting for a structural gene and a regulatory system gene is that structural gene mutations produce an enzyme that makes protein that in turn produces structure, whereas selecting for a regulatory system gene mutation may control the activation, acceleration, retardation or inactivation of a whole package or perhaps hundreds or thousands of structural genes (Gould 1977).

In only a few generations with selection against ancestral adulthood and for retention of ancestral juvenile traits into later stages of life history all of which may be governed by only a few regulator gene mutations, permanent changes in body and behavior could be brought about so that the neotenic "adult" would (except for sexual maturation) still be judged a youth relative to the ancestor. The neotenic process could be carried as far as there was a selective advantage to the absence of adult characters and the retention of youthful ones. Of course this neotenic retardation of whole systems of developmental genes would be accompanied by and followed by mosaic evolution (i.e., the normal selection

Figure 1 (Schmeck 1985, p. C1)

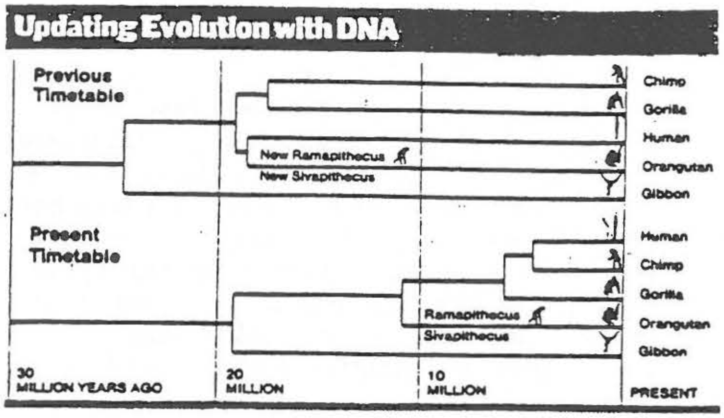


Figure 2 (Schultz 1969, p. 149)

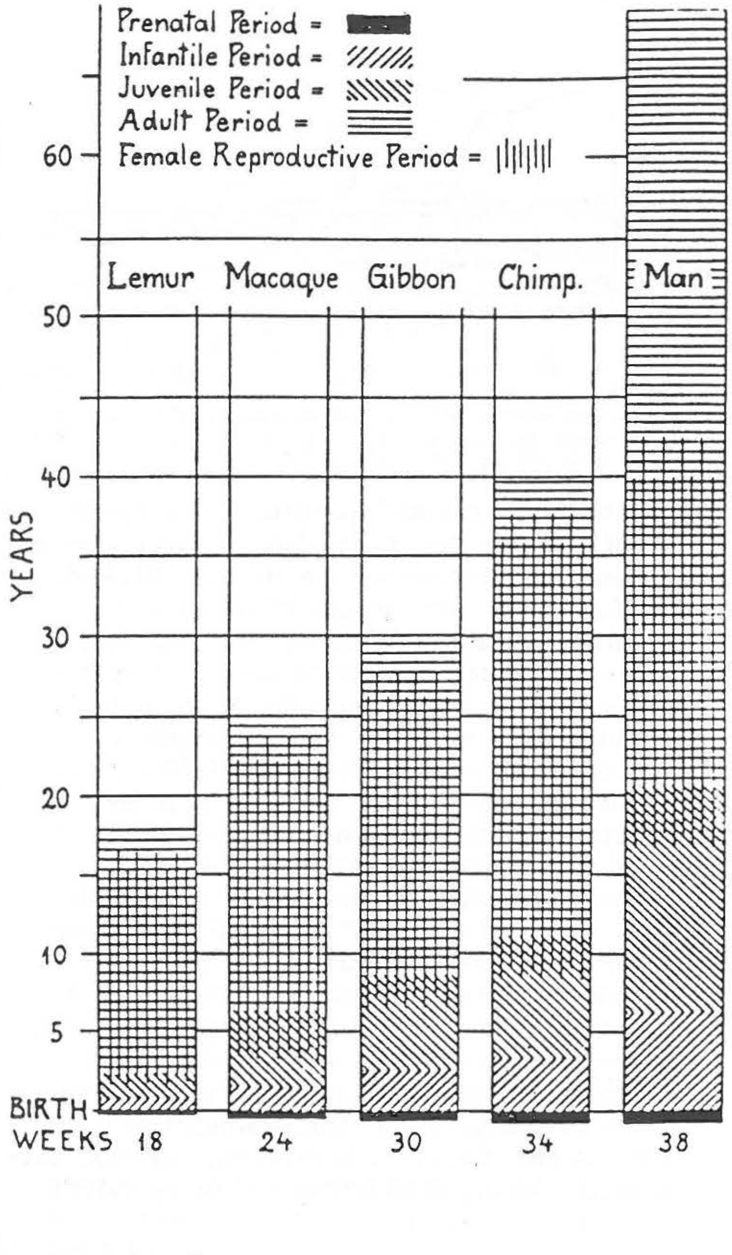


Figure 3 (Modified from Gould 1977)

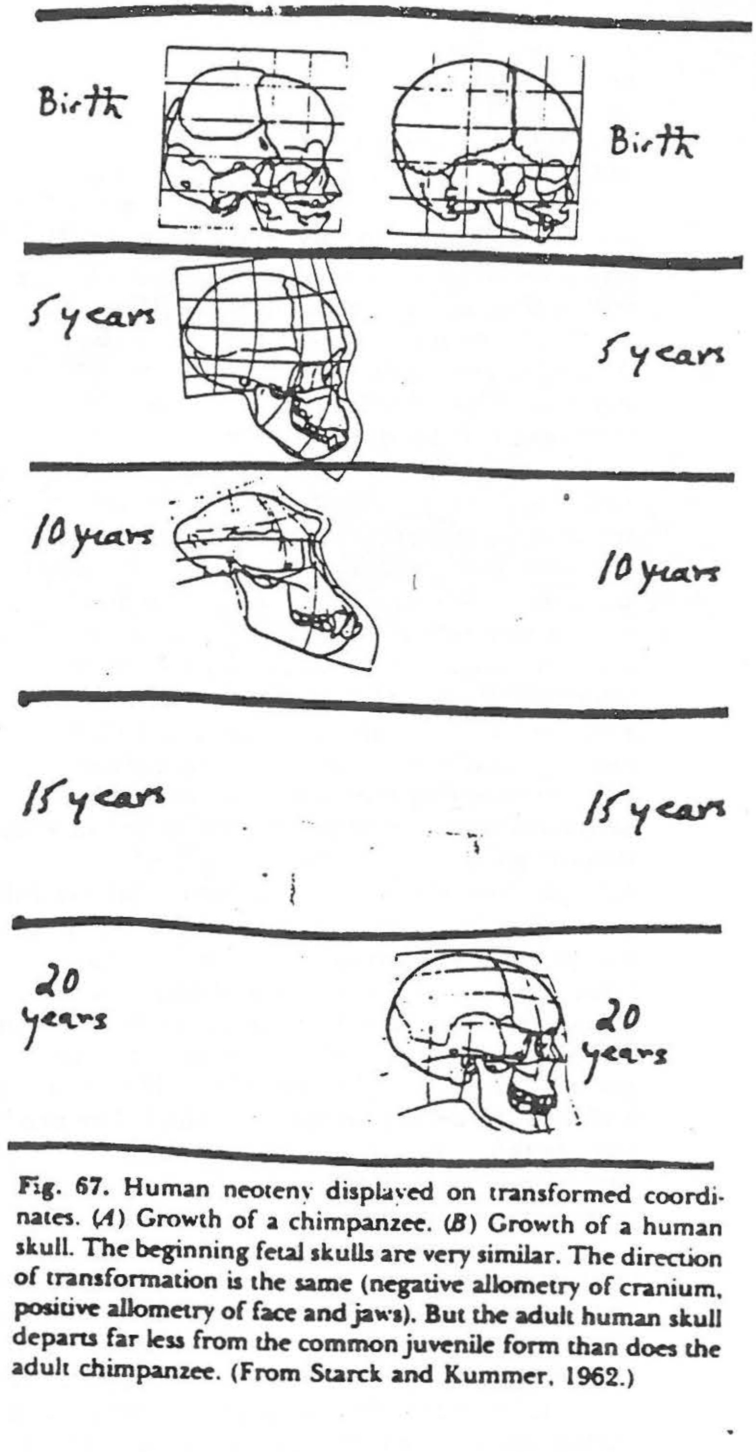


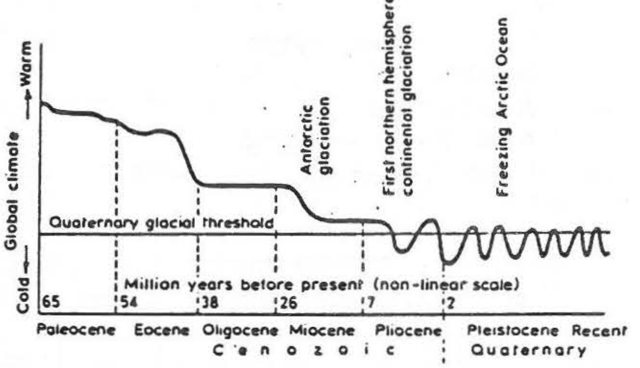
Fig. 67. Human neoteny displayed on transformed coordinates. (*A*) Growth of a chimpanzee. (*B*) Growth of a human skull. The beginning fetal skulls are very similar. The direction of transformation is the same (negative allometry of cranium, positive allometry of face and jaws). But the adult human skull departs far less from the common juvenile form than does the adult chimpanzee. (From Starck and Kummer, 1962.)

of random single gene mutations that are in marvelously various ways adapting animals of a population to their ever changing environment) that will modify or even erase some parts of the neotenic package and take advantage of other parts to readapt them for new uses. For example, in hominids more erect posture is probably a neotenic feature (Montagu 1982) but the growth of legs and modification of foot bones for upright walking and running is not a direct result of the neotenic process—indeed longer legs are the reverse of what neoteny would be expected to provide—and would seem to be selection for readapting an ape for an upright lifestyle.

Since during ontogeny different parts of the body, different organs and neural tissues and endocrine glands, grow and secrete at different rates from one another (this variation in proportions during development is called allometry), an animal's behavior as well as physical structures change as it grows up. For example, a young (2 year old) chimpanzee has about the same brain weight to body weight proportion as an adult human, and like ours its face is fairly flat, its first front teeth fairly small and its arms fairly short. Now suppose an advantageous feature of this package made selection for retardation of allometry during development somehow adaptive, then, provided selection acted over several generations, a new strain of chimpanzees could begin to evolve whose fully grown "adult" characteristics, because of the neotenic deceleration of developmental allometry, were more like the package of characters of youthful chimps. In the neotenic "adult," neither ancestral species-specific adult structures or behaviors would ever have a chance to be expressed. On the other hand, the youthful features, such as youthful curiosity, social cooperativeness and ease of learning, will be retained indefinitely.

Indeed, it may have been this lifelong youthful primate learning, social cohesiveness and investigative behavior, together with the absence of habitat-specific adult stereotypic behaviors, that proved adaptive enough to fit early humans for their migratory way of life during the last few million years of neotenic hominid evolution. The flat face, the short arms, the hairless body, even the bigger brain may be a-adaptive parts of the neotenic package selected because of the youthful behavior that was splendidly adaptive for migrating into the new territories opened up by either melting or growing glaciers of the Pleistocene period. For the past several million years many glaciers have grown and melted that not only opened up fertile and rich lands newly laid bare by retreating glaciers as well as land bridges exposed because of low sea level during a glacier that opened virgin territory, which would have made the youthful ability to explore and learn easily throughout life adaptive. Also there was about six times the normal fluctuation of climate during the Pleistocene (Kerr 1981) so that habitats were changing and opening relatively fast, particularly at the periphery of glacial masses (see Figure 4). This fact would have rendered habitat-specific adult behavior, that may have been too stereotyped to accomodate to the swift changes at the northern extremities of a population cline, less adaptive than youthful behavior that among mammals is less stereotyped, less habitat-specific and less specialized and thus more adaptive in a rapidly changing environment.

Figure 4 (Gribben and Cherfas 1982, p. 191)



The downward slide of global temperature since the Paleocene, 65 million years ago. Note that the horizontal time scale is not linear, so that more recent variations, largely the result of the Milankovich process, show up more clearly. (Modified from J. Andrews, in *Winters of the World*, ed. B. S. John, David & Charles, 1979; schematic only.)

Many genera and families of mammals, in addition to hominids, evolved neotenic species during the Pleistocene (Geist 1971; 1978) due to the adaptive advantage of losing adult habitat-specialized behavior and retaining more ability to continue to learn and explore throughout life. The culmination of neotenic evolution in a number of large mammal species during the last several million years was that many of them had lost so much species-specific recognition behavior and retained so much youthful care-soliciting dependency behavior that at the end of the last glacier about 10-15,000 years ago these neotenic species established the domestic alliance. The alliance has made humans together with their sheep, goats, cattle, pigs, horses, dogs, cats, etc. so successful as an interdependent group that their proliferation is endangering, indeed threatening the extinction, of all wild species that are habitat-specific, highly specialized and independent, rather than neotenically interdependent, so that they cannot easily establish symbioses with the domestic alliance that now amounts to about 20% (Westing 1981) of the total biomass of terrestrial earth.

The merits of this neotenic theory of human evolution are that it tends to lead toward fruitful new research. For example, there is much to learn about youthful primate behavior and how the absence of stereotypic adult behavior and the lifelong retention of youthful behavioral tendencies like care-soliciting, investigativeness and play might be universals that lie at the base of all human cultures. The theory explains what is inexplicable in conventional theories of human evolution, such as its ability to account for the new molecular biological discoveries of our close genetic affinity with chimpanzees and gorillas and the likelihood of a common ancestor only several million years ago. Finally, it is the most parsimonious explanation of hominid evolution since it groups and relates so many physical as well as behavioral characters, such as hairlessness, small canines, larger brains, increased social dependency behavior, that formerly needed separate adaptive explanations.

However, the neotenic history of human evolution is likely to upset conventional sociobiological assumptions about humans inheriting typical adult animal behaviors such as territoriality or dominance hierarchy. Also psychoanalytic theories based on a belief that instinctive drives of the Id are anti-social will need to be reassessed if humans in fact inherit the extremely social instincts of youthful primates. Its effect on political, economic and social thought will be to recognize the tendecies toward social dependency in humans rather than modeling basic human drives on an almost reptilian self-sufficiency and supposed lack of social motivation. Finally, it will afford the "punctuated equilibrial" school of evolutionary biology one more example of a swift evolution with natural selection acting not so much as the creative architect of humanity but more as a generalist chief executive officer who can only veto or pass a whole package of regulations without immediate line item veto power.

In designing humanity the contracting out of the genetic regulatory system working from an old blueprint of the youthful primate phase-plan had a major role, together with general encouragement from natural selection with occasional editing, redesigning or readapting of specific features; but only after the neotenic retardation had been passed as a whole new adult system of structure and behavior.

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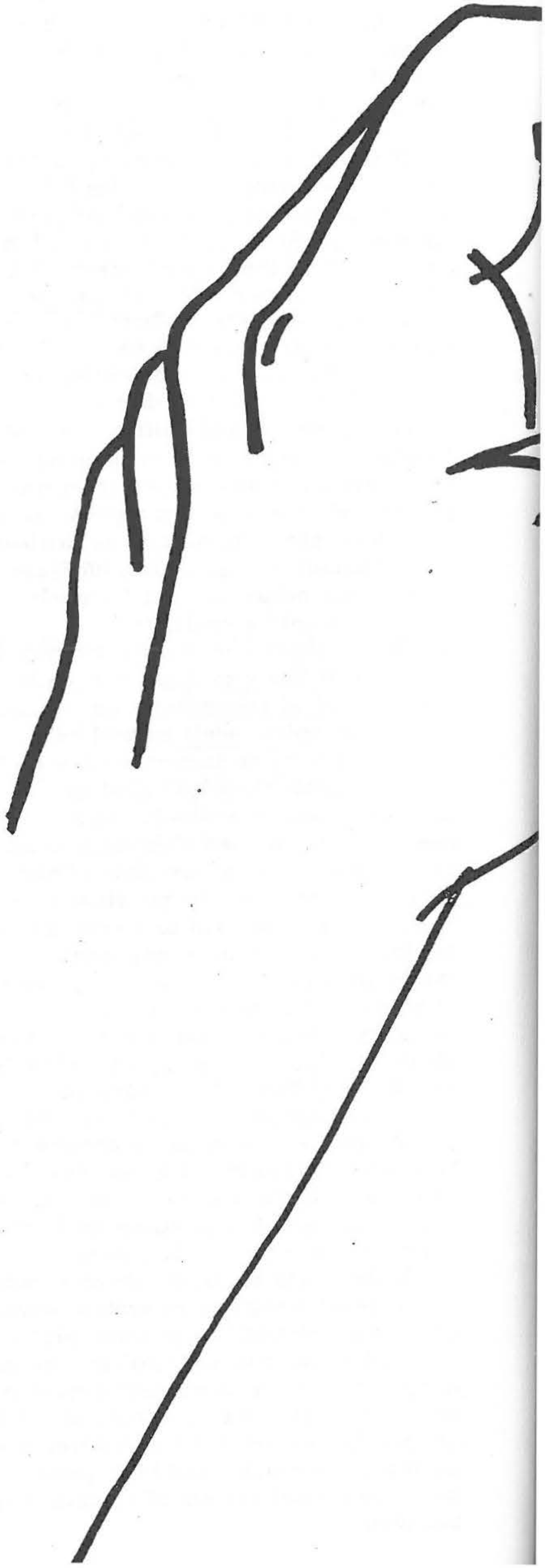
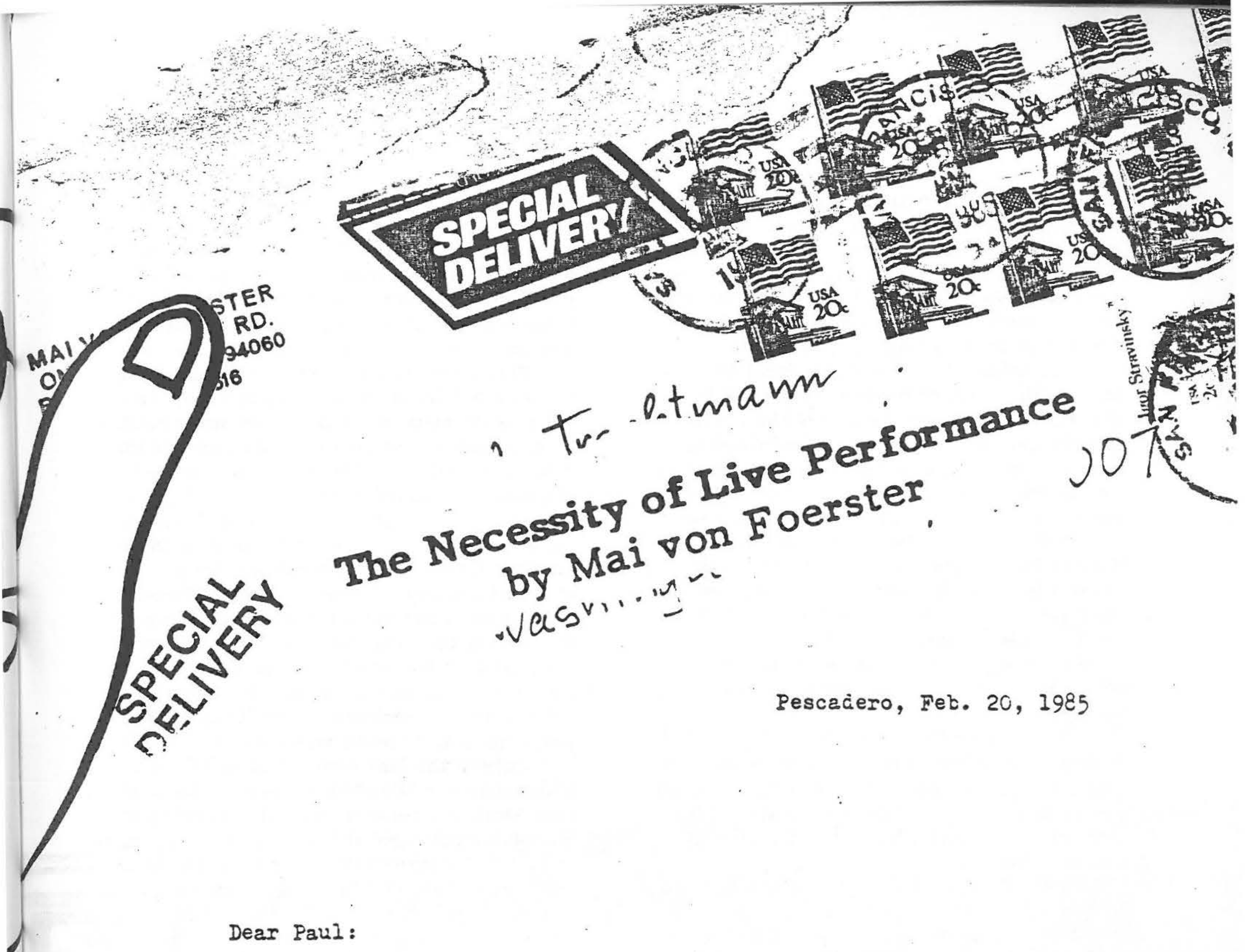




The Necessity of Live Performance
by Mai von Foerster

Pescadero, Feb. 20, 1985

Dear Paul:

I was touched by your reaction to my tale about a theatrical performance in which I had a part a long, long time ago. You remember? In a performance of a fairy tale, played before a very large audience of children, twice, one day before Christmas, I was playing a very wicked witch. I was out to seduce innocent Kasperl to take and eat a poisoned apple. All went according to script in the first performance. But in the second performance, when I tried to convince Kasperl in the most bewitching terms that he should take the apple, suddenly, as if it was coming from heaven, a child's voice from the far reaches of the fourth gallery cried out, piercingly, as if in extremis: "Kasperl, don't take it, it's poisoned!"

Every soul in that big theater held its breath, including the performers. We managed to go on and, with dialogue of the moment, carried the play to its conclusion. Yet, after 45 years, I can still hear the voice of that boy who changed a fairy tale into a theater of action, into world theater.

You said: "Tell me more about this!" - and I will. Without beating about the bush I will simply say: the theater is the ideal manifestation of circular communication among humans, a cybernetic manifestation. The playwright, we hope, and sometimes we know, has looked into the depth of his time and experience and has come up with this play to tell us what he saw. The actors take his words, and, the better they are, the more they give us the illusion as if they, at this very moment, invented these words. By acting, they hold the mirror of the writer's vision up to the audience, to perceive, to recognize, to react.

Thousands of years ago the playwright's task was to be the intermediary between man and his gods, to delineate the limits of their power in dealing his fate and to show his dignity - or his rebellion - in suffering his human condition.

In the course of several thousand years of theatrical history our dialogue and confrontation have changed. Following this trail one can wonderfully see how, with Christianity, man became the tug of war between God and devil. During the Rennaissance man's bearing, not under the will of God but under his own will, his urges to do good or evil, became the essence of theatrical action. The heroes were kings and queens and extraordinary men of power and ambition, their failures and achievements on a large scale.

As the environment changed from well defined kingdoms of power or of nature into a world populated by men, he was forced to look at others like himself, to hold the mirror up to his peers, to look at the conditions that formed society, to understand the currents driving him and so many others like him. Social drama was born. After that, in ever faster acceleration, man did not look at his fellows any more; he himself became the center of his universe, contemplating ever more intensely his own psyche. The focal point was not outside any more, it was within.

This whole docu-drama, and much, much more, was played to full houses "live," to "live" audiences throughout our history. And how the audiences reacted! Remember the little boy with the clarion voice, who felt inspired to help a friend in need? There were plays which changed the course of history, caused revolutions, turned tryants to their graves. Or in more subtle ways, they changed society. Think of Ibsen's "Nora".

There is the play; there are the actors; we, who listen, are the reactors who carry the play into the world. Without us the circle of communication is not closed, no information is exchanged, no change takes place, no soul touches another.

Only in the last generation have we abandoned our "live" dialogue with God, with fate, with our fellows and with ourselves. We have exchanged it for a passive existence in front of a screen in our private chamber; the screen does not feel our reaction, as the actors do on the stage. Others are not affected by our excitement. At the most, we become an atom in the Nielsen ratings and affect the scales of preparation X, Y or Z.

Let us hope that theater stays alive. Let us hope that we may go on looking into the mirror which our writers and seers, the ones who look deeper, hold up for us. I hope they go on writing for a forum that is alive with an audience who does not only want to be entertained, but to play their part in the eternal circle. The world is our stage, and the stage is our world. Without us to listen and to feel, to judge and to tell, it is all in vain.

Your friend, Mai.

. . . . to hold discourse at least with a computer . . . .

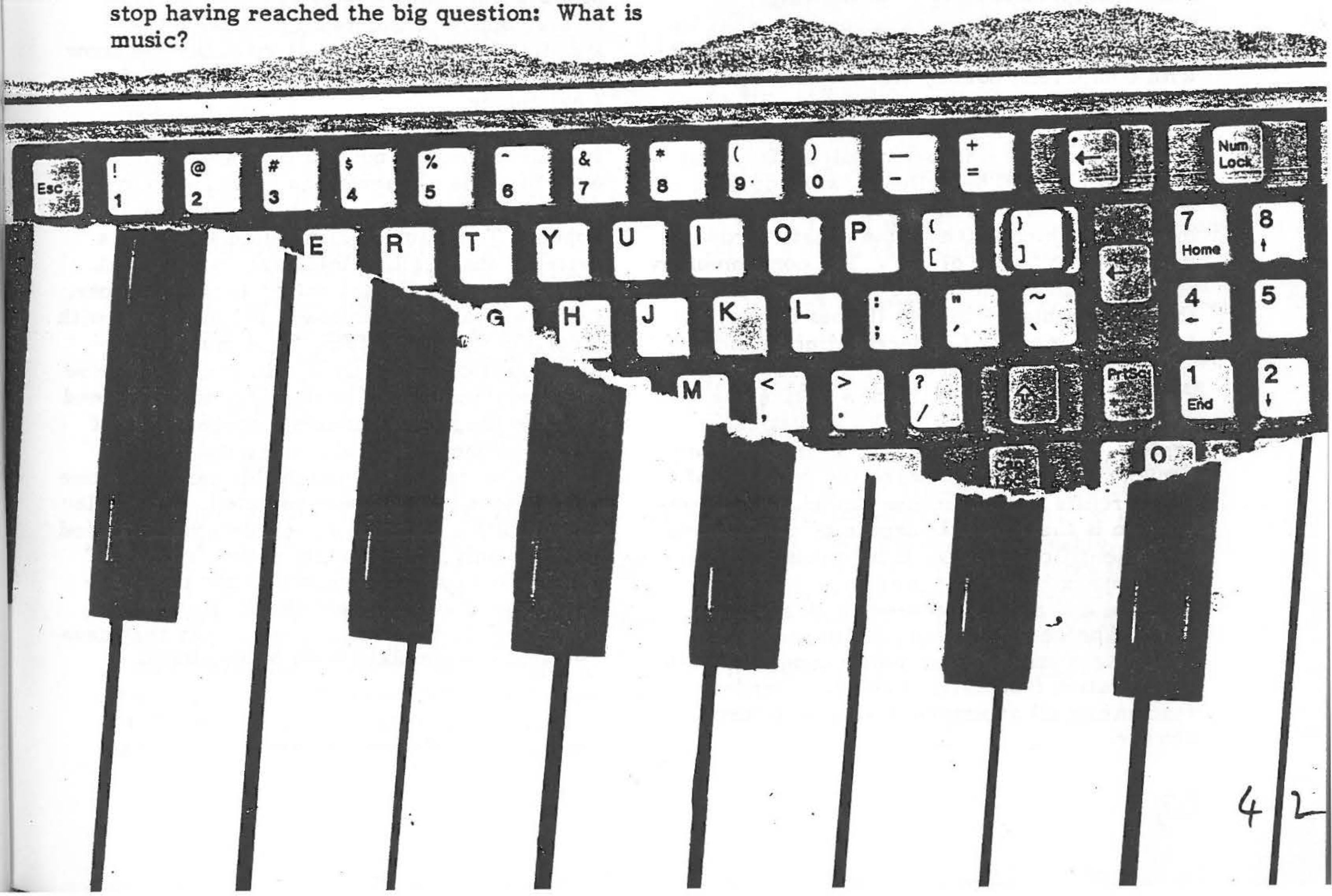
by Herbert Brun

The composer who attempts to compose his music with the assistance of computers, and who, instead of keeping his mouth shut, responds to the request to tell why and how he proposes to breed immortal beauty for all of us by marrying mere technical logic to fertile inspiration, this composer has to override such exalted expectations with a careful report on the notions, theoretical and otherwise, on which he bases his various interests for experimental research in music. I shall attempt to do that now.

Anyone who attends either a concert of new music or a lecture on speculative ideas concerned with new music may occasionally come away with a question on his mind. Was this music? Is that music? Did he mean "music"? Did all this even have anything to do with music? In the attempt to do justice to these questions as well as to the events which provoked them, one usually comes to a full stop having reached the big question: What is music?

Three cases may arise: A question is answered, and dies. The discussion stops.—Or, a question survives all its answers. The discussion then absorbs the answers and continues from there.—Or, a discussion survives the already answered question. This is unpleasant to behold and therefore best skipped over with a charitable smile.

Nobody can, under all circumstances, be quite sure with which of these three cases he is confronted. Nobody, however, can avoid implying by word, gesture and stress of choice, which case he assumes it to be. I would even go one step further and say which case I want it to be. And reasoning may be brought to bear on it. If I say that the question "What is Music?" survives all its answers: then it is because I have vested interest in music, being a composer, and because I know that once we know what music is—there won't be any. We may delve into the well of the past and inquire



what each man thought music could be and come up with useful documentation as to what music was then. Useful, because without it, we, today, would know only what music was today. We then can go to the composers and ask them. And if they know their profession, they certainly know what music was, but if they begin to say what music is, something flips, and turns their good intentions into advertisements of what music is to be.

Still, there must be something that allows us to use the general term music, if only to be able to set it off against the general terms "acoustical phenomena" and "aurally perceivable sensations". That something, of course can not be music, but it can be found in all music, can change continuously and tremendously while remaining the same something. I am speaking of a ratio, a rational relationship. In all music there is manifestly implied the rational relationship between the chaotic image of an unlimited, unconditioned and disordered universe of all audible phenomena and a tentatively defined image of an equally disordered, but artificially limited and conditioned sub-system that man at a given time considers his temporary acoustical ALL. Every composer of music has testified to this relationship, knowingly or unknowingly measured it, and his work reports on what he was able to measure up to. If today we try it with computers, nobody can possibly say whether any result of this attempt will correspond to what has up to now been called a "work of art", or whether it will define what from then on will be called a "work of art", or whether it will miss altogether that function in society which makes some creative communication a "work of art". The contemporary relevance and significance of a composition should be achieved in that it does not appeal to existing means of understanding music but rather creates new means of musical understanding. It not only will show noticeable changes in the concept of the acoustical system, not only propose new schemes of organization, but also provoke the creation of new circuits in the listener's mind. This provocation is the aim and purpose of all creative and scientific projects. It is in this sense that the cooperation of composer and computer is for here and now considered to be a natural idea. Whether it will lead to "music" or to "electronic brains" or to a new aspect of both is a question fascinating enough to render fascinating all attempts at a satisfactory answer.

Compared to these somewhat lofty ideas, the work on and for their implementation proceeds in rather small steps and no man at this moment has yet been given a chance ever to justly evaluate whether these small steps stumble in the right direction. The first step I took was to envisage both, the computer and what I call music, as two different systems, and to explore the possibility of their mutual compatibility. I use the term "system", whenever I mean to speak of a collection of elements wherein each element can be in either of at least two different states and where the change of state in one element results in a change of state of the whole collection. The term "element" I use when referring to something as a whole that I do not consider as made up of a set of elements. Indeed, it frequently depends on the observer and his particular purpose at a given time whether he regards an object as being a system or as being an element. A composer may at one time consider the piano to be a system which can adopt as many states as about 88 elements allow, each of which, and any number of which, can be "on" or "off", at least. At another time he may think of the piano as an element which changes the state of a system called orchestral timbre. I hope he frequently considers all possible ways simultaneously, but think it vital that he know which way of looking at them determined his final choice.

Dependent on the number of elements in a system and on the number of states which each of these elements can adopt, each system has a definite number of states in which it can appear. This number of possible states of a system I shall call its information potential. As this is an important notion for my purpose, I shall express it as follows: If I am faced with a certain state of affairs, be it music, language, politics or family, I will, for the purpose of understanding and evaluating, not only need to know the precise present constellation of all the elements, but also the number of possible states out of which this particular one which faces me had been selected. If you play several little tunes on a recorder, you will find that not only is the system called "recorder" able to be in as many states as the tunes demand, but that the tunes exploit the system "recorder" to the limit. One can say that here two systems simulate each other almost completely, they even imply each other. No number of little tunes played on a piano will ever define the large system called piano for you. This means that each message which we receive has to be investigated in respect to two questions: (1) What kind of a source-system does this message imply? (2) How much of that system did the message exploit?

Every musical composition is in this sense a message. In order to hear the musical events as they are being carried to you by acoustical events, it is necessary to find out as much as possible about the originating system before you can be sure you have heard what actually had been played and that it was music. For how is anyone to say whether what he heard was music or not, as long as he is not even sure as to what "it" was that he heard? And in order to even begin to know what it was that he heard, he must be able at least to estimate how many "similar" acoustical events the choice of each particular one eliminated. Not only the results of the composition but also the processes of composition are parts of this message. Here, one can see that we noticeably approach that concept of musical composition which considers the interrelations and interdependence that join acoustical events together as even more important for musical meaning than the acoustical events as such alone. Every decent analysis of a musical work will try not only to state the kind, form, and quantity of acoustical events in the piece, but, more than that, will try to find out as much as possible about the schemes, plans, processes, and logics which the composer may have employed for his decision making. These last mentioned methods of bringing a specifically planned order into a system of generally possible orders I shall call "the algorithms" by which changes in the system can be controlled. And I call them "algorithm" because this word has both a general and a specific meaning. It does not specify any one particular method; it does not imply any particular degree of complexity or convenience or efficiency. But it is specific in one point: It means any set of instructions which will control the changes of state in a system in such a way that from a given initial state to a given final state, each intermediate state generates its follower. If we now call an algorithmically controlled change of state a "transformation", then we can say that an algorithm produces an uninterrupted chain of transformations between a given initial and a given final state of a system. Or, the other way around: If two states of a system appear to be connected by an uninterrupted chain of transformations, then we may assume the presence of a controlling algorithm. Now, it is rarely the case that there is only one lonely algorithm responsible for what we hear, see or otherwise perceive when we look at systems. Usually there are many simultaneously active. But, usually, they are active in a kind of hierarchic power distribution. There are little algorithms which control counting, addition, multiplication, etc. They may obey an algorithm which tells them when to go into action. This may be controlled by an algorithm which controls the relative dimensions of sequences and thus may direct a "lower" algorithm to eliminate its product and to start again from another given state. And so on and so forth.

Let us cut this promising excursion short and say that we now have all I need in order to make the following statement: A system is defined by its information potential and by those algorithms that can control this particular system. Two systems are compatible with each other when they are similarly defined. The degree of compatibility of two systems determines the degree to which they can simulate each other, to which one system may behave in analogy to the other. We are interested here in three main degrees only: Fully analog, partially analog, and not analog at all. The system called "Thermometer" is fully analog to the system called "Temperature", partially analog to the system called "The Weather", and not at all analog to the system called "Language". An analogy is a chain of transformations in one system simulating a chain of transformations in another system. Communication is based on analogies, on degrees of compatability between different systems.

The largest, most general and thus most flexible systems men can control today are found among the electronic high speed digital and analog computer installations. The number of states representable by such machines is enormous; the elements, simple and semantically uncommitted, can stand for almost anything enumerable, quantizeable, measureable; the network potential offers the structural conditions for nearly any algorithm one can think of. Thus it is a system especially designed for utmost compatibility with all kinds of other systems, large or small, simple or complex, open or closed, numerical or logical. It is, therefore, up to the computer user to find or to construct the system in which his problems can be expressed and solved, in which the processes he desires to observe and to test can be seen as chains of transformations. Once he has defined the system he needs, the user is able to plant it as a subsystem into the computer. This "planting" procedure is usually referred to as "programming".

A computer program is a set of instructions. If fed into the computer system in an appropriate code, the program communicates to the computer the structure, size, dimensions, rules, algorithms, etc. of a system which the computer system is to simulate. Under the control of such a program, the computer system will act as an analogy to the system which the programmer had in mind when he wrote the program. It is quite probable that not all composers think of their activities as being operations on and in systems; that not all processes leading to the final appearance of a musical work take place in only one or in any system. However that may be, the computer has to be programmed in order to be of any assistance, and a program can only be written by one who considers at least part of the work, the processes and the data with which he is concerned, as changes in and states of a system that he has defined.

If the term "composition" is taken to mean "programmed operation on given data", then a computer can "compose" music. If, on the other hand, the providing of the "given data" is taken to be an important part of "composition", then the computer only executes a program, for it can not "give data" as yet. An apparent middle of the way concept of composition programming offers itself: Let all of the data which the composer provides define the initial state of the computer system; let one part of the composer written program instruct the computer to adopt this initial state and then operate on it, so that the results of this operation can be used as "given data" by another part of the program; under control of a third program segment, every now and then, let some state of the system be interpreted and operated on as the next initial state; finally, let a fourth section of the program select from system-states lying between these "initial" ones, those that are to appear as results in the output. This section also instructs the machine as to the format in which the output is to appear.

Here the composer defines a point of departure and the various processes and algorithms by which "given data" are to be generated and operated upon and by which results are recognized and notated. It is quite correct, in such a case, to say that the computer generates the result of the composition, the piece, but rather careless to conclude that the computer composes it. Even without a machine, the composer working at his desk with pencil and paper on a musical score, generates the finally notated result under control of some rules, conditions, stipulations, premises, liberties, memories, chances and so forth, all of which interact in ways that reflect a system, known or not known as such to the composer, which he considers his plan and idea of composition. This compositional concept initiates, accompanies, controls and eventually stops the process of generating data and results, but is not identical with it.

Every musical idea implies the system in which its acoustical realization may become its structural analogy. The compositional process begins with an analysis of the implication and continues with a search for, or with the construction of a system with the appropriate generating potentials. It may just as well be stated here that every generating system also implies the musical ideas which it can represent. Bad composition usually results from some failure in compatibility between idea and generator.

A programmed computer can be a suitable generator if the program has been determined by a composer who is aware of the implications of his musical ideas and of the implications of computer systems. The most important step toward a correct recognition of such sometimes vague and "never heard of" implications is taken when the composer, through knowledge or deliberate stipulation or both, determines the invariants which significantly define his idea and which should be preserved in the generated analogy. Most readily preserved in analogies, and thus by computers, are proportions, relationships, quantities, weighted probabilities, functions, statistics and multivalent simultaneous hierarchies of either permissive or restrictive rules and conditions. In fact, it would mean by-passing the possibilities offered by the machine system if a program were to instruct the computer merely tautologically to code a specified set of determined, discrete data, fixed point by point; one would thus actually degrade the computer to the redundancy of a glorified typewriter. It is admittedly not always clear to the composing programmer whether he, at any given moment of his work, happens to be programming analogies or only tautological coding and bookkeeping procedures. Nor does he who composes without computer assistance always know whether he is creating a coherence of sound where this did not exist before, or whether he just keeps on using an existing one to fill preplanned, plausible slots in an orderly fashion. The difference being that it is usually easier to inspect and to correct a program, than to inspect and correct a composer without getting painfully involved with his "personality".

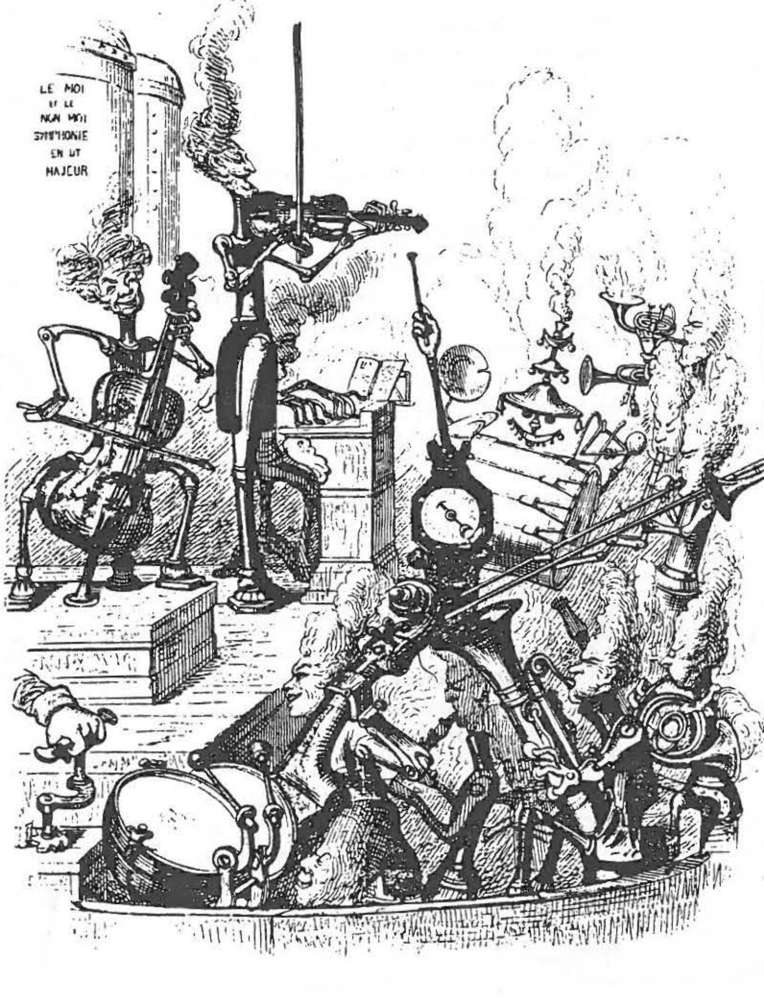
It is necessary, at this point, to mention that all composers who work with computers continue writing "pencil and paper" pieces which however show that the knowledge of immense possibilities they learned from machines keep encouraging them to look for a "like richesse" in their own minds. No matter how artificial man may make the systems he wishes to work with: their conception, their responses and the wealth of unpredicted questions they raise in man's mind as he contemplates their potentials are certainly not at all artificial, but genuine results of a feed-back which provokes visions of unknown territories for research and creation, edging us on to ask for more, while the little conservative skeptics and the big official guardians of culture can only cry yea or nay, their own feed-back being the cud they chew.

The composition of music is an analogy to communication with and within society in the following sense: It refers to a practically unlimited system, namely the acoustical universe. It chooses more or less strictly defined fields of this system as its working ground. It decides on the algorithms which are to control the changes of state in this system. It determines whether a musical message is to consist of interrupted or uninterrupted chains of transformations, whether all the controlling algorithms are to be made known or whether some are to be kept hidden and elusive. But the most important point is this: A composition of music attempts to be only analog to a communication. It does not attempt to be one. It has all the necessary makings; it obeys all the demands, it adheres to all the rules of communication; but it does not communicate anything but itself. Thus it expressly intends to simulate that which we usually define as "not intended messages", as "manifestations of circumstances", as "natural processes", only that this simulation is intended, and thereby represents and implies a criticism and a correction of conditions as they appear to be, and a proposition and plan for conditions as man would rather have them be.

In this sense, the composition of music is much more difficult then one might think at first and, furthermore, will always be just as difficult again the next day. For nothing is sooner lost than new ways and new languages.

To conclude: It simply is not the computer that threatens to replace man, the human brain, the composer. Much rather it should be asked whether these three could eventually learn how to understand and to handle the systems which they themselves have valiantly conquered from chaos; whether man could and eventually would learn how to have discourse with music, with society,—or, at least, with a computer, so that it may slowly dawn on him where, in reality, substitution does threaten. With such knowledge, he then might successfully try to make himself once again, even briefly, appear irreplaceable.

Herbert Brun is Professor of Music in the School of Music, University of Illinois. A three record set of his compositions, with an illustrated text, is available from Non Sequitur Records, Box 872, Champaign, Illinois, 61820.



To know and to let know an applied theory of knowledge

Heinz Von Foerster

Before I begin my topic proper, I would like to make a few preliminary remarks.

First, I wish to thank President Marianne Scott for her charming introduction and for the kind words she had for me, jumping at short notice into the place of my friend Ivan Illich, who was to speak to you but unfortunately could not make it.

Moreover, I am delighted to be allowed to serve a friend not only by helping to avoid a void that could have been caused by his absence, but also to deliver a message. Alas, not in his but in my words I hope will, nevertheless, invoke an Illichian spirit.

Remark number two: thanks to Scott again. Just a few days before leaving California for Saskatoon I received one of those air express letters in which she gave me enormously helpful hints about this conference. She told me of your essential concerns, the tremendous economic, political, social and legal pressures to which you are exposed, the difficult questions concerning the freedom of, and access to, information and, of course, those associated with the impact of the explosive "information technology" on your profession.

I felt that the crucial point in her letter was a concern that gave rise to the title of your conference: "Sharing our specialities: a national opportunity."

She described the unpleasant situation that, due to an increase of specialization in your profession, there is an erosion of the common bond that holds all of you together.

Remark number three: let me draw your attention to the fact that this situation is even more unpleasant because, when the common bond is eroding, the climate is set for even more specialization. That is, this is a case of circular causation of extraordinary viciousness.

However, let me console you by saying that you are not alone with this ailment; the same goes on in other fields as well. In fact, all science is affected with this social dysfunction which has now assumed epidemic proportions. What to do about it?

What to do about a slipped disc? The misery begins by the displaced intervertebral disc pinching some nerves that generate pain. The pain, in turn, produces muscle spasms that squeeze the nerves even harder: the pain increases and so on, with increasing misery.

Superficially, one may treat this state of affairs by cutting the vicious circle at one or both ends by reducing pain with pain killers, by reducing spasms with muscle relaxants. But, these remedies do not put the disc back in its proper place. Clearly, a therapy must address itself to the disc.

A physician with Hippocratic leanings will ask: "Why did the disc slip in the first place? Maybe this man has difficulty walking because of a faulty hip joint, or perhaps he is shortsighted and makes jerky movements? Let's look at these possibilities.

Remark number four: we identified a dislocated intervertebral disc as the somato-pathology at the root of the loop of progressing pain-spasm-pain, and I propose to see a perversion of the notion of knowledge as the socio-pathology at the root of our loop of progressing specialization-disintegration-specialization.

If, for the moment, you accept my proposal, the therapy should clearly address itself to rectifying the perverted notion of knowledge.

However, a socio-therapist with Hippocratic leanings may ask, "What caused the slip in our perception of knowledge in the first place? Are there related notions, for instance, memory, information, teaching and learning that suffered a similar fate? Let's look at these."

Remark number five: I claim that, with a corruption of the notion of knowledge, the notion of the function of a library has been corrupted as well. Hence, I will have to talk about what it means "To know"; that is, about a theory of knowledge. This justifies one part of the title of my lecture.

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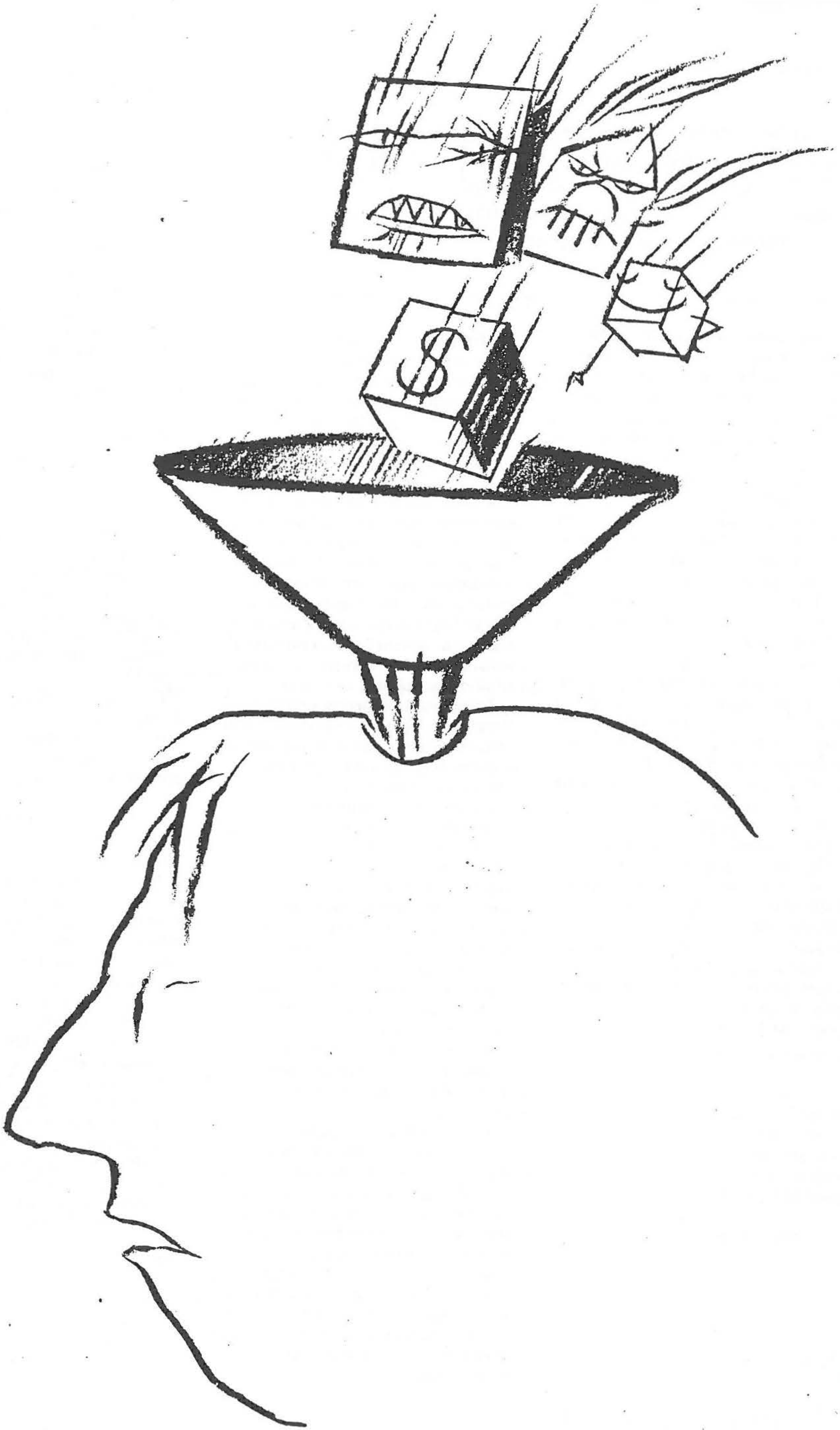


. . .I see in a library the most awesome manifestation of the traces of our civilization and the librarian, in the role of a midwife or an obstetrician, helping people giving birth to new ideas, understanding and insights.

I do not perceive a library as a *bonum librorium copia*, or a collection of good books, and the librarian as the custodian for these books. No! I see in a library the most awesome manifestation of the traces of our civilization and the librarian, in the role of a midwife or an obstetrician, helping people giving birth to new ideas, understanding and insights.

This means that I shall talk about how "To let know" those who wish to know; in other words about the application of a theory of knowledge. This justifies the latter part of my title which in full is "To know and to let know: an applied theory of knowledge."

I have completed my preliminary remarks and can now begin my presentation proper. Again, I shall do this in five steps. First, I would like to discuss the socio-pathology of which accelerated specialization is but one symptom. Second, I will address the concept of knowing from a central epistemological position and third, I shall report to you some delightful findings about learning, particularly about learning styles and strategies. Fourth, I will touch upon potentials and limits of the new technology which could become subservient to your needs instead of you becoming the servant of that technology; finally, I would like to invite you to see with me the library as a convivial tool in the sense of Ivan Illich[1] and Valentina Borremans.[2]

Pathology

The history of the development of criteria that identify a specific and widespread mental disorder, schizophrenia, (Greek: schisma — split; phren — mind), is relatively recent. It is only slightly more than one hundred years ago that Kahlbaum[3] first perceived mental diseases as functional disorders and attempted the monumental task of aiding diagnosis by classifying the perplexing mixture of fluctuating symptoms into stable criteria of functional contingencies. This brought an end to an era of superficial symptomatology and opened the path for a diagnostics which later allowed neurological, social and cultural interpretations of identified dysfunctions.

Three other eminent neurologists, Kraepelin,[4] Bleuler,[5] and Meduna and McCulloch[6] who built on this school of thought, succeeded, during the next few decades, in formulating the criteria that single out schizophrenia from other disorders. Because of the similarity between the most prominent criterion for schizophrenia, namely, the breakdown of cognitive integration, and that of social dysfunction, namely, the breakdown of social integration, I propose to call this socio-pathology "schizodemia" (Greek: schisma — split; demos — folks, people). Moreover, since the other criteria for schizophrenia show great affinity to those of schizodemia, I would like to give a short summary of Bleuler's three criteria plus the one added by Meduna and McCulloch in order that you may see this fascinating parallelism.

My justification for this exercise is that, if there is a strategy for extricating oneself from the grip of a disorder affecting the individual, it should be possible to perceive a corresponding strategy which could help extricate us from the grip of a disorder affecting society.

In each of the following four points I shall first summarize one criterion for schizophrenia as defined by Bleuler (i) (ii) (iv) or Meduna-McCulloch (iii), and then point out the corresponding situation in schizodemia.

(i) Breakdown of cognitive integration. Patients develop single track trains of thought within a highly compartmentalized framework of topics; an increased loss of the ability to connect these topics through contextual links. Hand in hand with this narrowing of the cognitive aperture there is an impoverishment of the semantic relational structure, leading to the well known schizophrenic speech pattern of excessively high frequency of normally rare words and excessively low frequency of normally frequent words.

If, in this description the word patient is replaced by "society" and "schizophrenic speech pattern" by "professional jargon," it could go as a paraphrase of Scott's description of what ails your profession or, as I would say, science in general.

(ii) Alienation. Self identity and the "I ⟷ thou" affinity is lost. In spite of former attachment to parents, lovers, children or friends, these patients not only lose all affectionate interest in other human beings but, in progressive states of their affliction, see others as threats from which they unsuccessfully seek refuge in solitude and isolation.

This depersonalization can be seen throughout the sciences on many levels. On the surface it shows itself in a required style of writing where the first person singular pronoun is unacceptable. If I were to submit an article to a scientific journal with a phrase like "I observed such and such. . ." it would be edited to read "It can be observed that such and such. . ." to exclude subjectivity from scientific discourse. In the grand scheme of natural science this tendency culminates in squeezing all subjects out of its models of the world in order to create a "subjectless universe."

(iii) Confusion of symbol with object. In some magic rituals the symbol of an object is taken for the object (voodoo, effigies, etc.). In schizophrenia this is a consistent, logical pattern. A textbook case is the answer given by a teenage boy asked for the product of 5×5: "It has four rooms, a kitchen, a livingroom, and two bedrooms and is painted white." The logic is clear if it is known that this boy lives on 25 Main Street.

I claim this confusion is directly connected with what I referred to in my preliminary remark number four as the perversion of the notion of knowledge, and is related to a misconception of the social function of the library and its librarians. It is the confusion that presents the library as a repository of knowledge and information. However, a library cannot store knowledge and information — only documents, books, maps, microfiche, slides, etc. When people use these materials they will become knowledgeable and informed. By obfuscating this distinction, knowledge and information can be made to appear as if they were commodities, to wit, the emerging "knowledge industry," "information processors," etc. With this the problems of how to know and how to let know are successfully pushed into a cognitive blind spot. We don't even see that we don't see.

(iv) *Sensorium clear.* Kraepelin was the first to use the notion of "sensorium" as the totality of the faculties of perception, orientation, memory and so on as distinct from those of reasoning, volition, affectivity, etc. It was Bleuler, however, who proposed to use the absence of a clouded sensorium as an additional determinant for schizophrenia.

In social interactions our faculties of perception, orientation, memory, etc. are not impaired; our "social sensorium" is clear. That is, we answer Bleuler's third criterion in the affirmative. This completes my "clinical" account of schizodemia, and now I have to answer the question "What shall we do with all that?"

Until 20 years ago schizophrenia was considered incurable and to project its symptoms onto those of another disorder would have proved the other one incurable as well. In the meantime, careful studies of the onset of this disorder have indicated that there might well be an organic proneness, a latency in some individuals for it to occur but, in many cases, a cultural, social or familial configuration is needed to facilitate its manifestation. If this were so, one could argue that a radical change in these configurations might remove the cognitive nuclei around which the network of malfunctions becomes attached in the first place, and then grows and stabilizes.

A strategy of radical circumstantial change is known as "reframing." As an antidote to schizodemia in my next step I shall apply this strategy by reframing the prevailing notion of knowing.

However, a library cannot store knowledge and information — only documents, books, maps, microfiche, slides, etc. When people use these materials they will become knowledgeable and informed.

Knowing

I always believed that thinking of knowledge as packagable, transmittable, marketable commodity was a recent perversion until I ran into a broadsheet printed in the late 16th century that dramatically depicts an elementary educational situation.

A young lad, apparently a student, is seated on a chair and has a funnel inserted through a hole into his head. Next to him stands a teacher with a bucket full of knowledge which he is in the process of pouring through the funnel into the student's head. A few letters, numerals and a simple equation are seen just falling from the bucket. Since this broadsheet was printed in Nuremberg, this remarkable educational device is usually referred to as the "Nuremberg Funnel."

From this I learned that some of the present day notions of teaching, for example, computer-aided information, can be traced back to respectable precursors, as, funnel-aided instruction.[7] We know the consequences of this tradition — schizodemia!

Let me present a perspective opposite to the view just given; it is the constructivist's position. How does one recognize a constructivist? Very easily. If you were to ask one whether something, say, a formula, a notion, an object, order, symmetry, a taxonomy, laws of nature, etc., etc., is discovered or invented, a constructivist would tend to say invented. Moreover, if hard pressed, a constructivist would even say that the world as we know it is our invention. Since whatever we invent is our responsibility, the constructivist position contains the seed for an ethic.

I realize that I might not easily get away with such far out propositions. I will, therefore, muster whatever help I can get. One thing I could do is toss a variety of literature at you that ranges from child psychology to the foundations of mathematics.[8, 9, 10, 11, 12]

Another thing I could do is give you a flavor of what constructionism is all about. Let me read a charming vignette written by Gregory Bateson. He packed a lot of epistemology into a minimal space by using the literary device of a dialogue between a precocious daughter and her father. He called them "Metalogues." I shall give you, along with some of my comments, the one entitled "Metalogue: what is an instinct?"[13]

Daughter: Daddy, what is an instinct?

Let me interrupt by asking you to stop and think how you would have answered your daughter's (or son's) question. I would have proudly come up with a lexical definition: "An instinct, my dear, is the innate aspect of behaviour that is unlearned, complex, etc., etc. . . ." Since the daughter could have found this kind of answer in any dictionary, her father reframes the context of the question by ignoring the semantic significance of the word "instinct" and shifts to its functional (even political!) significance when used by one partner in a dialogue:

Father: An instinct, my dear, is an explanatory principle.

Let me pause again and invite you to reflect on the question of whether a library could accommodate the contextual switch demonstrated by the father. I consider this transition from a monological to a dialogical situation of the greatest importance, and I shall return to this later. Now let us hear what the daughter has to say to this answer.

D: But what does it explain?

F: Anything, almost anything at all. Anything you want it to explain.

Please note that something that explains almost anything at all, most likely explains nothing at all. The daughter senses this:

D: Don't be silly. It doesn't explain gravity.

Constructivists would insist that not only do we invent the laws of nature, we construct our realities.

F: No, but that is because nobody wants instinct to explain gravity. If they did, it would explain it. We would simply say that the moon has an instinct whose strength varies inversely as the square of the distance, and so on and so on.

D: But that's nonsense, Daddy.

F: Yes, surely, but it was you who mentioned instinct, not I.

I shall not interrupt the dynamics of this dialogue any more but I ask you to pay attention to father's consistent reference to descriptions of observations and not to the observations *per se* (e.g., ". . . if you say . . . there was a full moon . . ." and not: ". . . if there was a full moon . . ." etc.). Most likely, you, as librarians, would have caught this anyway. Well, here we go.

D: But what does explain gravity?

F: Nothing, my dear, because gravity is an explanatory principle.

D: Oh. Do you mean that you cannot use one explanatory principle to explain another — never?

F: Hum, haw, hardly ever. That is what Newton meant when he said *hypothesis non fingo*.

D: And what does that mean, please?

F: Well, you know what hypotheses are. Any statement linking together two descriptive statements is an hypothesis. If you say there was a full moon on February 1, and another on March 1, and then you link these two observations together in any way, the statement which links them is an hypothesis.

D: Yes, and I know what *non* means, but what is *fingo*?

F: Well, *fingo* is a Latin word for "to make." It forms a verbal noun, *fictio*, from which we get the word fiction.

D: Daddy, do you mean that Sir Isaac Newton thought that all hypotheses are just *made up* like stories?

F: Yes, precisely that.

D: But didn't he discover gravity? With the apple?

F: No, my dear, he invented it.

The dialogue continues, but I shall stop here because I just wanted you to hear this punch line.

Constructivists would insist that not only do we invent the laws of nature, we construct our realities. Let me support this with two examples, one from neurophysiology, the other from biology, that, in the context of this lecture, I intend to be only pointers for where to look. Should you be tempted to look closer, my short reading list may let you do this painlessly.

In my neurophysiological example I will appeal to your high school memories. You may recall that all nerve cells, whether in the brain or distributed over the surface of the body (the sensory receptors), consist essentially of a cell body from one end of which grow branch-like ramifications (the dendrites) and from the other emerges a long, thin tube (the axon) which terminates in a small knob close to the surface of some dendrite of another (or sometimes the same) neuron. Only the moto-neurons terminate on muscle fibres. Almost all sensory receptor cells have no axons terminating on them. Neurons are electrically charged (about one-tenth of one volt) and when perturbed, say, at the dendrite, send a short electric pulse along the axon that, upon arrival at its termination, may produce one of two effects on the contingent neuron.

One is to initiate a pulse like the one that triggered it or to inhibit the effect of an arriving pulse from another axon which otherwise would have initiated a pulse. A sustained perturbation will produce a sustained train of pulses whose frequency is commensurate with the intensity of the perturbation. Figure 1 shows a recording of such a train of pulses that have been measured with an extraordinary small electrical probe placed in the vicinity of the axon of a touch receptor.

Instead of mechanically recording this electrical activity one can connect it to a loud speaker and listen to the "language of the neurons." As you may have already guessed, what one hears is just a sequence of pips that follow each other, either slowly "pip - pip - pip . . ." or quickly "pippippippippip . ." depending on the intensity of the perturbation that caused their activity.

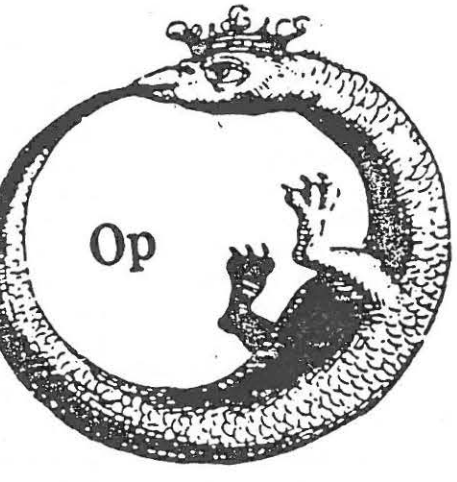
The important point to appreciate is that, whatever specific sensory receptors one is listening to — a heat or cold receptor, a touch receptor, light sensitive cells in the eye, the hair cells in the cochlea of the inner ear — they all report only the intensity of their stimulation with no clues whatsoever as to what physical agent caused this activity. This is the principle of undifferentiated encoding. In other words, the signals that stream from the body's surface toward the brain don't speak the language "hot," "cold," "green," "sweet," etc.; they say only "much here," "little there," "less here," etc., at these and those points of my body.

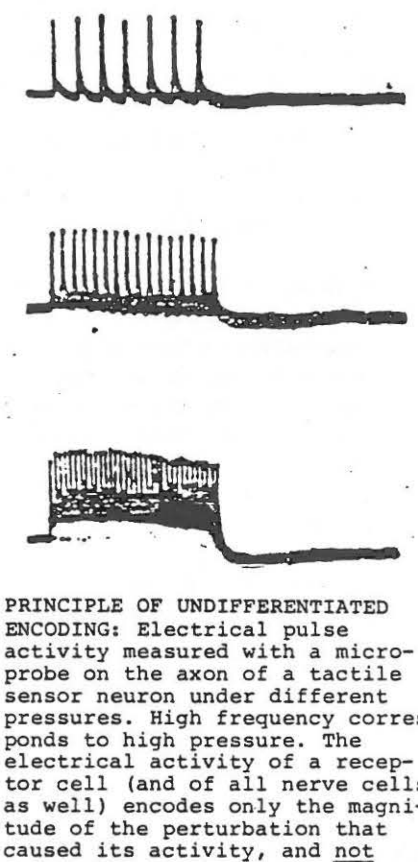
The monumental question that arose is how does the brain construct the magnificent richness of our experience from these anonymous pips?

The answer to this question emerged from the insight that sensation alone is insufficient for perception. It is necessary to correlate changes of sensation with one's own motor activity; that is, with one's own control movements, turns of one's eyes or head, changes of one's position, etc.[15, 16] As one of my friends, an eminent neurophysiologist, is fond of saying: "We see with our legs" or, as another one put it "Behaviour: the control of perception."[17]

Perhaps a certain circularity in this explanation can already be seen, namely, the need of movements for perception, and, of course, the need of perception for the control of movements. Indeed, it is this sensory-motor loop, its mathematical representation, and the emerging dynamic equilibria that have lately been given considerable attention.[18, 19]

It is these sensory-motor equilibria or, perhaps more to the point, it is these sensory-motor competences that ultimately can be associated with an organism's knowing. I mention this because I wish all of us to see how far we are from an epistemology that considers knowledge a commodity.





PRINCIPLE OF UNDIFFERENTIATED ENCODING: Electrical pulse activity measured with a microprobe on the axon of a tactile sensor neuron under different pressures. High frequency corresponds to high pressure. The electrical activity of a receptor cell (and of all nerve cells as well) encodes only the magnitude of the perturbation that caused its activity, and not the nature of the perturbing agent (encoded is only "That much at this point of my body" but not "What").

I would like you to follow me even a bit further to see the notion of knowing within the larger context of biology. I am thinking of the concept of "autopoiesis," a term coined by three Chilean neurophilosophers (as they jokingly wish to be called) Humberto Maturana, Francisco Varela and Ricardo Uribe.[20, 21]

They pushed the notion of circularity to its ultimate limit to obtain a definitive formulation of the organization of living things. The term "autopoiesis" is derived from two Greek words: *autos* — self and *poiesis* — a making, which is the semantic root for poetry. Autopoiesis means essentially a "self-making." Its authors justify this terminology by pointing to a universal feature of living organisms, in which their components are organized so that the results of their productive interactions are these very components again, hence "self-making," autopoiesis. A consequence of this organizational closure is autonomy, self-determination. Since whatever an autonomous entity determines its responsibility to be, the notion of autopoiesis contains the seed for an ethics. Autopoiesis manifests itself in an extraordinarily wide variety of different structures attested to by the variety of living things.

Perhaps, after all this, you may wonder what it is to know? A constructivist would answer, "It is to be." If, as a constructivist, you asked yourself, "What is memory?", you would say "I am my memory."

Learning

I hope it is sufficiently clear that teaching via the Nuremberg Funnel would not work, not because of the funnel, but because of the bucket — it won't hold knowledge. The other problem of teaching is usually summed up by the saying, "You can lead a horse to water, but you can't make it drink."

All this was seen clearly many years ago by Gordon Pask, a man I am very fond of indeed. I first met him in 1958 at an international conference on cybernetics in Namur, Belgium, and this young man, or should I say this ingenious leprechaun, impressed me with some highly unorthodox notions regarding teaching and learning. A substantial one among these is one I'm fond of calling "Pask's first theorem." It says, "A teacher must be a learner, otherwise teaching cannot take place." The teacher has to learn the student's idiosyncracies, learning habits, competences, shortcomings, goals, etc. Likewise, the student has to learn the teacher's idiosyncracies, one of which could be the field of study, say, organic chemistry. A corollary to this theorem is that the teaching-learning situation is symmetrical.

More than 20 years ago Pask drew on these ideas and built the first "learning machine"[22] whose complementary function was to facilitate its operator in the acquisition of an "intellectual skill." In this case it was to become a proficient computer punchcard operator. The machine (which, of course, looked like a punch card machine) perpetually monitored the proficiency of its operator and posted tasks slightly more difficult than the operator's present state of competence. The rapidity of learning and the euphoria experienced by the learner were unheard of previously. I am not going to talk about the further development of these machines as this can be found elsewhere.[23, 24] However, I would like to talk about what we learned from these machines.

Since the entire process of interaction between student and machine from the first steps to the final performance test was recorded within the machine and could be inspected, these systems gave us a unique opportunity to learn about learning. Among the many unexpected and fascinating things that happened, I shall report only one item that I find particularly pertinent to my topic and of interest to your profession. It has to do with learning strategies.

By inspecting a vast number of machine records it became quite clear that among the various methods employed by motivated learners to comprehend the required material, two fundamentally different learning strategies emerged.

In the early stages of this study Pask called these two kinds of strategists "lumpers" and "stringers," but later gave them the more respectable names of "holists" and "serialists."[25] I prefer the earlier terminology.

While lumpers consider a particular problem as a whole and turn it around in their head until they see the first step towards resolution, stringers take a problem apart at once, and see how it can be restrung to obtain the desired solution.

While lumpers consider a particular problem as a whole and turn it around in their head until they see the first step towards resolution, stringers take a problem apart at once, and see how it can be restrung to obtain the desired solution.

Pask's observation did not stop here. The extension of this work yielded results which in my opinion are of the greatest significance in the construction of an educational program and even in the organization of a library's operations. What he found was that a habitual lumper, being taught in the style of a stringer, or a stringer being taught in the style of a lumper, will learn nothing. I shall return to this in a moment.

Computing

I shall now touch upon potential applications of the astounding computer technology to the operations of a library, not only because of Scott's hopes that I would address this topic, but also because I think that this technology could have been, and may still become, instrumental in facilitating the process I have called "to let know."

This technology suffered two semantic derailments in some of its basic notions in the last few decades. If we could clear the field of the resulting debris I would have high hopes for a successful marriage between libraries and appropriate technology.

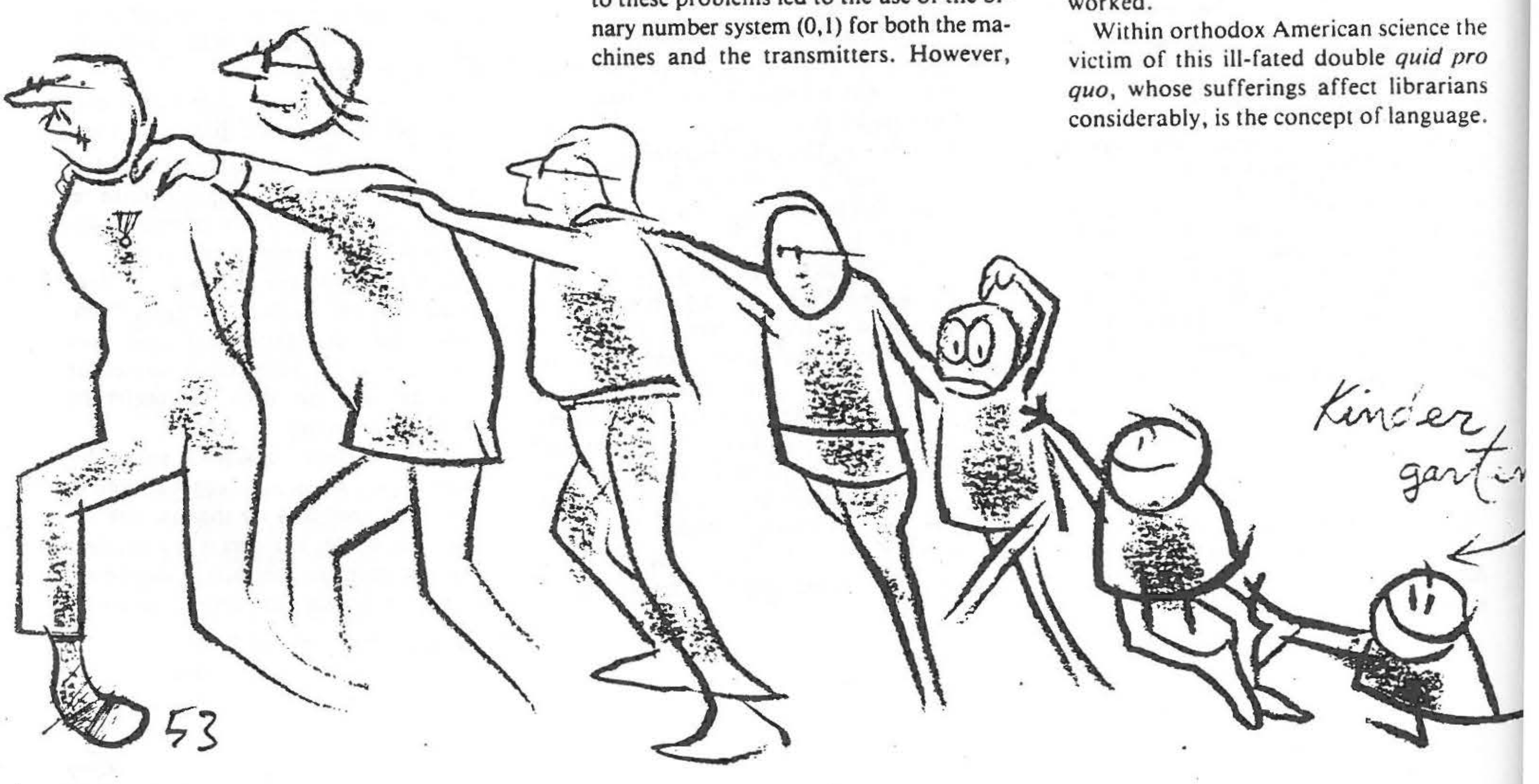
The first derailment took place during the Second World War when the needs of two apparently different fields converged. One was the need for high speed computing, the other for the high fidelity transmission of electrical signals over long distances. The problem that these two had in common was representation. In computation, the problem was how to represent a number through different strokes of the machine so that it would be least affected by operational perturbations. Similarly, in communication it was how to represent a message transmitted by signals so that it would be least affected by noise in the transmission channel. As you all know, one part of the solution to these problems led to the use of the binary number system (0,1) for both the machines and the transmitters. However, computational speed could be gained by providing storage for intermediate results that could be called upon later when needed, and communication fidelity could be gained by ingenious methods of encoding messages into signals. So far so good.

For reasons that still baffle me, it was the pragmatic American engineers and scientists, not the romantic Europeans, who began to toss anthropomorphic sand into the gear box of evolving notions and ideas. To name two such cases, the computer people began to talk about a machine's storage system as if it were a computer's memory, and the communication engineers began to talk about signals as if they were information.

I am sure that by now you have no difficulty in diagnosing this disorder — onset of schizodemia! I am also sure that you remember the later developments in this confusion, the learned discussions about mentality in machines, the debates about whether or not computers could think.

Perhaps these were the precursors for the second derailment which, ironically, was the inverse of the first. It worked as follows. The first phase was anthropomorphization: mental functions projected into machines. However, we knew how these machines worked because we built them and wrote the programs. Consequently, an appropriate "mechanomorphization," the concepts dealing with computer hard- and software were projected back into the workings of the brain and, presto!, we knew how the mind worked.

Within orthodox American science the victim of this ill-fated double *quid pro quo*, whose sufferings affect librarians considerably, is the concept of language.



This concept was modelled more and more after those emerging from interactions with computers, the "computer languages." It is clear that the syntax of these languages must be obeyed meticulously, otherwise "garbage in - garbage out."

Unfortunately, under the leadership of one of the foremost linguists in America, Noam Chomsky,[26] the logico-mathematical principle of fulfilling rigorous syntactic requirements in so called "well-formed formulae" was transplanted into the domain of natural languages and became a criterion for "linguistic competence." This aspect of language ignores the essential role as a means for communication and perceives language as an end in itself. It is in this castrated form that one believes language is "linear," that questions have unique answers, that the linguistic problem is to generate "well-formed sentences," and other misconceptions that have their roots in perceiving language as monologue.

You have all experienced, and are still experiencing, the spinoff of this position in "indexing languages," "cross reference file structures," "abstracting procedures" and other conceptual devices that are supposed to facilitate your job as if it consisted of indexing, cross-referencing, abstracting, etc. You know that I do not believe that this is your job. Even if it were just that, I am sure you have also experienced these aids as hindrances if the collection of items exceeds a critical size.

I claim that, with the preoccupation with syntax, one could not see language as an instrument of social coherence; one could not see its inherently dialogic character and all that follows from this view. With few exceptions[27, 28, 29] the fascinating problems of computing in the semantic or in the contextual domain were either ignored or avoided. Ten or 20 years ago the excuse for this omission was the complexity of these tasks.

Indeed, unlike the simple rules of syntactic concatenations, semantic relational structures are of extraordinary richness. Take a "semantic operator," for example, the preposition "of," and check in a dictionary for your own enlightenment the multitude of logics that this "simple" operator commands. *The American Heritage Dictionary of the English Language*[30] lists 19 different operational possibilities which, when pursued to two or three steps further, lead to arborizations that include nodes in this relational network that are in the thousands and, in others, even in the millions. Moreover, the particular path to be followed in this network depends on the context in which these "operators" (words) have been uttered, and the context, in turn, evolves only in the course of the dialogue, that is, only after the words have been uttered (so much for "linearity of language")!

However, it was true 10 or 20 years ago that the available computer architecture was unable to handle effectively computations in relational structures. This is no longer true. The development of miraculous pieces of hardware, which concentrate on a tiny chip an amazing diversity of computation power, that can be assembled into microprocessors of almost unlimited operational flexibility, allows for implementation of operational units commensurate with the complexity of the kind of operators I touched upon before.

When in an optimistic mood I can see a development in computer design that seriously considers semantic computations in which machines adapt to the language of the user and not where the user adapts to the functioning of the machines. A consequence of this inversion of today's state of affairs is that the "man/machine interface" which for most of us is now opaque, becomes transparent.[31]

When in a pessimistic mood I not only see the present state of affairs extended and specialization encouraged, I also see that these systems were built by the perfect stringers, exported for teaching the peoples of the Third World who most likely are the perfect lumpers. You know what they will learn from us and we from them: nothing!

Conviviality

I would like to invite you to see the library as a "convivial tool." It was, of course, Illich who inspired me to use this term, who invented this notion in the early '70s, and discussed it in his important book *Tools for Conviviality*.[32] I wondered why I, as well as my friend Illich, was so attracted to the notion of conviviality until I looked it up in the dictionary and remembered that we both originally come from Vienna, Austria. "Convivial"[33] means: "Fond of feasting, drinking, and good company . . ." in other words, living together well.

However, in *Tools* Illich deepens the significance of this notion:

> "Convivial tools are those which give each person who uses them the greatest opportunity to enrich the environment with the fruits of his vision. Industrial tools deny this possibility to those who use them and they allow their designers to determine the meaning and expectations of others. Most tools today cannot be used in a convivial fashion."

And he extends this notion to society:

> "A convivial society should be designed to allow all its members the most autonomous action by means of tools least controlled by others and use-value oriented. The growth of tools beyond a certain point increases regimentation, dependence, exploitation and impotence and cannot but produce exchange-values."

The door to my invitation to see the library as a convivial tool was opened by a small but extraordinary book, *Reference Guide to Convivial Tools*.[34] It was written by Valentina Borremans, Illich's co-worker for many years.

I think it can best be described in Illich's words in preface:

> "At first glance this is just one more book on reference books. It lists and describes 858 volumes and articles that, in their turn, list books on alternatives to industrial society or people who write on that subject. The seven essays at the head of the list are like road signs placed by the author, by which the newcomer may recognize a few comprehensive handbooks, catalogues, bibliographies or addressbooks to start on his search. The index, at the end, cross-references hundreds of subject-matters. Altogether, this looks like a book to be used in a library — but the library, where it could be used, does not yet exist: I recently checked in the largest technical libraries of Boston, Berlin, Oxford and Washington, and nowhere could I find even half of the reference-tools which are annotated in this volume. This is the champion list of un-listed reference tools: a bibliographic claim to a new kind of territory." . . . "Why . . . are the reference tools listed in Borremans so rare? This has certainly nothing to do with squeamishness, with racial prejudice or with sexism. It does have something to do with the unusual process by which many of these items are published and distributed and with the suddenness with which they have appeared in the seventies. But the absence of these research tools must be primarily due to the fact that no classification system provides quite the right number. The logical coherence of

the new literature has to be discovered before the reference paths into the new field can be assembled. In her introduction Borremans shows how this might be done."

Valentina Borremans said,

"Scientific discoveries can be used in at least two forms. The first leads to specialization of functions, institutionalization of values, centralization of power, and turns people into accessories of bureaucracies or machines. The second enlarges the range of each person's competence, control

> and initiative, limited only by other individuals' claims to an equal range of power and freedom."

I can't conceive of a better place than the library to ". . . enlarge(s) the range of each person's competence . . ." a truly convivial tool, allowing its users to see and to know of others, unlimited by time and space. It is a place where one can see oneself through the eyes of the other.

In 1938, when the Nazis invaded Austria, the neuropsychiatrist Dr. Victor Frankl and his family were arrested and sent to concentration camps. He lost his entire family but, he survived and walked back to Vienna after the Allied troops had opened the gates of the camps.

Since he had suffered through the nadir of human experience, his presence in a city still occupied by foreign powers was of immense importance. He helped many, many people who suffered deeply from the experiences of the war. There was a case that was brought to him. A husband and wife had, by miraculous circumstances, survived the Holocaust in two different concentration camps. They met again in Vienna and couldn't believe they were both alive. However, the wife, after being re-united with her husband for a few months, died of a disease contracted in the camps. After that, the husband became completely despondent, he didn't want to eat any more, he isolated himself and sat passively in a corner. Clearly, he had given up. Friends wanted to help him but he refused. He was finally persuaded to see Frankl, and they talked to each other for an hour.

At the end of their interaction Frankl made the following proposal to this man: "Assume that God would give me the power of producing a woman identical to your wife; she would remember all the details of your conversations, know the jokes and the experiences you had. You would not be able to see the difference, whatever test you gave her. You would see she is like your wife. Would you like me to produce such a woman"? After a while, the man said, "No." Dr. Frankl said, "All right. Thank you." They separated. The man began to recover.

When I heard that I asked, "Dr. Frankl, what happened? What did you do?" And he said, "It is quite clear. This man was seeing himself through the eyes of the other — through the eyes of his wife but, when she was dead, he was blind. When he could see that he was blind, he could see."

With this in mind, let me paraphrase the theme of your conference: you will share your specialities when you see yourself through the eyes of the other. This is a personal opportunity!

Dr. Heinz Von Foerster is a noted biophysicist and cybernetics expert. He was associated for many years with the University of Illinois engineering and biophysics departments and is professor emeritus at the university. He was involved in the development of the UNIVAC computer. His address was given at the June 11 theme session at the CLA conference in Saskatoon.

This article is an adaptation of his address. The author wishes to express his gratitude to Phebe Chartrand, library personnel officer, McGill University, for encouragement, help and advice in preparation of the article.

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POEMTHINK

By Gerd Stern

is a process
I can describe
but not demonstrate
for you: describe
but not demonstrate

first about think
do you know much
how you think?
how other people
thank, thunked, thoughted

how conscious thought?
your thoughts?
can you hear yourself
thinking? you can?
one way of thinking?
an only way?

if you can hear it
is it in words thinking
I don't know
if I think
that most thinking
is in words
or can be heard
but the think
poemthink
I'm describing
not demonstrating
is in words
and when I poemthink
I can hear it
inside hear it
if that's hearing

sometimes
I even catch myself
moving my mouth
though I'm not speaking
out; not out loud speaking

there's not a large literature
on the mechanics of think
as something to learn
there's lots on thought
of all kinds
but how to think
to use the generators,
switches, crossings. . .
pardon the metaphors,
semaphores, phosphors. . .
just how to think
have you conversation,
communication, learning
on think process?

the next jump
(. . with care . .
in the presence . .)
personal history
recollection
in re: collection
ever since before thenwhen
its been necessary
for me to write (down?)
words, phrases, poemparts, wholes

once up on that time
I thought, felt, heard
near that threshold
where there's just so much
you can remember
and you write
to not let it spill
into forgotten

as I in bed lying
about to get up and grab
for extensions
paper and lead
overstood that this moment
with these words
moment with words all mine
connected me-circuit
around the positive
amplifying looped feedback
to me-circuit
contact was and is
contact is the only
love circuit

in bed then
with my unnamed
poemthink riff
vanished, disappeared
but recognized
evanscent artifact
trace element
flashing imagination scan

follow or not to be
motion enormous scale
off the balancing act
between now and then
sometimes you can keep it
to yourself
one to three forever

life
this time around
provides plenty
more or less
alone time: frinstance
driving, waiting, being
and a lot of time
around others
not with them
enuf moment inertia
language compatible
with your head
for poemthink mindware

you: programmer, artificer,
wordstringer
however many
you can fit, squeeze, allow
in this/that moment
of poemthink consciousness

along a thread
through your maze head
on stretched, condensed line
jump-rope words
for each point
in figure

nude, of speech, geometric
catch it
when it falls
into your head
wrap or trap it and gofer it
reach high over
one follows another
piggyback
jump brother
in the presence
of a word care
center as in potwheel
or scatterseed

you a muthahword grabber
only if you do
poemthink poem think
poemthink

stuck on a noun
in your deck
pin-stripes
and single-breasteds

a little tight-assed
like the Troppian cow
by the stream
plop it go
loosen word-rein
or chop 'em into alpha bet

any foreign language
especially those you
don't know well
a poemthink fountain

why?
if you don't like it
you don't have to do it
not like drugs
something you can
make up your mind about
without trying

poemthink
a totally different head
than poemwrite, speak, read
having described
not demonstrated
poemthink
others have tried it
liked it and not
changed, added, used
it replicates

there's that how many question
of holding like a bowl
how many letters, words, lines
can you maintain, juggle
transform and back out of
momentum to loop
the moebius strip, klein bottle,
ryan tube topology

are you coming along
or copping
are you in poemthink
let's take 5
first poem thinks
for everyone

*   *   *

take whatever you had
weigh it as experience
could this become something
truly meaningful in your life
get into it
off on it
rubadub poemthink

not a blanket or a towel
'tell the truth
there's no weight
when you're carrying
poemthink
because the only rule
is let go
when you're through
don't hold, write, store

memory is both a virtue
and a vice
as the Roshi bakes
and the Rebbe comes
years ago I quoted
"if you can't count don't blow"
for poemthinking mindware
counting is slowing
bubbles is more like
the kind of blowing it is
in your mouth like pebbles
in your head like
poemthink words
a few rattling
reassembling
daisychaining
huggable
untouchable
W O R D esses

but there's a limit
interruptus
poemthink no regrets
for lost nuggets, shards
a word for each eye
behind the retina
with fists against closed eyeballs
phosphoring in the Rodinpose
the Poemthinker at it

if you're remembering
you're doing it
-you're not doing it
if you remember
you can do it
do it

jump cut or fast fade
why not try a hexagram
barnstorming was also
a popular pastime
like mah-jong
still on your first poemthink
have another quickie
on the house N O W
take the no out of now/NOW

*   *   *

"Do words and thoughts
follow normal rules or do they not"
Is poemthink that question?
or maybe according to Hofstadter
poemthink is an "isomorphism"
"an information preserving transformation"
more likely Ovidian metamorphosis
now tell me the difference
which is one of the connections
between words

actually
its not the poemthinking words
that really get to you
give you the juicy joy
of insight breathing together
but the web; connective tissue
intervals, silences, voids

poemthink: how to
just keep it going inside
for your my self
not really enuf play
to get your bearings
not enuf happening
for keepsake
insufficient nutrition
for the spirit <u>in media res</u>

according to William James
"much of our thinking
consists of trains of images
suggested one by another
of a sort of spontaneous revery . . .
(which) leads nevertheless to
rational conclusions both practical and
theoretical."

Jung has thinking divided:
"active; an act of will . . .
passive; a mere occurence . . ."
and writes, "thinking . . .

brings the content of ideation
into conceptual connection . . .
linking up ideas . . .
to an act of judgment . . .
whether intentional or not . . ."

he quotes Baldwin,
"The individual must use his old thoughts
his established knowledge
his grounded judgments
for the embodiment
of his new inventive constructions.
He erects his thought . . .
in logical terms, problematically,
conditionally, disjunctively
-projecting into the world
an opinion still personal . . .
Thus all discovery proceeds . . ."
and Wundt
"a further important consequence
of the interaction of sound and hearing
is that many words come to lose
their original concrete significance
altogether and turn into signs
for general ideas . . .
In this way abstract thought develops . . ."

and Anatole France
"What is thinking
we think with words . . .
the perfected cries of monkeys and dogs . . .
onomatopeic cries of hunger, fear and love . . .
to which have become attached
meanings that are believed to be abstract . . ."

high headstart
drawing away from: abstract
coasting between the edges
in formation
out of formation words fly
try poemthink

as re-creation, sport, pursuit
of words, stepping-stones
poem think way
time-passing, concentrating climactic
aware magnetic practice
words to and from
poemthink
edutain, elevate con
sciousness
expancontract
blessed aha syndrome
down and out with it

take full count
instant word
pattern recognition
poemthink
no end of wordtences
meaning sound
on the going to come
triggerstroke
description not demonstration

aren't you ecstatic
you have the rest of your life
to poemthink

no i wouldn't call it
a kind of meditation

true i do think
just about anyone can do it

maybe it is something like
whateverthename's ideas about

yes open to questions, advice,
insight, love, peace

it is possible
that it is possible
it is possible
that it is possible
it is possible
that it is poemthink

*

What is it to see?

¿Qué es ver?

HUMBERTO R. MATURANA

We as neurobiologists studying vision usually do not ask the question *what is it to see?* because we considerer it a philosophical and not a biological question, and do not realize that we answer it implicitly by doing what we do in our research. This implicit answer entails the basic assumption that we exist in an objective world independent of our acts of cognition and accessible to our knowledge. My contention is: a) that by answering the question *what is it to see?* one can show that this assumption cannot be sustained because the phenomenon of perception cannot consist in a process of grasping the features of an independent world of objects; and b) that by reflecting upon the nature of a scientific explanation one can show that this assumption is unnecessary because a scientific explanation is a particular kind of coordinations of actions in a community of observers that does not entail it. In this context, a) by puting objectivity in parenthesis, that is, by using the operational generation of scientific explanations and not the object as the criterion of validation of my statements, and, b) by recognizing that the nervous system operates as a closed neuronal network in the generation of its states of activity, I show that the phenomenon of perception arises in the description of an observer as a manner of referring to the operation of an organism in congruence with the particular environment in which it is observed. In these circumstances, my answer to the initial question is: to see is a particular manner of operating as a closed neuronal system component of an organism in a domain of structural-coupling.

Finally, I propose that by dwelling in languaje as a peculiar system of coordinations of actions, we human beings bring forth an objective world through using our own changes of states as describers that specify the objects that constitute it.

A. INTRODUCTION

When I was invited to give the opening address in this symposium I decided to considerer the question *what is it to see?* Although this question is in the background of all our research on vision, it is rarely asked in an explicit manner by neurobiologists. This is so because this questions is usually considered to be a philosophical question, and biologists, generally, dislike philosophical questions because they fear to be lead into abstract speculations, and away from facts. This aprehension, however, is unjustified and originates from a misunderstanding. The question *what is it to see?*, as a question that reflects on what we do as neurobiologists studying vision, is indeed a philosophical question. Yet, because this question addresses us to the foundations of what we do as neurobiologists, its answer bears upon the manner we use our research to understand what we call the phenomenon of vision, and determines what particular questions we ask and what answers we accept in the field of visual perception. Accordingly, the aprehension mentioned in unjustified, because it is precisely the explicit or implicit answer to this question, which is necessarily entailed in what we do in visual research, what determines what is a fact in the study of the phenomenon of vision. Yet, the belief that because this question is not asked explicitly its answer does not bear upon what we do as biologists, arises from a misunderstanding. By the very act of accepting a given phenomenon as a phenomenon of vision, we implicitly accept an answer to this questions that permeates all what we do, even in daily

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life. What we rarely do, however, whether as neurobiologists or as ordinary people, is to inquire into the foundations of our accepted answers in the field of vision, perhaps because such an inquiry necessarily leads to question the ontological and epistemological basis of our certainties about perception and cognition. Indeed, the answer to the question *what is it to see?* implies an answer to the questions *what is reality?* and *what is it to know?*, and the present essay, by asking such question, is both a research in vision and an inquire in the epistemological and ontological basis of our perceptual certainties.

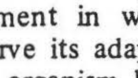
B. THE PROBLEM OF PERCEPTION

Many years ago, Roger Sperry showed that when he presented a prey to a frog or to a salamander whose eyes had been experimentally rotated, and had recovered vision, these animals oriented themselves or struck their tonges in a direction that appeared displaced in an angle equal to the angle of rotation of the eye that viewed the prey. The usual questions asked in face of such experiments refer to whether the animals learn or do not learn to correct their aims, or whether they recover or do not recover their ability to handle the environment without committing the mistake of trying to catch a prey where it is not. I have never heard anyone but myself saying that such experiments rotate the world of the observer with respect to the operated frogs and salamanders, and that these do not commit mistakes even if they starve to death because they never catch a prey again.

This, however, is not strange. We usually speak and provide explanations to the biological phenomena that we consider as if the organisms that we observe operated perceptually in the environment in which we see them to exist. Or, in other words, we usually speak and provide explanations for perceptual phenomena as if we as observers and the animals that we observe existed in a world of objects, and as if the phenomenon of perception consisted in grasping the features of the objects of the world, because these have the means to permit or specify this grasping. This is, indeed, apparent in the etymology of the world perception that, coming from the latin *per capiere*, literally means obtained through grasping or capture. Yet, does the phenomenon of capture of the features of the objects of the world implied in the usual connotation of the word perception exists? Can the environment in which we see an organism exhibiting a perception, specify what happens to it so that we may indeed speak of perception by an organism as a phenomenon of grasping?

My contention is that this is not the case, and that the phenomenon connoted by the expression to perceive, is not to grasp the features of an outside world of objects. Furthermore, my contention is also that when an observer claims that an organism exhibits perception, what he or she beholds is an organism that brings forth a world of actions through sensory motor correlations congruent with the perturbations of the environment in which he or she sees it to conserve its adaptation. Finally, I claim that an organism has a many perceptual spaces as domains of sensory motor correlations an observer can see it to implement, while conserving adaptation, in the different domains of interactions in which he or she distinguishes it by specifying for it different domains of perturbations.

I maintain this, of course, under the view that these claims also apply to us as perceptual animals. In what follow I shall give support to these claims, first, by showing that the phenomenon connoted by the word perception cannot be one of grasping features of an independent object world, and, second, by showing that the phenomenon that we call perception consists in bringing forth a world of actions.



C. OBJECTIVITY

Our daily experience is one of existing in an objective world, that is, in a world of objects whose existence does not depend on us. Accordingly, we usually dismiss any situation in which the presence of the objects that we experience seems to depend on our experiencing them, and call such objects and situations illusions and hallucinations. In agreement with this, our language is a language of objects. Furthermore, we as scientists generally view science as a domain of objective knowledge, and claim that the existence of an objective world accessible to our perceptions and cognitions, is a necessary condition for the existence of science, and consider the operational success of scientific explanations a proof of this objectivity.

Such an attitude about the objectivity of the world brings no difficulty unless we try to give a scientific explanation to the phenomenon of perception as a phenomenon of grasping an external objective world. Indeed, when we try to do so, we encounter several difficulties of which I wish to examine two: a) the non-objectivity of scientific explanations, and, b) the structural determinism of the systems that can be handled in scientific explanation. Let us examine them:

Scientific explanations

Scientific explanations are generative explanations. That is, scientific explanations are propositions of mechanisms (systems) that: a) generate the phenomena to be explained as a result of their operation; and b) are accepted as valid in the community of scientists because they satisfy the conditions that constitute the criterion of validation of scientific statements which this same community has established. These conditions, usually viewed as the scientific method, are the following:

i) A description of the phenomenon to be explained. This entails the specification of the phenomenon to be explained by specifying the conditions that an observer must satisfy in his or her domain of experiences in order to observe (witness) it.

ii) A proposition of an explanatory hypothesis as an *ad hoc* mechanism (or system), that by its operation generates the phenomenon to be explained in the domain of experiences of the observer.

iii) A deduction through the operation of the explanatory mechanism in (ii), of another phenomenon not considered in its proposition, and the description of the conditions under which it would be observed.

iv) The observation of the phenomenon deduced in (iii) by an observer satisfying the required conditions in his or her domain of experiences.

A serious examination of this criterion of validation of scientific statements reveals a system of operational coherences that has not need of objectivity in order to operate. Or, in other words, it is not the case that for us to make scientific statements it is required a world of objects. All that is required, is a community of standard (operationally coherent) observers that generate statements validated by the criterion of operational coherence described above. Scientific explanations arise in the domain of experiences of a community of observers, and thus pertain to the operational coordinations of the members of such a community.

The success of scientific explanations in providing an operational matching to what we call our perception of the world, we does not constitute a proof of the objectivity of the world that we experience, and cannot be used either as an indirect proof that the phenomenon of perception consists indeed in grasping the features of the objects of a world independent of the observing of the observer.

For this reason the object described in a coordination of actions (and distinguished in language) cannot be used to validate statements about it in the domain of science. Also for this reason I shall proceed putting objectivity in parenthesis. That is, although I must use a language of objects (the only language we have) (see Maturana, 1978 a and b), I shall not use the object as an argument to validate my statements, which will be founded only on scientific explanations.

Structural determinism

Scientific explanations entail the proposition of systems that through their operation generate the phenomenon to be explained, and which, therefore, do not have the features of the phenomenon to be explained preexisting in their constitution. For this reason scientific explanations are mechanistic propositions, and as such consist in propositions of structure determined systems. In order to see what this means, let me clarify certain basic notions that we necessarily use in our language of objects.

Observer. Any human being who, by operating in language with other human beings, participates with these in bringing forth a domain of coordinated actions as a domain of distinctions, and can, thus, generate descriptions and descriptions of descriptions. In short, I and all those who read this article.

Distinctions. An observer makes distinctions through operations that cleave a continuum and bring forth entities as distinguishable unities or wholes, specifying them and the background in which they exist. The observer exists by making distinctions of distinctions, and brings itself forth by making such distinctions in a recursive manner (see Maturana, 1978a, 1978b).

Unities. We as observers distinguish two kinds of unities, simple and composite unities. We distinguish a simple unity as an entity in which we do not distinguish components, and which is, thus, characterized only by the properties with which it appears endowed by the operation of distinction that brings it forth. We distinguish a composite unity as a continuum in which we perform further operations of distinction, and bring forth aditional unities that are specified as a components in relation to the simple unity that they integrate as a continuum prior to its decomposition. Therefore, a component exists as such only in relation to the composite unity that it contributes to constitute (integrate) as a unity that can be distinghished as a simple unity (a continuum) of a particular kind. The properties of a composite unity result from its manner of composition, that is, from its *organization* and *structure.*

Organization. The relations between the components that define a composite unity as a unity of a given kind, constitute its organization. The organization of a composite unity, therefore, defines its class identity, and is conserved as an invariant set of relations, while the class identity of the unity is conserved. If the organization of a composite unity changes, the class identity of the composite unity changes and the original unity disintegrates.

Structure. The actual components, and the actual relations that realize a particular composite unity as a composite unity of a particular kind, constitute its structure. The structure of a composite unity realizes the relations that constitute its organization, but includes more relations than these. For this reason, while the conservation of the class identity of a composite unity entails the conservation of its organization, it does not entail the conservation of its structure. In fact, the structure of a particular composite unity may change without it losing its class identity, either through changes in the characteristics of its components (if these are themselves composite unities) or through changes in their relations, and this can take place recursively as long as the organization of the unity is conserved, otherwise it disintegrates, and another unity, or several other unities, appear in its stead.

Interactions. A simple unity interacts through the operation of its properties. A composite unity interacts through the operation of the properties of its components.

Existence. A simple unity exists in a space defined and realized by its properties as a simple unity. A composite unity exists in a space defined and realized by the properties of its components. There are not empty spaces, and a space is brought forth by the unities whose properties define it. A unity only interacts in its space of existence.

Structure determined systems. Since the structure of a composite unity is at any instant determined by its components, any change in the structure of a composite unity can only arise determined by its structure through the operation of the properties of its components. In addition, since a composite unity interacts through the operation of the properties of its components, its interactions can only trigger in it structural changes determined in its structure without specifiying them. Finally, and as a result of this latter condition, the structure of a composite unity determines the structural configurations of the medium with which it may interact. Composite unities, therefore, are *structure determined systems*, and their characteristics as such can be systematized by saying that it is the case that the structure of a structure determined system determines at every instant:

a) its domain of possible estructural changes without loss of class identity (with conservation of organization), that I call its *domain of changes of state;*

b) its domain of possible interactions that trigger in it a change of state, that I call its *domain of possible perturbations;*

c) its domain of possible structural changes with loss of class identity (loss of organization), that I call its *domain of possible disintegrations;* and

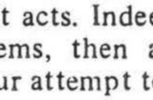
d) its domain of possible interactions that trigger in it a disintegration, that I call its *domain of possible destructive interactions.*

In a dynamic structure determined system, therefore, there are structural changes that arise both through its interactions and as a result of its own structural dynamics, but which are always, at every instant, determined by its structure. This general characteristic of structure determined systems has one fundamental consequence, namely, that they do not admit instructive interactions. In other words, there is no operational mechanism through which the medium could determine the changes of state of a structure determined system, these are always determined in it. Furthermore, since mechanistic systems are structure determined systems, and since science deals only wifh mechanistic systems, science cannot deal with system that admit instructive interactions.

It is apparent after these considerations that if living systems are structure determined systems, the phenomenon of perception as a phenomenon of capture of features of an environment, cannot occur because there is no mechanism through which the medium could determine what happens to a sensory system in an interaction. The medium can only trigger a structural change determined in the structure of the sensory system of the organism. Furthermore, if there were instructive interactions we could not use them to generate scientific explanations. In fact if such were the case, an acting agent would determine what happens to the system upon which it acts. Indeed, if we were instructive systems, then anything that we touched in our attempt to analyze it would have characteristics determined by our touch, and everything would appear the same. We could not make distinctions.

It follows from this, that the phenomenon that we call perception in living systems, and which appears to permit to an organism its appropriate handling of its environment, cannot be one of grasping or of capturing the features of a world of objects external to the organism if living systems are amenable to scientific explanations. What is then the case?

In order to proceed further we must reflect upon the condition of structural coupling in which every scientifically analyzable system exists, and upon the operational characteristics of our main analytical instrument, the nervous system.



D. STRUCTURAL COUPLING

Every structure determined system exists in a *medium.* This condition of existence is necessarily, also a condition of structural complementary between system and medium in which the interactions of the system in the medium are only perturbations. If structural complementary is lost, if there is a single destructive interaction, then the system desintegrates and does not exist. This necessary structural complementarity between structure determined system and medium that I call structural coupling, is a condition of existence for every system. The part of the medium in which a system is distinguished, that is, the part of the medium that is operationally complementary to it, I call its *niche.* The niche is always specified and obscured by the system which is the only one that can reveal it. Furthermore, I call *environment* the part of the medium that an observer sees surrounding a system while this obscures its niche.

The very existence of a structure determined system, then, entails its structural coupling and the conservation of its structural coupling through all its changes of state. What changes in the relation system medium along the changes of state of a structure determined system, is its niche. When actually speaking of living systems, Francisco Varela and I call the conservation of structural coupling the conservation of adaptation. Furthermore, we maitain that living systems (as every system) exist only in conservation of adaptation, and that their ontogenies are necessarily histories of structural changes in congruence with a structurally static or chanding medium that allows them the realization of their respective niches, and that if this is not the case they disintegrate.

Moreover yet, since the medium can only trigger in a living system changes of structure that it does not determine, the ontogeny of a living systems, as a system in continuous structural change, constitutes a structural drift with conservation of organization and adaptation contingent to the interactions of the living system in the medium. A consequence of this ontogenic structural drift with conservation of adaptation of living systems is that, while they are alive, they are never operationally out of place. Living systems exist only while their interactions trigger in them structural changes congruent with the structural changes of the medium. That is, living systems exist only while their interactions trigger in them changes of state that result in further interactions that again trigger in them further changes of state, and so on until a destructive interaction takes places because the independent changes of state of the medium or the internal dynamics of structural changes of the living system do not permit the conservation of adaptation to continue. To live is to glide in a niche.

Yet, while the ontogenic structural drift takes place with conservation of adaptation, an observer that sees this conservation in terms of an operational congruence between a living system and its environment, may describe this operational congruence in terms of perceptual interactions, as if the living system were grasping the features of the environment and using them in computing its following changes of state. Nothing of the sort takes place, however. From the regularity of the recurrent interactions it appears as if that were indeed the case, and it is this appearance what seduces us to talk as if the phenomenon that we connote when we talk of perception were indeed a process in which an organism grasps the features of an outside world.

But, if there is no grasping of the features of an outside world, how does the nervous system participate in the generation of an adquate conduct? What phenomenon do we denote by the word perception?

E. THE NERVOUS SYSTEM

We, neurobiologists, usually work with the view taht the nervous system is a system designed to obtain information from the environment in order to compute the behaviour of the organism. According to this view we generally study perception trying to show how are the features of the environment abstracted by the sensors used to generate a representation of the outside world as a reconstruction of it. From all that I have said it is apparent that the nervous system cannot operate in that manner. Indeed it does not. Moreover, the experiments of Sperry that I mentioned at the beginning showed this by showing taht the nervous system operated generating internal correlations only, but nobody that I know has seen them in this manner. Nor even myself, because I came to view the nervous system as I do now, not by reflecting upon those experiments, but through my own studies in color vision. In 1968, fourteen years ago, I published, with Gabriela Uribe and Samy Frenk, an article, which nobody took seriously, in which I showed that one could generate the whole human color space if one tried to correlate relations of activity of the retinal ganglion cells with color naming, in an act that closed the nervous system. In fact, what that article does is to show that while one cannot generate the human color space as a perceptual space by trying to correlate the activity of the retina with the visual stimuli, one can generate it by correlating classes of relations of activity holding between different kinds of retinal ganglion cells, with the name given to the experienced color.

A nervous system is a system organized as a closed network of interacting neuronal elements (including receptors and effectors among these), that interact with each other in such a way that any change in the relations of activity that takes place between some elements of the net, leads to changes in the relations of activity taking place between other elements of the net. This organization can be realized through many different structures that may differ in the particular properties of the components (sensors, effectors and neurons) involved, as well as in their particular connectivities, as long as these operationally implement it by closing the network of changing relations of activity that takes place between them. As a result of this operational closure, all that takes place in the operation of the nervous system are changes of relations of activity between its component elements. The sensory and effector surfaces of the organism are not an exception in the closure of the nervous system because every change in the effector surface of the organism leads to a change in its sensory surface, as happens in the changes of the pre and post synaptic surfaces of an internal synapse. What is peculiar to the effector and sensory surfaces of an organism, is that we as observers stand between them as if we had opened a synapse and defined its synaptic gap as the environment. In these circumstances, the environment with all the features that we may distinguish in it exists only for us. For the operation of the nervous system of an organism, the synaptic gap where we stand is not different from any other synaptic gap, that is, it is not a gap (Figs. A to D).

A

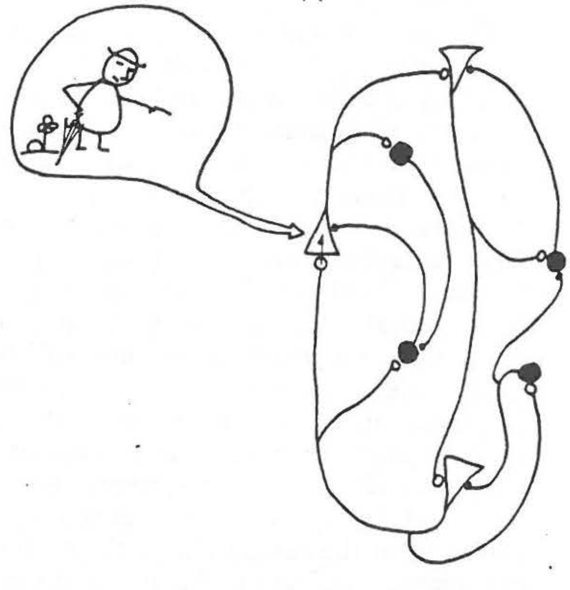


Figure 1: The observer looks at a nervous system as a closed neuronal network, and interacts with it interacting with its components in a structural domain orthogonal to its dynamics of states. Open arrow, interaction orthogonal to the dynamics of states of the closed neuronal network that triggers a structural change in a neuronal component without constituting an input to the nervous system. Thin arrow, synaptic transmition.

The environment that we describe, as part of the medium where we stand as observers, does not exists for the nervous system of the observed organism in its operation as a closed network of changing relations of activity between its components (Fig. B). Yet, to the extent that the organism and the nervous system in it operate as a unity in the domain of existence (medium) where we distinguish it by standing between its effector and sensory surfaces, the organism and its nervous system undergo their coupled structural drift with conservations of organization and adaptation as a unity in that medium. In fact, since any system conserves adaptation in its domain of existence whatever this may be, if we

B

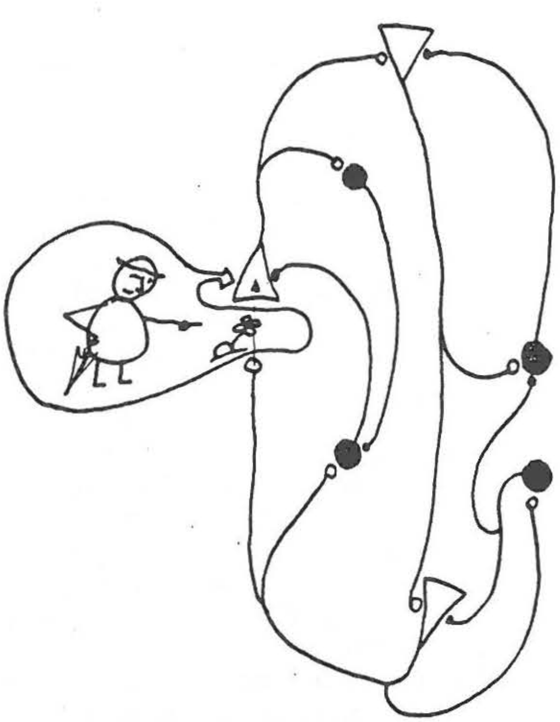


Figure 2: The observer opens a synapse defining both a sensory (above) and an effector (below) surface. Arrows like in Fig. A.

C

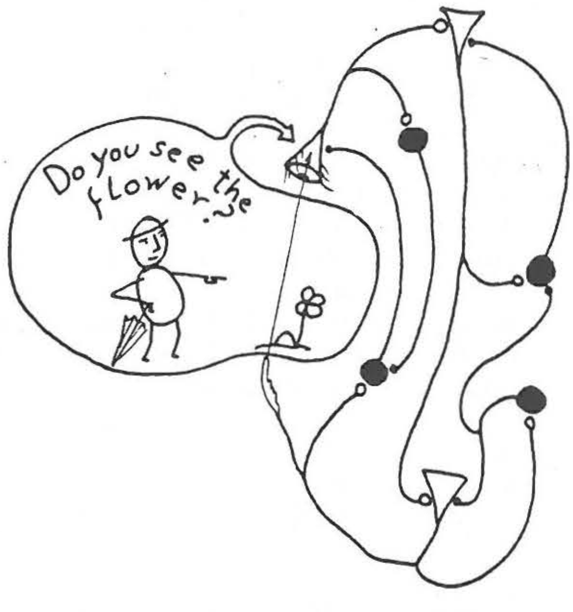


Figure 3: The observer by stepping in the synaptic gap defines his or her domains of distinctions as the environment of the nervous system. For the observer there is a flower in the environment; for the dynamics of states of the nervous system as a closed neuronal network there is no flower, only a synaptic gap that is not a gap. The structures of the environment that the observer sees constitute only orthogonal perturbations for the sensors, not an input to the dynamics of states of the nervous system. Arrows like in Fig. A.

as observers, through some operation of distinction enter a standard synaptic gap of the nervous system of an organism, and stand in it specifying it as the medium (domain of existence) of a new system distinguished by defining the pre and post synaptic surfaces of the synapse as its effector and sensory surfaces, then we are bound to find such system in structural coupling in that medium as long as we distinguish it (Fig. C). Therefore, what is peculiar to the medium in which we usually observe an organism with its nervous system, is not that the medium spans the effector-sensor synaptic gap, but that we stand in it as observers.

In these circumstances, while the nervous system undergoes its closed dance of changes of relations of activity completely oblivious to the environment that we describe, we see the organism in a medium undergoing changes of state that appear to us as changing sensory effector

D

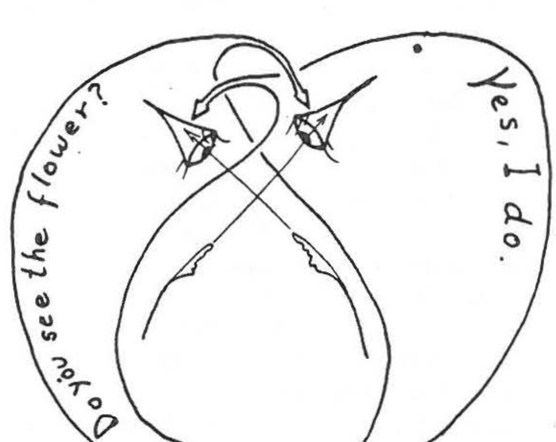


Figure 4: Structural dance of two interacting organisms with closed nervous systems that perturb each other structurally, but which, even though they stand opening each other at the effector sensor synapse, do not constitute inputs to their respective closed nervous systems. Arrows, like in Fig. 1.

(motor) correlations that we describe with respect to the environment as behaviour. Different organisms have different structures in their nervous system which, therefore, undergo different internal dances, and different structures in their bodies and sensory and effector surfaces which appear to us as giving rise to different behaviours through different sensory effector correlations. In every particular case, however, nervous system and organism, individually and together, operate as structure determined systems in conservation of their respective structural couplings and organizations, or disintegrate. An organism is coupled to its niche in the medium in which we distinghish it, and the nervous system is coupled to its niche in the organism that it integrates.

Let me be more explicit about the behaviours of the organism and the internal states of the nervous system.

i) *Behaviour.* An observer who beholds a living system in an environment does not see its changes of state as a composite unity, he or she only sees its changes of position or its changes of shape with respect to the environment as changing sensory effector correlation, either triggered by its interactions or generated as a result of its internal dynamics. These changes of shape or of position of a linving system with respect to the environment in which an observer sees it, are its behaviour or conduct, and must take place under the condition of conservation of organization and adaptation by the organism, or this disintegrates. Therefore, although a behaviour is, of course, the result of the changes of state of the organism that exibits it, and, thus, it depends on the structure of the organism, the structural changes of the organism (its nervous system included) do not constitute its behaviour. The changes of state of an organism (its nervous system included) and its behaviour pertain to different non intersecting phenomenal domains. This has a fundamental consequence, namely, that although the behaviour of an organism is not a feature of the operation of its nervous system, which as a closed neuronal network only generates internal changes of relations of activity, the conservation of the structural coupling of the nervous to the organism that it integrates necessarily results in that its ontogenic structural drift must take place in congruence with the behaviours that the organism generates. In other words, although the nervous system does not determine behaviour, the behaviour of the organism sets constraints on the ontogenic structural drift of the nervous system. This is so because the behaviour of an organism is implemented through the sensory effector correlations that its nervous system generates, and either the organism conserves adaptation through the behaviour that nervous system contributes to generate, or it disintegrates.

ii) *The nervous system.* The organization that is conserved in a nervous system during the ontogenic structural drift of the particular organism that it integrates, is that of a closed neuronal network that generates internal changes of relations of activity that appear to an observer as changing patterns of sensory effector correlations. To an observer that manages to behold simultaneously the behaviour of an organism and its changes of state, the latter appear to reflect the operational distinctions of the environment that the sensory effector correlations appear to perform through the behaviour of the organism.

For an animal the sensory effector correlations of its nervous system do not exist because the organism exists as an animal in its domain of behaviour, not in the domain of states of its nervous system. For the dynamics of states of the nervous system the animal that it integrates does not exist for similar reasons. Yet, an observer sees that the sensory effector correlations that result from the dynamics of state of a nervous system specify an organism as a behaving entity in its medium.

The separation of these two phenomenal domains, the domain of behaviour and the domain of states, in living systems, is constitutive. They correlate only as a consequence of the phylogenic and ontogenic structural drifts contingent to the conservations of organization and structural coupling (adaptation) that takes place in the succession of ontogenies that is the evolution of the organism. The operational congruence between behaviour and niche that an observer witnesses while beholding a living system, is always the result of these conservations, and never of a breach of this constitutive separation between its domain of conduct and its domain of states. In these circumstances the nervous system concretely operates generating, through its internal dynamics, changes of state that appear to an obverser as reactive actions upon an environment after a perceptual grasping of its features. Yet, they are not. The observed actions, however adequate or inadequate they may seem to an observer, arise as sensory effector correlations in the operation of the nervous system as a result of a dynamics of states produced in it by its particular structure at the moment in which they take place. All this under circumstances in which, at any instant, the structure of the nervous system as a neuronal network is the result of a phylogenic and an ontogenic drift with conservations of adaptation, from which the only way out is disintegration. Accordingly, a conduct appears adequate or inadequate depending on the expectations of the observer that define the kind of living system that he or she distinguishes. For the operation of the living system as a living system there is not adequate or inadequate conduct because there is no conduct at all. In it, as long as it remains alive, all its changes of state are adequate.

The many different neuronal architectures evolved in many different kinds of animals, constitute different manners of generating sensory-effector correlations proper to correspondingly different niches that have arisen through different structural drifts in different lineages of ontogenic conservation of adaptation. This is apparent, a) in that the general structure of the nervous systems of all animals is that of a system of recurrent criss/crossed internal proyections of the sensory and effector surfaces of the organism, with fine and gross retention of their somatotopic relations, and b) in that different kinds of animals that differ in the possible sensory motor correlations that their different body architectures permit, differ in the particular architectures of their nervous systems as systems of internal correlations based on different combinatorials of the retained somatotopic relations of the sensory and effector surfaces. All this in the understanding that sensory and effector surfaces are only surfaces of interaction of an organism in the domain of existence in which it is observed, and not surfaces of operational opening of the nervous system.

iii) *Relations of neuronal activity.* The structure of a nerve cell (its shape, the distribution upon it of the excitatory and inhibitory synapses with respect to the point of origin of a nerve impluse, the structure of its membrane in its various parts) determines the temporal relation of activity in its field of afferent influences to which it responds. Different kinds of nerve cells differ exactly in this, and operate, metaforically speaking, as different filters that simultaneously pick up different relations of activity from a field of afferent influences through their overlppaing different collector surfaces. This has several consequences for the operation of the nervous system as a closed neuronal network: a) all synaptic afferents to a particular nerve cell, whether they are active or not at the moment, participate at every instant in the generation of the relations of afferent activity to which it responds; b) if the structure of a nerve cell changes, the relation of afferent activity to which it responds changes; c) since the structure of a nerve cell changes continuously through its activity, either through its synaptic interactions with other nerve cells, or through its non-synaptic interactions (trophic, hormonal, etc.) with other cells (nerve cells or not), the relations of activity in the field of afferent synaptic influences impinging upon it to which it responds, may also change continuously; d) when the structural changes of a nerve cell are reversible, the changes in the relations of afferent synaptic activity to which it responds are also reversible; e) when the structural changes of a nerve are not reversible, or the time constant of reversion is long with respect to other changes, the changes in the relations of afferent synaptic activity to which it responds may also be irreversible, and drift following the structural drift of the nerve cell; f) to the extent that nerve cells connect with each other through synaptic contacts, each nerve cell participates in the field of afferent synaptic influences of all the other nerve cells with which it connects; and g) all this applies also to the sensory and effector cells as components of the nervous systems as a closed neuronal network.

It is because of this manner of operation of the components of the nervous system that the nervous system as a closed neuronal network operates in the closed generation of changing relations of activity between its components, regardless of what triggers in these their changes of state. And it is because of this that the states of activity of the nervous system are changes in relations of activity between its components, and not changes of structure in its components. And, finally, it is also because of this, that the components of the nervous system may participate in interactions outside their participation in the dynamics of states of the nervous system, and do this at the same time that they participate in this dynamics of state through the same structural changes.

iv) *Sensory and effector interactions,* To the extent that the nervous system operates as a closed neuronal network in its dynamics of states, changes at the sensory surfaces of the organism do not constitute inputs to it. Similarly, changes at the effector surfaces of the organism do not constitute outputs in the operations of the nervous system. They are only post and presynaptic changes at the effector-sensor synapse, which is the synapse in whose gap the observer stands (Fig. C).

Sensory interactions are structural perturbations of the sensory cells that trigger in them changes of state that result in changes in their properties as components of the nervous system. Since the nervous system as a closed neuronal network operates in the continuous generation of changing relations of neuronal activities, in a dynamics determined by its structure (connectivity and properties of its components), the changes of state of the sensory cells, by changing the structure of the nervous system, change its dynamics of changing relations of activity in a manner which to an observer standing in the effector-sensor synaptic gap appears as changes in the sensory effector correlations of the organism. In addition to this, changes of activity in the effector surfaces, arising in the changing relations of activity that take place in the closed dynamics of the nervous system, result in changes in shape and position of the organism with respect to the medium, and in perturbations at its sensory surfaces proper to the operation of the nervous system as a closed neuronal network. As a consequence, a change in the effector surface always constitutes a change in the sensory effector correlations of the organism that an observer standing in the effector-sensor synaptic gap may see as a behaviour or as an action upon the environment.

Concomitantly with their participation in the closed dynamics of changing relations of activity of the nervous system, the structural changes that take place in the sensory cells as a result of their perturbations are expressions of structural interactions of the nervous system in a different domain than its domain of states. This domain is the domain of structural coupling of the nervous system in the domain in which the observer distinguishes it as an open cellular network in the physical space by specifying in it a sensory and an effector surfaces: If the observer who stands in the same domain of existence (medium) in the physical space as the nervous system thus distinguished, treats it as an open network (of changing relations of activity) with respect to its dynamics of states, he or she does six misleading things: a) does not see the changes of state of the sensory cells, whichever the circumstances that trigger them, as part of the closed dynamics of changing relations of activity of the nervous system; b) does not see the changes of state of the effector cells, whichever part of the environment they may seem to act upon, as part of the closed dynamics of changing relations of activity of the nervous system; c) gives preeminence to the environment, and treats the structural perturbations of the sensory cells arising in it as inputs to the operation of the nervous system, confusing the structural changes of the nervous system as a cellular system with its changes of state; d) does not see that the structural changes of the sensory cells that arise from their perturbations in the domain in which he or she distinguishes the nervous system by opening it, keep the estructural drift of the nervous system as a closed neuronal network continuously contingent to the structural changes of the medium in which he or she sees it to interact; e) calls feedback from the envorinment the structural perturbations of the sensory cells that he or she sees arising from it as a result of the changes of state of the effectors of the organism, assuming in the process that the features of the environment that he or she sees giving rise to the perturbations constitute inputs to the dynamics of states of the nervous system; and f) does not see that the environment that he or she describes in the effector-sensor synaptic gap is, operationally, as transparent for the closed dynamics of states of the nervous system as any other synaptic gap.

Only when the observer is aware of the operational closure of the nervous system as a neuronal network that operates generating a closed dynamics of changing relations of activity, he or she can see: a) that the domain of states of the nervous system is a domain of changing relation, of activity between its components, and that the course that these changing relations of activity follow in it as a closed neuronal network is determined by its structure (connectivity and properties of its components); b) that the changes of relation of activity in the nervous system arise through transient changes of structure in its components; c) that there is a domain of structural changes in the nervous system as a cellular (physical) entity that also takes place through the structural changes of its components; and d) that these two domains are operationally different, and that they indeed constitute non-intersecting phenomenal domains, even though they are interdependent at the level of the structural changes of the components of the nervous system.

All this has a fundamental consequence. While the nervous system operates as a closed neural network its structure is in continuous change through the interactions of its components both in their operational realization of the closure of the nervous system, and in what an observer sees as interactions with an environment outside of it. As a general result of this situation, the nervous system is in a continuous structural drift in which it either remains in structural coupling with the medium, through a dynamics of states with conservation of organization and structural coupling that an observer sees as a behaviour of the organism adequate to its circumstances, or the organism disintegrates, and the nervous system with it, because its structural coupling is lost through what an observer may describe as an inadequate behaviour. Also, only when an observer is aware of the operational closure of the nervous system, he or she can be aware of the strict dependency of the dynamics of states of the nervous system upon its structure as a closed neuronal network. And, also, only then it can be apparent that local lesions in the nervous system must produce discrete interferences with the relations of activity that it generates, and that these will appear to an observer as discrete interferences with the sensory-effector correlations that the organism performs.

F. OBJECTS

From all that I have said so far, it is apparent that an observed only sees an organism in adequate behaviour in its medium if he or she looks at it while it operates in its domain of structural coupling (or conservation of adaptation). When this happens, the observer that sees the organism reacting with effector-sensory correlations congruent with the perturbations from the environment, as if some features of the perturbing agents had been grasped by the organism and used to generate the appropiate matching responses, may claim that the phenomenon called perception has occurred, even though nothing like grasping has taken place. An observer will see inadequate behaviour in an orgaanism only when he or she demands from it a behaviour outside its domain of structural coupling; that is, when he or she in the same structure distinguishes an organism and a different system, and expects in one an adequate behaviour proper to the other. Thus, when the eye of a salamander is rotated, an observer sees the behaviour of the salamander as inadequate because he or she expects the salamander to be a different system from what it is after the operation. Accordingly, for the observer the *expected salamander* does not operate in structural coupling, commits a mistake because it does not perceive the outside world adequately, and disintegrates. Yet, the unexpected salamander that was left after the operation operates in its domain of structural coupling without commiting mistakes as long as it conserves its organization and adaptation.

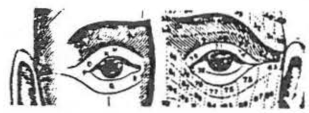
For the operation of the nervous system as a closed neuronal network it is irrelevant how its changes of state arise. For this reason the nervous system cannot make in its operation the distinction between perception and hallucination that an observer makes when observeing the interactions of an organism in a medium. What an observer does in such circumstances is to distinguish different kinds of sensory-effector correlations in the observed organism, noting whether the structural changes of the nervous system that give rise to them result from perturbations from the medium, or from the internal dynamics of structural changes of the organism itself. The observer calls the former perceptions and the latter hallucinations. The environmental circumstances that an observer associates with the perceptions of the observed organism are the objects (features) of the world. Yet, the objects that an observer describes in the environment of another organism do not participate as such in the operation of the latter's nervous system; they do not exist for it. The structure of the medium participates only through structural perturbations (parametric perturbations) orthogonal to the dynamics of states of the nervous system of an organism. As a consequence, although the structure of the medium does not enter in the dynamics of states of the nervous system, the structural drift of this is contingent to the structural changes of the medium through the interactions of the organism which, either conserves its structural copling through adequate behaviour, or disintegrates. The objects that two conversing observers describe, arise as such only in language as a manner of ontogenic coordination of conduct that results in some organisms from their ontogenic structural drifts in reciprocal structural coupling (Fig. D). In other words, objects arise only in the particular coontogenic history of recurrent ontogenic coordination of conduct that language is (see Maturana, 1978, and Maturana and Varela, 1980).

G. PERCEPTUAL SPACES

Since a sensory surface becomes so through an operational specification of a medium by defining a domain in which a synapse is opened by an observer, and since this is done by treating the features of the synaptic gap transparent to the synaptic transmition as an environment, there are as many sensory surfaces as kinds of synapses can be opened in this manner. But, since whenever this happens a domain of structural coupling in which an organism conserves organization and adaptation is brought forth in the domain of distinction of the observer, a perceptual domain for the observed organism is also created. Accordingly, there are as many perceptual spaces in an organism as sensory surfaces or combinations of sensory surfaces an observer can define in it.

The different features that an observer describes in these perceptual spaces would appear to him or her as features of the world of the organism that he or she may claim as features of an objective world if he or she believes in perception as grasping (see Fig. C). If the latter is the case, then the observer will claim that weights, hues, edges, smells or sounds, reflect features of an objective world that the nervous system reconstructs through perception to compute the behaviour of the organism in it. To see would be for such an observer to grasp a visible external world, and his or her task as a biologist that studies color vision, for example, would be to disclose how is the information of hue coded and retained through its various stages of central processing, so that it may be recognized and used to make chromatic distinctions in the environment by the nervous system.

For a biologist who thinks as I propose we should do, to see would be to operate in a domain of sensory-effector correlations in which the sensory cells involved in structural interactions (parametric interactions, orthogonal to the domain of states of the nervous system) in the medium would be photosensitive cells, and in which the different perceptual dimension (such as form, hue or movement) would be different manners and circumstances of generating these sensory-effector correlations while the organism remains in structural coupling in the domain of existence of the involved sensory cells. The research task of such a biologist would be to describe how are generated the different sensory effector correlations that he or she sees as different perceptual distinctions by the observed organism, and to describe how the different domains of internal correlations in the operation of the nervous system as a closed network, constitute the perceptual spaces that appear expressed in such perceptual distinctions (see Maturana, Uribe and Frenk, 1968). Or, in other words, his or her task would be to discover how the different sensory effector correlations of the organism specify the different dimensions of the perceptual spaces, and how these arrise as different operational edges in the intersection of the changes of activity that result in the closed dynamics of the nervous system from the changes of state (parametric changes) of the sensory cells, when these are perturbed in a particular domain of structural coupling of the organism. For such a biologist, the word perception would connote the instance that triggers an adequate behaviour in an organism operating in structural coupling through a particular sensory surface. Also, for such a biologist, the sensory-effector correlations of the observed organism would define the objects and features of a world that he or she would describe, through the coordination of actions of language, as part of his or her environment.



H. THE POWER OF THE PHARMACOLOGIST

All the considerations that I have made permit me to assert that to perceive is to bring forth sensory-effector correlations as a result of operating in a particular domain of structural coupling, and that to an observer these sensory-effector correlations appear as distinctions in an environment. I know all the difficulties that this approach brings while we are deluded by our experiential certainties about the need of an independent world of objects that can be perceived in order to make descriptions that permit effective action. Yet, we may be helped by remembering the descriptive power of pharmacology in its golden days, when different substances were described with bioassays, as, for example, when estrogens were characterized by the changes of state of the ovaries and the uterus of a rabbit. In those days one could distinguish and describe (that is perceive) estrogens in the urin of a pregnant female with the changes of state of the ovaries of a rabbit, and one could characterize the properties of the ovaries of a rabbit (that is know them) with the urine of a pregnant female.

Our world of cognition through perception is like that: we bring forth a world of distinctions through the changes of state that we undergo as we conserve our structural coupling in the different media in which we become inmersed along our lives, and then, using our changes of state as recurrent distinctions in a social domain of coordination of actions (language), we bring forth a world of objects as coordinations of actions with which we describe our coordinations of action. Unfortunately we forget that the object that arises in this manner is a coordination of actions in a social domain, and deluded by the effectiveness of our experience in coordinating our conducts in language, we give the object an external preeminence and validate it in our descriptions as if it had an existence independent from us as observers.

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NOTE ADDED IN PROFF

It is a necessary consequence of the organization of the nervous system as a closed neuronal network that it should admit lesions, sections, and resections, that alter its structure with the consequent change in its dynamics of states, but which leave it as a closed neuronal network and do not destroy its operational unity. Also, it is a necessary consequence of the organization of the nervous system as a closed neuronal network, and of the regularity of morphogenetic processes, that localized lesions in the nervous system of different members of the same species should interfere in a discrete and repeatable manner with the internal relations that it can generate. In these circumstances, each configuration of sensory/effector correlations that arises in the operation of the nervous system, and that an observer distinguishes as a particular behaviour or perception in relations to an environment, should be interferable in different discrete manners by lesions placed at different points of the closed neuronal network that generates it. Aphasias and apraxias are cases to the point. In fact, aphasias and apraxias are, according to what I have said, necessary consequences of localized lesions that interfere with the generation, in the nervous system, of the relations of activity that give rise to the particular sensory-effector correlations involved in the coordinations of actions that constitute the human operation in a linguistic domain. Furthermore, according to what I have said, all disturbances arising from lesions of the nervous system should be describable as changes in the configurations of relationst of activity that arise in a closed neuronal network without reference to an outside world. In fact, it is the recurrent attempt at describing what happens in the nervous system in terms of an outside world, what has obscured the proper understanding of the consequences of the lesions of the nervous system as expressions of internal disconnections in a closed neuronal network.

In these circumstances, a patient with a spatial agnosia that shows negligence for the left side of an object, does not reveal his or her negligence for the left side of an external entity, but reveals his or her inability to generate the changes of relations of neuronal activity that give rise to a sensory/effector configuration that involves a sensory/effector correlation across an operational line of sensory/effector symetry, while this line of symetry is defined by a particular sensory/effector correlation that entails, from the perspective of the observer, the postural specification of an object with right and left sides also defined in terms of sensory/effector correlations. The clinical and experimental observations of localized functional disturbances that result from localized lesion in the nervous system of man and other animals, do not reveal localized functions in terms of an outside world, nor do they reveal the operation of the nervous system in terms of representations of an outside world. They reveal the particular relational connectivity of a particular kind of nervous system that operates as a closed neuronal network in structural coupling, through the organism that it integrates, with the domain of existence in which the observer distinguishes the latter.

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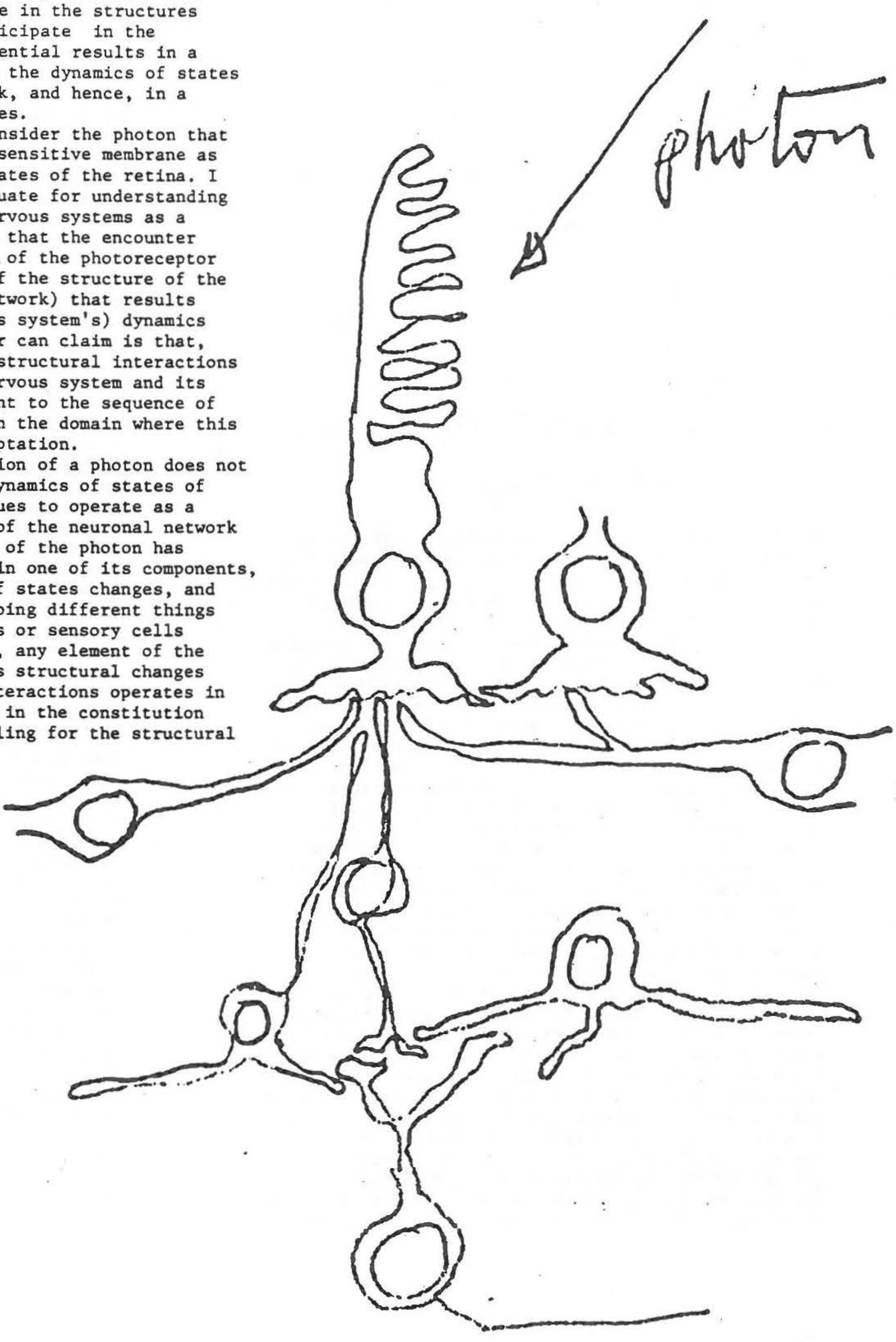
Addendum

FIG. 1. Schematic drawing of a photoreceptor as part of the retinal neuronal network. The photoreceptor is continuously involved in the dynamics of states of the neuronal network of the retina in a manner that is at any moment a function of the present state of those features of its structure that participate in the generation of its synaptic potential. As a consequence of this, any change in the structures of the photoreceptor that participate in the generation of its synaptic potential results in a change in its participation in the dynamics of states of the retinal neuronal network, and hence, in a change in its dynamics of states.

An unaware observer will consider the photon that triggers a change in the photosensitive membrane as an input in the dynamics of states of the retina. I say that such a view is inadequate for understanding the actual operation of the nervous systems as a component of the organism; and that the encounter of the photon and the membrane of the photoreceptor is an orthogonal interaction of the structure of the nervous system (the retinal network) that results in a change in its (the nervous system's) dynamics of states. All that an observer can claim is that, as a result of its orthogonal structural interactions the dynamics of states of a nervous system and its structural drifts are contingent to the sequence of interactions of the organism in the domain where this conserves organization and adaptation.

In other words, the absorption of a photon does not constitute an opening in the dynamics of states of the nervous system that continues to operate as a closed network. The structure of the neuronal network changes because the absorption of the photon has triggered a structural change in one of its components, and as a result its dynamics of states changes, and appears to an observer to be doing different things than before. The photoreceptors or sensory cells are not unique in this. Indeed, any element of the neuronal network that undergoes structural changes triggered by its orthogonal interactions operates in the same way, and participates in the constitution of a domain of structural coupling for the structural drift of the nervous system.



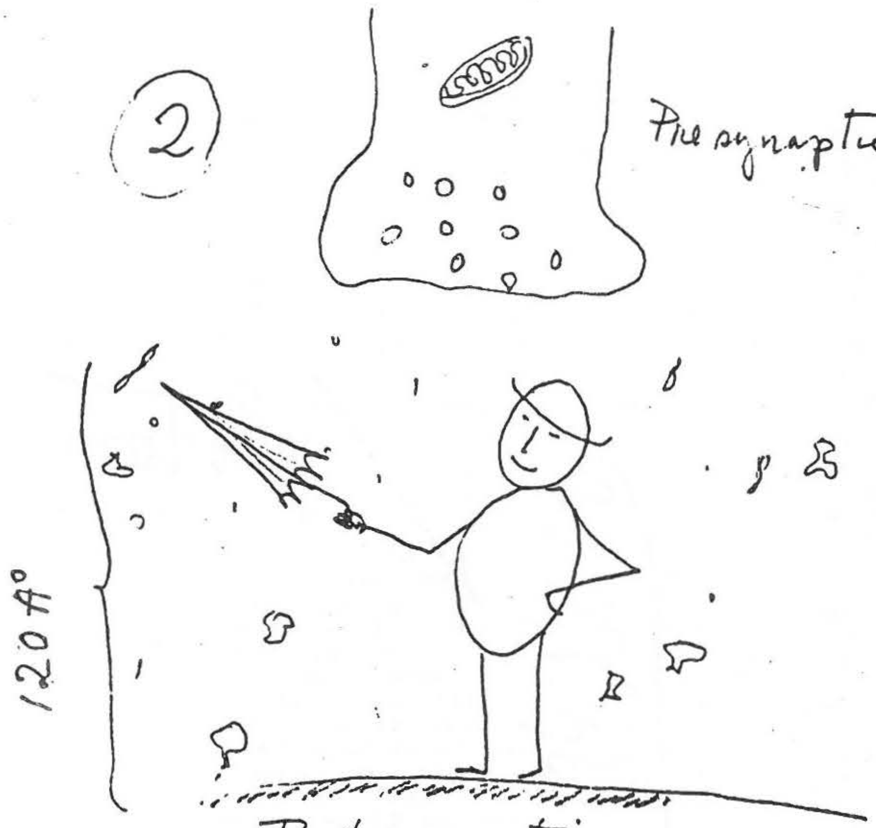
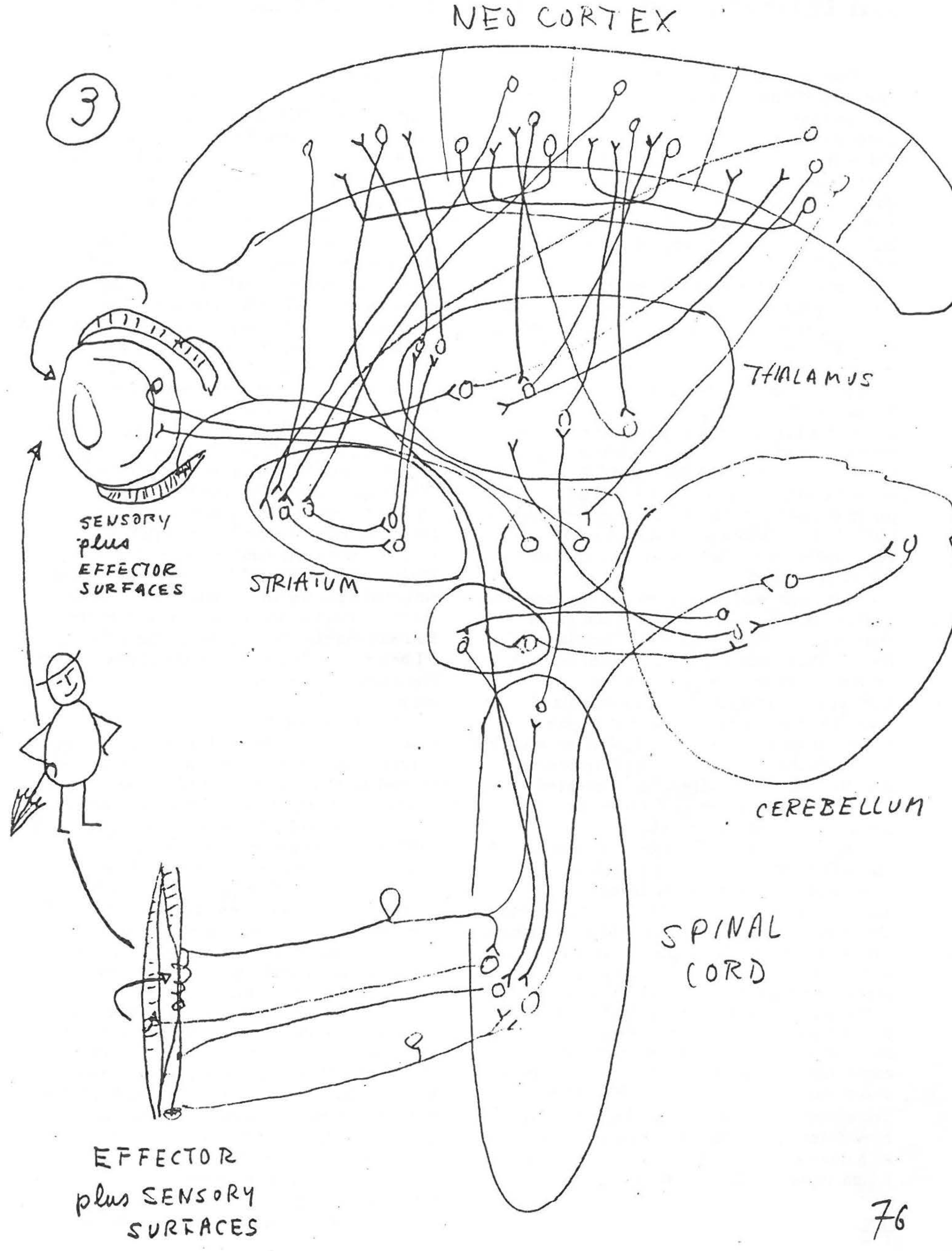


FIG. 2. This figure shows an observer standing in a synaptic gap. By doing this the observer opens the nervous system and transforms the intersynaptic space in the medium where the organism exists <u>and</u> he or she distinguishes its environment. Thus, in the drawing, the presynaptic element becomes the effector surface and the postsynaptic one the sensory surface while the molecules that the observer distinguishes become part of the environment. Yet, we that see the place where the observer stands know that that is only a synaptic gap, and that the features that he or she describes as features of the environment do not exist for the operation of the nervous system in its dance of changing relations of neuronal activities. The nervous system in its operation as a closed neuronal network is blind to what the observer sees as the environment; all that matters for it in its operation is the flow of changing relations of activity that constitute it. Whether synaptic interactions are chemical, electrical or through what an observer calls the environment, is immaterial to it as it operates as a closed neuronal network. The dance of changing relations of activity varies according to the characteristics of the synaptic interactions in terms of delays, time constraints, etc., but that is something that has to do with the kind of dance danced, not with the dancing. The same happens with respect to trophic interactions between the neuronal elements and the hormonal interactions of the nervous system with the rest of the organism. These have to do with the structural changes of the neuronal elements, and pertain to the domain of their orthogonal interactions, and although they result in changes in dynamics of states of the nervous system, do not participate in it.

FIG. 3. Schematic drawing of relations taking place in the mammalian nervous system with no attempt at anatomical rigor. The purpose of this drawing is to show: a) the closure of the neuronal network as taking place at all levels, including through the medium; b) that the closure of the nervous system through the medium is operational as an effector sensory synapse where the observer stands, and as such is blind to what the observer see; c) that the neocortex, through its thalamic connections, stands for the generation of modulation of sensory effectory correlations through the motor cortex, in the same position as the sensory surfaces do through their connections with the thalamus, namely: sensory surface-thalamus-cortex-striatum-thalamus-motor cortex and cortex-thalamus-cortex-striatum-thalamus-motor cortex; d) what is indicated in (c) permits, in principle, an endless internal projection and reprojection of the activity of the nervous system upon the activity of the nervous system contingent to the continuous flow of interactions of the organism; and e) the inter-cortical connections permit that the activity of different cortical areas be contingent to the activity of other cortical areas in a manner also contingent to the flow of interactions of the organism.

The mammalian nervous system operates as a closed neuronal network with recurrent internal projections upon itself that conserve the particular topological relations that constitute its pattern of connectivity. From the perspective of the observer that opens this closed neuronal network in the particular synaptic gap where he or she stands (see FIG. 2), the topological relations conserved are those of the effector and sensory surfaces of the organism. This has several consequences: a) the dynamics of states generated by the recurrent internal projections of the neuronal network always can appear express from the perspective of the observer as the effector sensory correlations that he or she sees as actions upon the environment; b) the structural changes that the nervous system undergoes contingent to the interactions of the organism, take place within the constraints of the conservation of these topological relations, and appear expressed from the perspective of an observer as changes of effector sensory correlations that he or she sees as changes in the actior of the organism contingent to its interactions; c) the observer can see that the complexity of the internal dynamics of the nervous system in its recursive dance operationally relates only to the flow of changing configurations of effector sensory relations and to the moment in which these take place with respect to what he or she sees as recurrent or novel structural perturbations of the organism; and d) the observer can see that the complexities of the actions of th animal in the environment pertain only to the history of encounters between organism and medium in their co-ontogenic structural drift, not to the complexities of the operation of the nervous syste


NEO CORTEX
3
THALAMUS
SENSORY plus EFFECTOR SURFACES
STRIATUM
CEREBELLUM
SPINAL CORD
EFFECTOR plus SENSORY SURFACES

An Introduction to the Many Gordon Pasks

The name of Gordon Pask has long been associated with cybernetics but not always for enough reasons. Few would confess to understanding his work, but for good reasons. His writing amounts to well over 200 papers, seven books and uncounted research reports and proposals. Often unavailable, these works when found do require a major investment before their countless topics provide a coherent whole.

Writing in his own idiosyncratic style, with many qualifiers and extraordinary vocabulary, his ideas relate to such a range of disciplines that cybernetics, an under-valued category of modern science, has not served him well. Flamboyant in personal style, Pask refuses to be limited by simplifications and leaves audiences breathless the world over after a two-hour lecture on proto-logics and the inadequacies of serial Turing Machine architecture. And just when you think you can pin him down in a one-to-one conversation, his immediacy in talking in your terms is confounded by his British accent and his relentless mumble.

But Pask is always listening. In response to criticism, he has recently made great strides in expressing his ideas "outside-in." Rather than start from his-or-others' first principles, he will begin (as in the accompanying paper) from a recognized conundrum and weave around it his own perspectives that, in the end, shatter what had been a conceded view, a closed discourse. Almost single-handedly, he has created a body of work so strong and so diverse that its horizons are not yet known.

Andrew Gordon Speedie-Pask was born in the late 1920s (and characteristic of his existence there is some disagreement as to the exact year). Educated initially at Cambridge University, he expended considerable efforts there theatrically, both in his style of living and his writing and producing for the musical stage. With his wife, Elizabeth Pask, and collaborators, he set about England in vans containing a (semi-) portable interactive light show, which either produced audience excitement bordering on riot or, on at least one occasion, made everyone ill. The principles were continuous adaptation and closed-feedback that next saw physical form as a device to teach keypunch and, later, touch typing. After establishing a private, non-profit research firm in England that would remain unique for over 35 years, Pask was funded by the U.S. and U.K. governments and industries to extend his experimental work from perceptual/mechanical skills (such as typing and tracking tasks) to conceptual skills (such as learning and conversing).

One landmark was called CASTE (Course Assembly System and Tutorial Environment), literally an environment, consisting of a small room crowded with switch panels, light displays and audio-visual media. Too expensive to replicate, CASTE anticipated the software of computer-aided instruction (CAI) systems but, even in his electro-mechanical technology, with none of the restrictions and cognitive insults of modern CAI.

One issue with CASTE was the structure of the course material. Just as the coupling of audience and light display produced a model of skill acquisition so did the transfer of knowledge in a learning interaction produce a theory of conversations. In collaboration with his research staff (and, notably, Kallikourdis), Pask produced a full-blown cybernetic and scientific theory that could model human-to-machine interaction as well as human-to-human language interaction. The subjective ("I believe . . .") could now stand next to the objective ("We agree . . .") in the same science.

Conversation theory speaks of participants in a conversation, but refuses to make precise correspondence between, say, a human being (called an M-individual, M for "mechanical" or physically-distinct entity) and perspectives (called P-individuals). One M-individual will take many perspectives, sometimes conflicting, and hence correspond to many P-individuals. Social organizations (religious communities, for example, or political groups, even schools of thought such as physics) consist of many M-individuals, but in that they have strongly overlapping perspectives, may be only one P-individual.

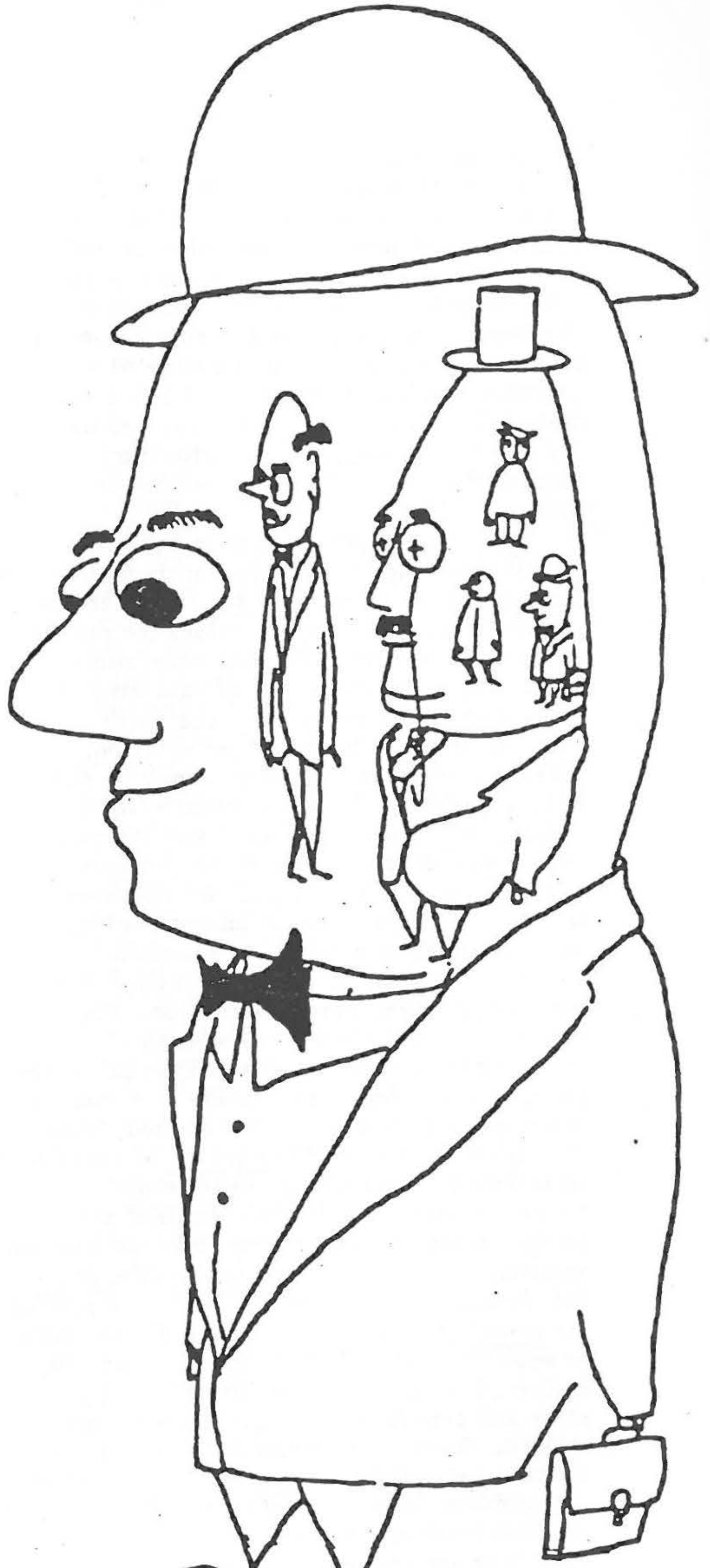
If one wishes to separate, for the sake of discussion, embodiment from representation, it is necessary to consider how to represent the transactions that take place between P-individuals. Digital computers, as Pask does not let us forget, are currently locked into the pre-supposition that the logic of 0,1 is sufficient for everything from "data processing" to "symbolic processing"—the latter intending to even encompass expert systems and natural language problems.

By Paul Pangaro

Pask shows that logics based on "0 represents false" and "1 represents true" are hardly a basis for bootstrapping into "I believe . . ., you believe . . ., we may have believed." Though referencing others, Pask has developed his own logic, called L_p ("L" for logic or language, "p" for "proto"; underlying). L_p is an organizational description for what underlies the languages that P-individuals use to communicate, whether in sight or sound, together or apart in space and time. L_p is interpretable as a computer program albeit with many restrictions imposed by particular implementations and present-day hardware. At last there exists a "knowledge representation" (in the AI sense) that comes from studies of cognition, not the convenience of LISP and computer science.

Pask has (and one feels will always) push hard beyond current boundaries. He recently completed a three-year contract to develop new computer-based interpretations of his theory. His work makes direct and invaluable contributions to research programs here and in Europe in education, sociology, and intelligent systems.

One can associate Pask with cybernetics because some of his early influences (von Foerster, McCulloch) were in and of the field. Pask's basis for experimental study was the interaction between observable systems and the subjectivity of control, which are conceptual foundations of cybernetics. Indeed, it was this epistemological stance that allowed for his discoveries and invited a scientific theory of conversations that would answer to psychology and computer science, sociology and epistemology alike. There may be countable ways to associate Pask but we need never know when we have enough.



PROBLEMATIC SITUATIONS
By Gordon Pask

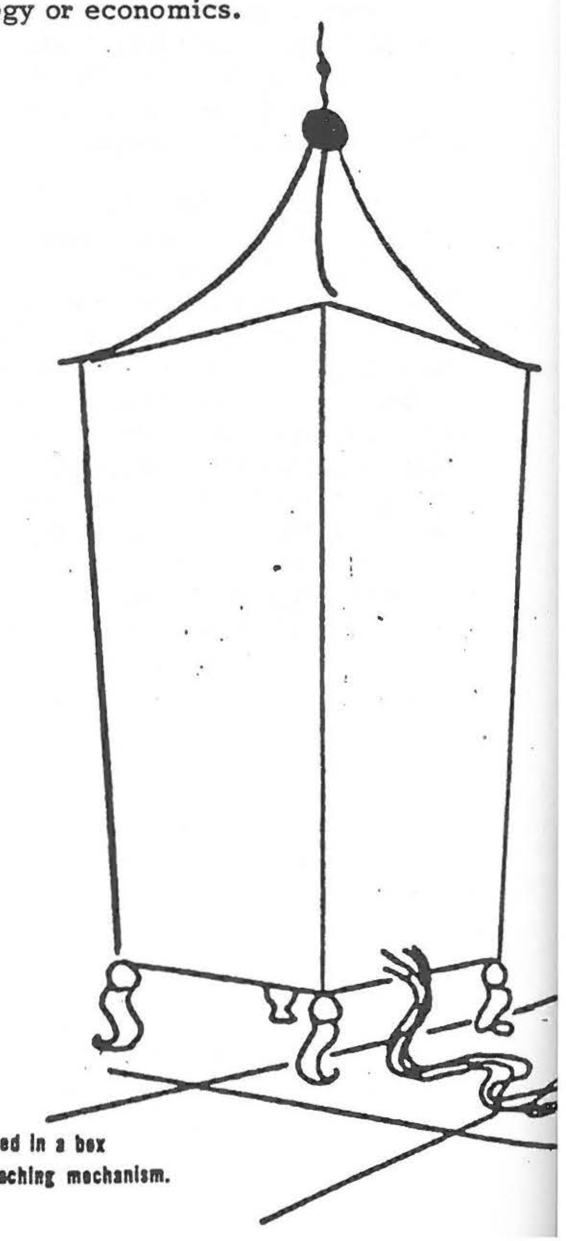
1. Introduction

We speak more or less casually of "problem solving" as though problems are found prepackaged, already formulated. This use of "problem solving" goes hand in hand with the idea that means for solution exist. Further, these means for solution amount to clever deployment and application of a calculus which is, in essense, either a mechanical process or its abstract equivalent: the operation of a computer program; or thought process that follows well-specified rules.

There is a grain of truth in both the notion of "given problems" and the contingent notion that insofar as a problem is given, then its solution consists in the ingenious (or rapid) application of rules. For example, some problematic situations are of that kind. Any contrived puzzle comes into the category, whether or not it has a unique solution, several, or even none (when it may be shown to be unsolvable, with sufficient effort). Possibly all "given" problems are like puzzles, regardless of whether they are humanly construed or due to natural circumstances. In the latter case, the situation must, of course, be humanly recognized as a "problem."

These notions do not depend upon the content of a problematic situation. For instance, they apply just as well as to variable and aleatory situations where a probabilistic calculus is employed to provide a statistical solution, or to imperfectly specified, "fuzzy" situations. Although the content of these hazy situations is certainly not deterministic in character and the solutions required are seldom deterministic, it remains true that the solution method, the rules applicable, are deterministic. "Cleverness" in puzzle solving (or given - problem - solving) really amounts to selecting short cuts; often according to criteria that are independent of the applicable rules and generally at-most-dimly comprehended. Surely cleverness is important: in practice, it may be the only way of tackling the problem during one lifespan. But shortcut selection marks out the limits of "cleverness" and these are severe limits.

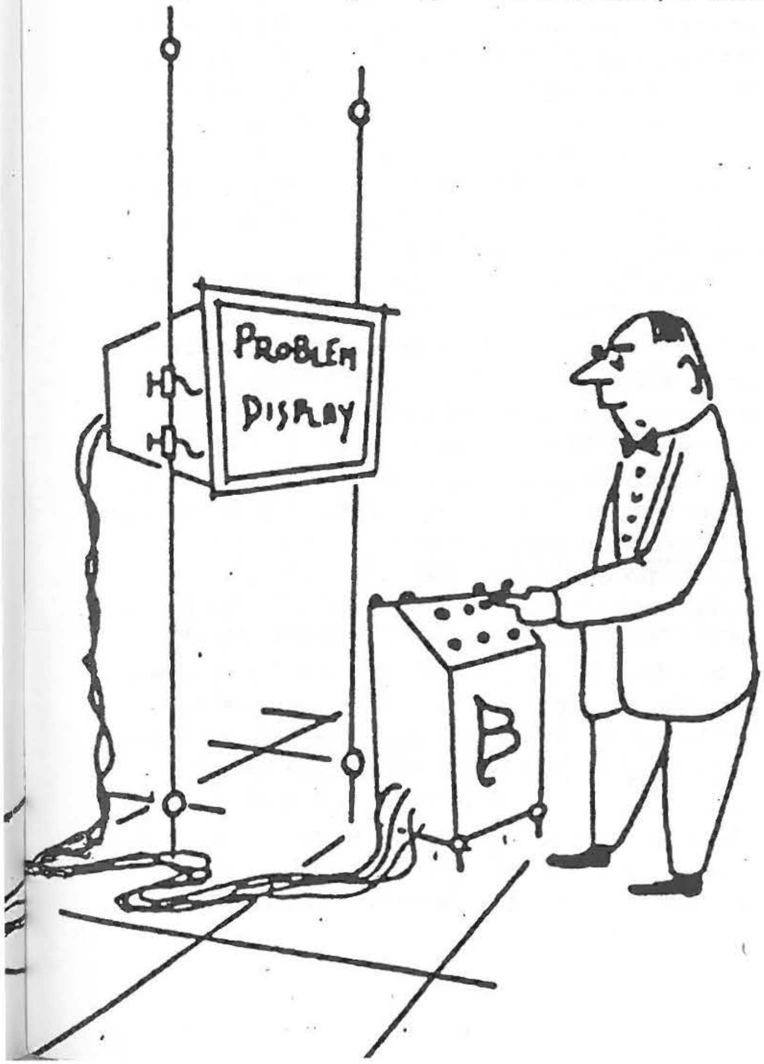
The question is: How many of the situations we regard as problematic fit the problem-and-solution paradigm? I conceded that some natural situations and all contrived puzzles (even those contrived by mathematicians and dealt with, seriously, by their peers) do fit the problem-and-solution paradigm. But, the main contention of this paper is that very few situations of concern to science, technology or social and human affairs are of this type. Puzzles are seldom encountered amongst situations of genuine human concern in any field, whether it be philosophy, the classical sciences or more recently developed disciplines such as ecology, anthropology or economics.



Subject A enclosed in a box to simulate a teaching mechanism.

Suppose the view expressed in the last paragraph is correct. If so, then there are dangers in retaining the prevalent image: of, for example, "the scientist as a problem solver". If the burden of human endeavour (certainly scientific endeavour) is creative and lies between major innovation, technical invention and, in some cases active problem formulation, then the problem-and-solution paradigm is not a model likely to produce correct inferences in non-problem situations (the paradigm applies ony when a problem is formulated and its solution desired).

A quite different sort of danger also comes with a too-dogged adherence to the idea of problem-and-solution. It is the unintentional but just as harmful degradation of human effort to the point where humanity is excluded from activities more than needs be. If so, science (any science, but physics is convenient) could be automated. The apparatus comprising an accelerator, a cloud chamber, the camera for observing "particle tracks," the interpretative computer program that detects certain marks on the photographic plate as "significant tracks" (indicating hypothetical new particles or new particle behaviours) are, in a good sense, all mechanical products. Yet, if science is construed as a problem-and-solution activity, these instruments, alone, are just as able to perform the task as real scientists. The currently fashionable title "expert system," is used to designate a variety of "intelligent" programs and, regardless of whether you regard them (or any other computer program) as "intelligent" in a human-like-sense there is no doubt that they are better than human at "problem-and-solution" activity, especially when augmented by programs, often called heuristics, that embody clever suggestions rather than rules.



Personally, I reject the "problem-and-solution" paradigm as an adequate representation of what goes on in science or for that matter in less specialized walks of life. This rejection is quite certainly motivated by the hazards outlined during the last few paragraphs but is buttressed by much deeper reasons that are well founded in history or philosophy. One of these is concerned with the ancient, modern and pervasive usage of the word "induction". The next, upon notions of truth and falsity, which are legion and divergent (for example the "veridical truth," or "juridicial truth" or "analytic truth" of propositions or more elaborate expressions). Finally, there is a prevalent use, both within science and beyond her asserted boundaries, of a convenient but probably untenable notion; to be dubbed the "universal dustbins," namely, the dustbins of time (of both instant and interval of time), or randomness (however the randomness is produced), of subjectivity/objectivity, of consciousness/information and independence. As hinted already, my own inclination is to see the essential part of human science or human activity as creative or innovative, and to relegate analytic thought, even deductive thought, to an honoured although seldom exercised category of mind.

Mind, that taboo term for an apparatus which no one can explain but upon which everyone relies.

2. Induction: its various and variegated meanings

Some years ago, perhaps until the mid-Renaissance, this word "induction" had two natural meanings. One of these was the induction (invention, creation) of an hypothesis; the other, induction (in support or denial of an hypothesis, previously induced) from exemplars. The exemplars gained the status of unitary data: "signs of nature" at one extreme or "hard and factual observations" at the other. The distinct kinds of induction (of an hypothesis as opposed to from evidence in support of a given hypothesis) became dominant; or, more accurately perhaps, the first was utterly dropped from the scientific vocabulary. The thoroughness with which the primary meaning of "induction" became discarded is underlined in the history of (natural, in contrast to contrived, i.e. by dice throws) probability. It is recorded with elegance by Hacking in The Emergence of Probability. But the trait becomes clear both in the rationalist and the empiricist schools that are characteristic of much late 17th and 18th century thought. As a result of it, the scientific domain was held, with few serious exceptions, to exclude consciousness, creativity, insight and the like from scientific scrutiny.

There would be no objection to this carving up of phenomena such as thought (supported by divisions like mind/body duality or, more recently, the consciousness/information duality) if only the other-than-scientific remainder was dealt with by other-than-scientific, but rational, discipline. As it is, no fully adequate discipline seems to have emerged; mind and the like are in the province of a mysticism alien to the prevailing Western theories, or else they are ingredients of reality simply omitted from rational debate. (I am not well enough versed in Oriental philosophy or its evolution during comparable periods to remark upon the matter at all cogently. However, it does seem that there a somewhat different and in some ways more successful resolution took place.) The situation was such that North American philosophers, Pierce in the mid 1800s and Spearmen (the psychologist and philosopher) several decades later, introduced words to replace the missing and primary component of induction, that is, the induction of an hypothesis. Pierce called this inventive or creative capability "abduction" whilst Spearman called it "eduction". Whatever the name, "abduction" or "eduction", the missing part of induction is innovation, creativity, or invention.

One indication of this state of affairs is the relatively unsuccessful attempt of naive behaviourism to adumbrate mental operations; another is the sophisticated attempt on the part of "pure" cognitive science (in contrast to cognitive psychology) based upon the computer program model and seemingly enamoured of the idea that "pure" cognition exists devoid of conation or emotion or of affect. Both attempts are outstanding in the 19th century history of psychology. They appear as a train of reductionist thought which rendered association (active reproduction operations upon debatable "images" or "sense data") as the passive combination of reflexes (a doctrine introduced by Tichtner and by Watson's misconstruction of Pavlov's work on the conditional reflex). So a motor or motive had to be injected to stir this counterfactually sessile organism into activity; it is evident in motivational calculi (McDougall's for instance) and (later on) as the "operant reflex" of Skinner's behaviourist point of view. Ashby dealt with the matter more fundamentally in his principle of "variety" and "requisite variety" using an axiomatic cybernetics: although he is often accused of reductionism, pure and simple (probably because of the rigour in the work), the notions are more in the spirit of those functionalists, like Bartlett; of those neuro-physiologists like Hebb or Grey Walter; and those Gestalt psychologists like Werthermer who avoided committment to the somewhat misleading perceptual Gestalt models and addressed their hypotheses towards a Gestalt logic of problem creation, problem formulation and (possibly) problem solution: namely, productive thought.

In a fusion of reductionist/atomistic and wholistic/Gestalt oriented schemes there is ample recognition that the abductive/eductive or creative/innovative aspect of induction requires attention and constitutes a major component of both human activity and the development of science. Moreover, it seems clear that an underlying mechanism is analogy creation (not just recognition of an analogy that is pointed out). Barnett, deBono, Koestler (calling it bissociation), Sachs (with is often forgotten resonance, years before), Schon (displacemenet of concepts) and others, specify the ingredients in different spheres and using different idioms. The bulk of human reasoning is, in a sense which can be formalized (Gaines, or Gergely, Nemetti, et al, or my own group) centered on analogy: the relationship that makes the similar different and the distinct, the "same." This, I maintain, provides the skein of scientific evolution upon which deduction and induction in the abraded sense, are overlaid, for, in their proper and specific universe, they are tools of great elegance.

True, "artificial" intelligence has tried to incorporate explanations of innovative phenomena. Using the dominant paradigm of the late 50s and early 60s (clever theorem proving programs and the occasional emulation of human methods) this endeavour met with little success. More recent paradigms, extending the "expert systems" which are represented in Selfridge's "Pandemonium" of the 1950s to "populations of machines," offer more hope provided that the population is contrived as a society of machines and not a fancy "pipeline" or parallel-but synchronous entity. Unlike the earlier "cognitive science" or "computer science" essays in the field, these promising (recent) developments are not necessarily tied to the algebra of currently available machines or to their restricted architecture. That algebra, not the concrete fabric, is just as much a straight jacket as the stimulus/response and operant/reinforcement mores of behaviourism. Such algebras, such operational edicts, prevent any other-than-trivial developments.

3. Forms of Critical Debate

Facts and scientific laws do not usually emerge by accidental discovery. Serendipity does play a part, but most facts and laws arise by a deliberate creative process.

Let us put aside, temporarily, the question of whether this process is, or is not, a proper object of scientific enquiry. (Whereas I hold that it should and could be, many publishers are inclined to view that there are different kinds of knowledge: Popper, for example, is at pains to emphasise the existence of creative activities, responsible for hypothesis generation, that are not, however, in the purview of science; Bunge, that "common knowledge" and "scientific knowledge" belong to different categories, although he accepts that scientific theories arise from problematic situations belonging to common knowledge. The following section, whilst relevant to science, is not necessarily about science. It is about rational debate (rarely, however the rule-applying rationality characteristic of a problem-and-solution type).

Plato called this debate (usually between philosophers) a Dialectic, in which forms or ideas were created and refined. Aristotle qualified this statement by requiring that each component of the dialectic be demonstrated (but neither usually nor necessarily proved; for example, demonstration could be the construction of a mutually acceptable model, whether concrete or intellectual).

The elements of dialectic are as follows, but their ordering is not sequential as suggested by a convenient exposition:

(a) One or more hypotheses (or theses) are invented and agreed by the participants.
(b) One or more opposite and thus competing or conflicting hypotheses, the antitheses, are invented and juxtaposed.

Either:

(c) One or other is discarded (not meaning "forgotten", but "held to be untenable")

or:

(d) The conflict between theses and antitheses is resolved in a synthesis, a novel (abduced or educed) hypothesis which commonly stands as the next thesis.

(e) Each element, the thesis, the antithesis and the synthesis, is demonstrated.

Hegel revitalised the notion, after a long period in which "dialectic" came to signify any kind of debate, but usually a contentious debate, by an insight: Participants need not be people who are philosophers, scientists or theologians; they could be perspectives adopted by one person. In this case the debate is a form of thought, an internal, mostly concealed, dialogue. However, this form of thought, weighing up rival or competing hypotheses, is a common form of thought. When conflict between a thesis and an opposed antithesis is resolved by a synthesis, then it is a creative form of thought.

In view of Hegel's primarily idealist position it is not surprising that he did not emphasize Aristotle's requirement for demonstration. The post-Hegelians (Marx and many others, for example) did so, but a fully adequate logic of dialectic is due to Gottard Gunther around 1959, and subsequently, Gunther logics are, in a defensible sense, minimal logics able to accomodate science and creativity, abduction, or eduction. They have truth values of self and other reference designating the participants, either people or perspectives (points of view) adopted by one person, as well as truth, falsity and various kinds of possibility and likelihood.

Once dialectic is placed in a firm logical position it becomes clear that (amongst other things) it is a process of analogy creation. A synthesis is necessarily a step in creative analogical reasoning: the participants (however many and of whatever kind) have different "universes of discourse" which are juxtaposed in partial conflict and the resolution of this conflict, by a synthesis, is analogy creation, usually entailing the construction of a further "universe of discourse." This seems to be, also, a general process of problem formulation, even though the method is frequently employed (as Polya points out, for example) in the short-cutting moves of problem solving. Now an analogy, designated by a metaphor, comprises one or more similarity relations (for instance, between principles that are applicable in mechanics and in biology or just between the participants in debate and the hypotheses they entertain). An analogy also contains a distinction (between the domain of mechanics and the domain of biology, or just between the participants and their hypotheses). In order to represent this point logically requires a logic of distinction (or, equivalently, of autonomy). Spencer Brown pioneered this field; it has been greatly extended by Varela, Matturana and others, and it is congruent with Gunther logics.

4. Agreement and Truth: the role of coherence in science

Amongst others, Taylor casts doubt upon the property of veridical or factual truth in the social, psychological and political sciences. He believes that a more appropriate truth value has to do with coherence or agreement, alluded to as hermeneutic cycle. The historical roots of hermeneutics (the refinement of the meaning attached to a phrase or event) goes back for a century or more and involves phenomenologists (examining legitimate objects of enquiry) such as Habermas and Gademar. The hermeneutic cycle, itself, is a loop of inferences sufficient to spell out the meaning of an event. So, for example, the loop of inferences needed to encompass the meaning of a (particular kind of) feeling implicates the term itself, the persons who feel, the interpretations given to an act such as laughter and, quite possibly, other entities. Since the events of a dialectic are dynamic and amount to concept sharing or agreement between the participants, any one event must involve the repeated iteration of an inference or operation through the participants and that element of the dialectic which is agreed upon.

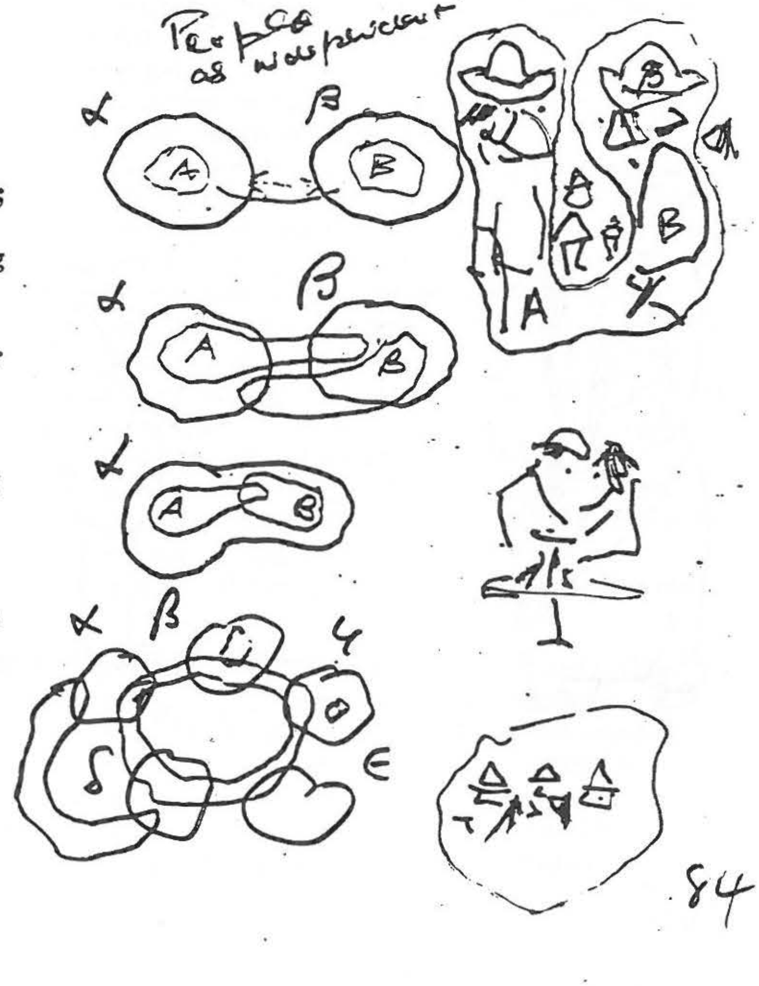
The hermeneutic cycle thus resembles a fixed point or fixed cycle transformation in control theory or (equisignificantly) the repeated application of an eigen operator to provide one or more complementary (and, thus, representative) eigen values. In these cases, however, the space in which the operator acts is fixed. On the other hand the debate would have no stable existence without agreement on some points and transformation operation (the application of an inference) creates its own "space": namely, the debate.

Consequently, the stability of (dynamic) equilibrium represented by a fixed point (or cycle) operator in control theory and axiomatic cybernetics must be replaced by a more general kind of stability known as "organisational closure" (Zelany, Editor, Autopoeisis, a Theory of Living Systems). A system of any kind is "organisationally closed" if and only if it consists of operators, acting upon a matrix or fabric and if their products include the productive operators themselves (others, perhaps). For example, cells, most parts of an organism, ritual and regulatory cycles in stable ecologies, living creatures, are, all of them, organisationally closed. This type of stability is tantamount to existence (identity, autonomy) which, when it exists, may harbour various stable behaviours.

Many years ago, I came to the same conclusion as Taylor, independently, and in the context of thinking, educationally sized learning, design, creativity, problem-formulating and problem-solving and similar mental activities: it seems hard-valued psychological data (in contrast to hard-valued behaviours, which may or may not be psychologically hard-valued) could only be collected in the course of a conversation where, by various means, the mental operations are rendered visible. Events such as agreements (including agreements to disagree) would be hard-valued because they spell out concept sharing between the participants. The theory of conversations gives a liberal interpretation to what a conversation is: for instance, a dialectic is a (commonly encountered) type of conversation; and a conversation need not be verbal but maybe mediated by symbolic behaviour having (like ballet, mime or music) the essential capabilities of a natural language. A similar liberality applies to what a participant is: for example, a participant may be a person, the perspectives (partly-independent mental organisations of concepts) of a person, or social groups provided that certain criteria of autonomy and also a possible interaction are satisfied. For example, stable systems of belief, schools of thought, and the self-replicating programmes of scientific research described by Lakatos, are all participants.

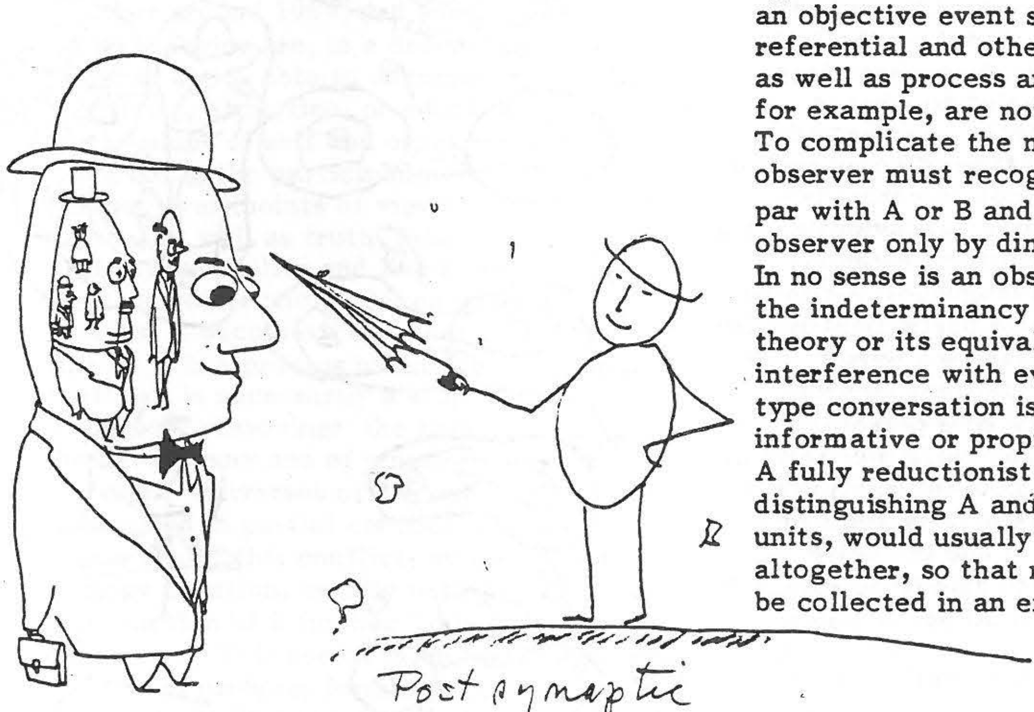
I called this criterion P-Individuation or "Psychological Individuation". But it is equivalent to the (independently-devised and in the context of biology and immunology) stability of organisational closure, together with a requirement for informational-openness signifying possible concept-sharing interactions. Between them, organisational closure and informational-openness add up to a condition, formalised and developed by Von Foerster in 1958 or before, namely, "self organisation", since the theory is held together by a principle of conserving information transfer (interaction).

Since the theory (Pask, Conversation Theory, Elsevir 1976) has been researched continually for more than 20 years with no essential element refuted, I have some faith in the argument of this paper. Since the theory is formalised (both in terms of Gunther logics augmented by an hermeneutic truth value and in terms of a protologic, designated L_p, distinction, coherence and process, augmented by self- and other-reference), I have confidence in its generality. I think that the theory is a scientific theory, but there are some reservations on that score to be viewed below. Certainly, it is productive and capable of explicating (not quite the same as strictly explaining) learning, some kinds of creativity,



problem formulation, consciousness and thought. This paper could, in principle, have been written "the other way round," focussing on the theory, initially. That, however, would probably have distracted the reader's attention from a large class of related theories that exist, or may be invented, of essentially the same kind. Some of these are clearly more applicable to the domains of greater immediate interest (growth, cultivation, genetics, fertilization, ecology, ethology for example) than educational, psychological and social transactions. My intention is to advocate serious consideration of this kind of theory in connection with problematic situations that are salient in these areas of concern and to point out, immediately, some cautionary qualifications which apply here as well to the other areas.

The pivotal reservation is introduced by "I think it is a scientific theory." That dependes upon how you interpret "science," or "veridical" (factual) truth. The agreements that are hard-valued according to any normal canon (for example, they are rigorously specified, determinable, open to various but valid, certainly neither statistical nor even fuzzy, quantification) are not, in a strict sense, objective; that is, "it-referenced."



Similar difficulties appear in respect to the ingredients of an agreement; or, answers or metaphors designating analogies. None of these is either true or false; still less, probably true or probably false. Only statements about these statements, that is, metastatements have truth values; for example, in Rescher's theory of commands, the "termination" statement "it is true that A addressed command C to B under conditions D on the occasion E: further, that B . . . obeyed." Or . . . similar statements in Harah's theory, or the question logics of Aguavist or Belnap. Now for "A" and "B" to make sense in these metastatements they must have values, in the original, of "you" and "I"; that is, the values of self- and other-reference (not truth or falsity). So must the process "on occasion E"; so must the distinction of A from B. The metastatements are propositions in the propositional calculus, or description in the first order predicate calculus (to which the nth order, n greater than 1, is reducible); the statements are not. Nor is an agreement (or agreement to disagree). If I say that "A is conscious with B and of T" or that "A and B share some of concept T" this is a metaphor designating an analogy. Given all the apparatus, logical and experimental, of conversation theory, the analogy is very precise and well specified: the event of agreement is a hard valued datum, but it is not an objective event since it entails self-referential and other-referential statements as well as process and distinction. A and B, for example, are not things but participants. To complicate the matter even further, an observer must recognise that he or she is on a par with A or B and might be a participant; an observer only by dint or an arbitrary stance. In no sense is an observer utterly impartial and the indeterminancy principle of conversation theory or its equivalents is such that minimum interference with events of the phenomenon-type conversation is not necessarily the most informative or propitious expedient to adopt. A fully reductionist approach, arbitrarily distinguishing A and B as observer-demarcated units, would usually inhibit the conversation altogether, so that no hard-valued data would be collected in an experiment.

What is the truth value of an agreement, a concept sharing? Well, given the values of Gunther-and-distinction logics required to express the autonomy of A and B, agreement can be modelled as a procedure or process-oriented extension of Rescher's coherence theory of truth; that is, an intertwining of concepts or hypotheses. The truth values T and F are similarly modelled by "1" and "0" in a Boolean algebra or a computer program; algebraic manipulations work in the correct way. But, obviously, "T" or "1" is not "true," and "F" or "0", is not "false". Another useful and correct model exists for agreement; namely coherence (as used in connection with the coherent light from a laser, as in holography). But agreement is not reducible to a standard, T-or-F-valued, logic; the algebra does not work in most cases. It is usually nonsensical to talk algebraically about the union or intersection or inclusion of, say, concepts, or of participants. A different calculus is required, such as the calculus of L_p, noted previously.

Whether or not you reject the values assumed by these schemes of truth assignment as "veridical" or "factual" is largely, if not completely, a matter of taste. The truth assignments in question are, or can be, precise and formally manipulated. But, as a rule, they are not objective in the strict and structural sense of objectivity. They affirm or deny the occurrence of hard-valued and mainly subjective events. Moreover the map of these events is not usually the topologically linear map of causality, or Newtonian temporality. Conversations seldom consist of a linearly ordered succession of instances of agreement with intervals between them; nor does a dialectic.

5. Overall summary of the argument up to this point

In summary, I have agreed that science should include the creation of hypotheses; that if it does, a dialectic mode of argument (a special case of a conversation) must be considered as able to accommodate the abduction or eductive components of induction; and that, if so, the logic of conversation, including analogy, is of a certain type and that its truth valuation schemes are different from standard schemes. You may or may not call a theory constructed on this basis, tested by means proper to this basis, a scientific theory but it does have a predictive, generative, explicative but not strictly-speaking explanatory or proof-theoretic power and considerable generality. Participants may be scientists, their points of view, social organisations or systems of belief like Lakatos "programmes of scientific research": to science as a totality. The hypotheses of Section 1 are invented and agreed by the participants; so, also, are the test instruments used to select evidence for datahood, to determine measured values affirming or denying the data. These are all, ultimately, consensual, and their invention, to be agreed (or not) is not simply mechanical in the sense of section 1.

The lack of standard objectivity is the price paid for proper scrutiny of the phenomena of concern and interest when it comes to problem formulation and even, maybe, to problem solving. If you accept my argument, the epistemology, logic and ontology of science must be enlarged to encompass the old but as a subject of the emerging enterprise.

6. Dustbins

At least in psychology and sociology (I suspect the real-life problematic situations of any science or any region of genuine concern), it is easy to fudge the matter: to sound respectable but say little, or nothing, that is useful. The fudging involves placing appropriate findings within the framework, well-fitted to classical and moderately well to currently-standard science, which, however, is not able to express the intended meaning. Much data from these fields (at least) is well collected, admirably processed, but pointless because its basis has not been thought out; had it been thought out, the frame of reference would have appeared as inadequate. I confess to trying this trick, and soon abandoning it in our work on self-organisation during the 1950s and the early to mid-1960s; in any case, the framework of reference had been under suspicion for some while. There are several, in practice interchangeable methods of playing the trick; especially convenient when combined together. These are the "universal dustbins."

(a) It is easy to suppose that events like agreements (in a dialectic process or a conversation) are ordered or can be imaged (or veridically mapped) as ordered, upon the sequential topology of standard causality, or Newtonian temporality; even upon the relationistic orders such as Einstein's.

Because of the wholistic character of many agreements, this supposition is conterfactual. Its adoption frequently gives rise to confusion, especially when it is recognised (as it is, for example, by Atkin), that the statistical interpretation of the more fundamental idea of likelihood incorporates this assumption. It is a beautiful edifice built upon foundations that are firm only for events that can be so ordered. Often, the confusion leads to "significant," but meaningless, "results." Before that, of course, both "controlled conditions" and (ordered) replication are open to question. So is the lack of distinction between a computer-simulated model (up to simulation) and a usually concurrent reality.

(b) "Randomness" is the next dustbin. The concept may be valid and useful but it has a limited scope which does not include theories of the type discussed in this paper (it very likely does include statistical mechanics and quantum dynamics). Why, except by scientific tradition, should a random sample of subjects be drawn? Why should the most frequently occurring, perhaps least variable, value of a measurement be the preferred alternative or, for that matter, should there be a set of alternatives? This objection is not an issue of computing digits of pi, rather than looking up a random number table, rather than sensing the random emission of a decaying atom by a Geiger counter. It has to do with the character of the universe.

You can quite easily set up a model of a conversation, including a dialectical debate, as a computer program using several different stochastic processes to resolve the conflicts that arise. It is useful exercise (see Nicholis) as it gives the correct, or predicted, statistical results. It is not correct to go much further because to do so obscures the character of conflict resolution by a hidden contention that thoughts behave like gas molecules; at any rate, in the limiting case of indefinitely-many runs of the program.

A very closely related dustbin is independence, in contrast to dependency, or systems. On the one hand, there is a belief (contrafactual, for the most part, insofar as participants are concerned) that heads are independent unless their activities turn out to be correlated; on the other hand there is a belief that instants in a succession are independent (but only if the events can be sequentially mapped and usually they cannot). In general, independence and sequentiality may be traded off against each other: the connecting link being interaction or information transfer (in the Petri, not syntactical, sense of this paper). To assume independence without creating or being able to create distinction mystifies the notion of consciousness and obscures the glue which sticks parts of universe together (those addressed, chiefly, in this paper).

(c) Finally, but particularly, there is a dustbin known as "semantics", even "semantics and pragmatics". For example, how can data storage be confused with memory, which appears to depend upon reconstruction or recomputation or even knowledge retrieval as often happens. Is knowledge belief? Or is it veridically affirmed belief? Are untenable hypotheses lost or forgotten? Is there knowledge without belief? What is the difference between the personal knowledge of a participant and the public knowledge of a society of individuals? Is coherency believed and knowledge known (even written in textbooks or stored in flip-flop devices)?

These questions, so commonly obfuscated by some statement like "they are matters of semantics" (used derogatively, as irrelevant) or "philosophical issues" (and thus irrelevant), are answerable, very likely within the skeleton already outlined.

If problem solving, let alone the more pertinent matter of problem formulating is taken seriously, the dustbins should be avoided and the ossature of science reviewed so that the results obtained are given their proper meaning.

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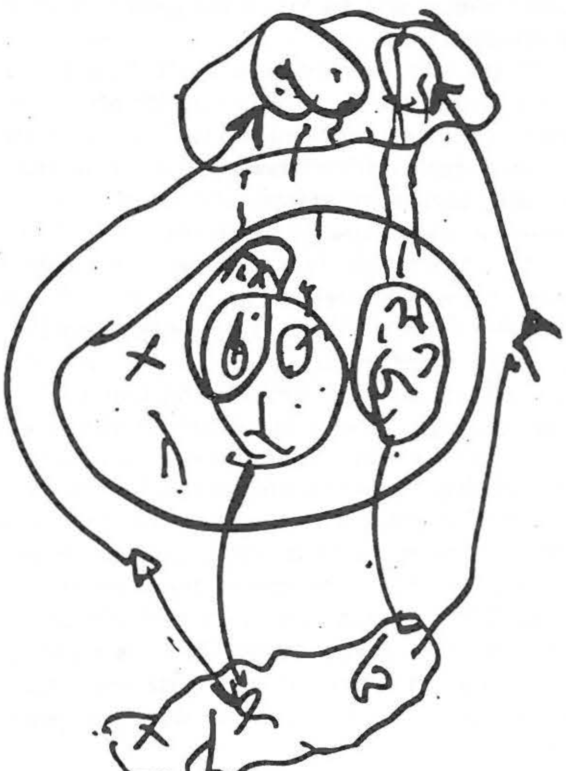


Blackberry Authorities

When I first came into the county
I knew nothing.
I watched as people planted, harvested,
picked the berries,
explained the weather, tended the ducks
and horses.

When I first came into the county
my mind emptied
and I liked it that way. My mind
was like a sky
without clouds, a summer sky
with several birds
flapping across a field on
the eastern horizon.

I liked the slowness of things. The empty
town, the lake
like a mirror. The man I met who seemed
contented, who
sat and talked in the dusk
he had chosen this long ago.

I did better dreaming then. The colors
were clear. I was
finding something important in myself:
capacity for renewal,
And at night, the sky seemed so high
and intense. Incredible,
clear stars! Almost another earth.

But now I see there are judgments here.
This way of planting
or that. The arguments about fertilizer
and organics,
problems of time, figuring how
to allocate
what we have. And so many matters
to fasten on and dissect.

That's the way it is with revelations.
If you live it out
you start thinking, examining. The mind
loves to insist and
cries out for materials to play with.
Right now, in fact,
I'm confused about several vines
and waiting
for the blackberry authorities to arrive.

By Lou Lipsitz

A Primer on Petri Nets

By Robert Shapiro
Interviewed by Jeanne McDermott

Jeanne McDermott is a freelance science writer and Bush Fellow at MIT. This article is adapted from her conversations with Robert Shapiro on Petri Nets. She offers this observation to the reader:
It took me awhile to digest these notions. Only after several hours of conversation did I begin to understand that a deeply embedded way of seeing was being challenged. In Petri nets, things are not represented in the traditional orthodox way—as a set of objects. Petri nets shift the emphasis, focus the eye and attention on something else entirely. What is of primary importance is not the objects but the process, the continuity of interconnected movements and change. In Our Own Metaphor M.C. Bateson gave a good and simple example of the difference in outlook. She was drinking a cup of coffee. She realized that in a Petri net, it would be represented as a progressive transfer of fullness from the cup to her stomach and at the same time, the progressive transfer of emptiness from her stomach to the cup.—JMcD

I was working for a Massachusetts Computer firm on optimizing-compilers when I first heard about Petri nets from Anatol Holt. He had a project doing fundamental research in computer science. I started working with him in 1963 because I felt I was up against a kind of stone wall. He was not immediately offering something that solved those problems but he was talking about ideas like local clocks, relativistic expressions. Tolly would go to Germany, disappear for a while and come back and he'd put diagrams on the blackboard and start talking about all the stuff he heard from Petri. Somebody in the project was assigned to translate Petri's thesis into English.

Petri works at an institute called Gesellschaft fur mathematik und datenverabeitung (GMD). Its main research center is located outside Bonn in Ste Augustin. In 1968, Petri came over here and his number-one lieutenant, Genrich, came with him; I subsequently became good friends with Genrich. About that time, I stopped working for the computer firm and started a computer collective. We had a very different objective. It was to try to do computer work that had some human purpose and was not determined by the DOD.

Then in 1972 I got an invitation to go to Germany and lecture in a course that was being given at the GMD. Part of the GMD fulfills an educational function for computer scientists. I was invited back in 1974. I gave talks at the University of Hamburg, at the Electron Synchrotron Lab in Hamburg and at the technical university in Berlin. In '75, I spent a month working with Petri. I was there for a month or so each year until 1979 or 1980. After that, I had a project where I worked in Germany four months out of the year. That is when I really got to know how the Institute functioned.

Petri was trained originally as a physicist or a mathematician. He must be about sixty, five ten, not exceptionally tall, a little stocky. Sits at a desk with elbows propped on it, smoking almost continually. He drinks a lot of coffee, speaks slowly, deliberately. He is not a rigid German professor type. The first time I went there I stayed at his house in the guest room for several days. He speaks English well but sometimes he does not like to speak it. He plays chess, likes to drink good German wine, likes to laugh. Petri is certainly not formal.

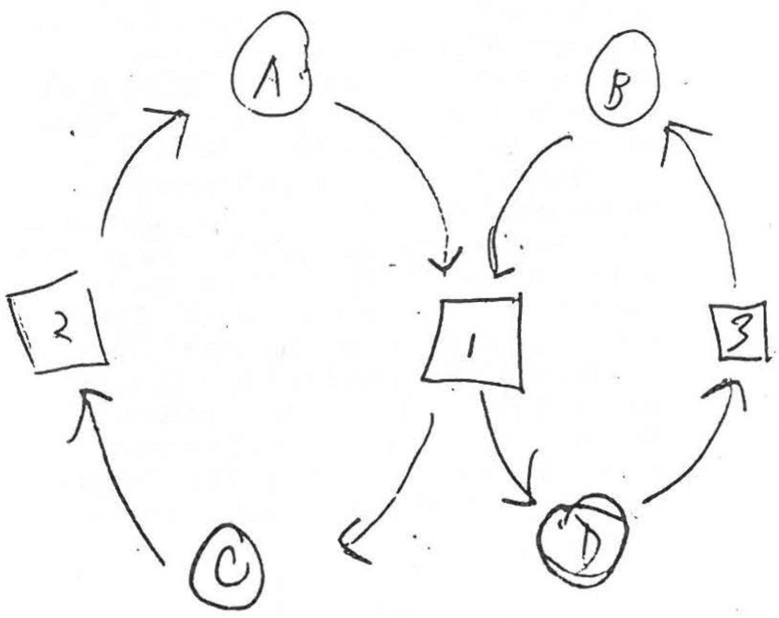
In Petri's work the concept of a local relationship between objects is fundamental. In fact, the relativistic nature of Petri's work comes from rules of interaction which are defined strictly in terms of local relationships. That means you don't talk about things like time as a global idea. That is stricken. That does not exist. It is a misconception. Measurement as an absolute does not exist either.

Petri wrote, in 1961, what is the equivalent of a thesis—its title was "Communication with Automata". His intent was to portray a very basic way of viewing a lot of questions that arise with computers from a perspective really quite different from the classical computer science approach at the time. Petri wanted to have a way of talking about questions in computer science that did not presuppose a physics that was unrealizable. In reference to hardware for instance, computer design proceeded as if there was such a thing as a global clock. A clock is a synchronizer. All a clock can do is send messages. There is no difference between a message that one thing sends to another that says "I am done you start" and what a clock is doing. You imagine that everything has access to what the universal clock says. That is a world view that is not Einsteinian. You can not achieve that in the real world. But people do evolve principles of design and description that are based on universal clocks.

Petri was primarily interested in altering the way people think. He was interested in establishing a new way of thinking which would lead engineers and computer designers of both hardware and software to work with principles that were sound on some fundamental level. He would say it is going to take thirty years before people think differently, that you can not expect to see the affect of this for a long, long time.

Of course Petri had many different ways of describing the things he was interested in, and one of the very confusing things is that he would switch amongst these different ways, some of which were more suitable in one framework and some of which were more suitable in another: and Petri would insist they were all relatable in a very strict manner. The demonstration that this was true he frequently left to his students. In any case, if you look at Petri nets there are two types of things: events and conditions. It can be formally portrayed in mathematics as these two types of objects and a set of relationships among them.

From a graphical point of view, a Petri net is a directed graph with two kinds of nodes: events are portrayed as rectangular objects and conditions as circular objects and the relationships between the two as arcs. Each directed arc, represented as an arrow, connects one condition with one event. An arrow from a condition to an event means that the condition is an input to the event; an arrow from an event to a condition means that the condition is an output of the event. Every condition in a net is an output of at least one event and an input of at least one event. No condition may be both an input to and an output of the same event. A condition is capable of two states—full or empty.



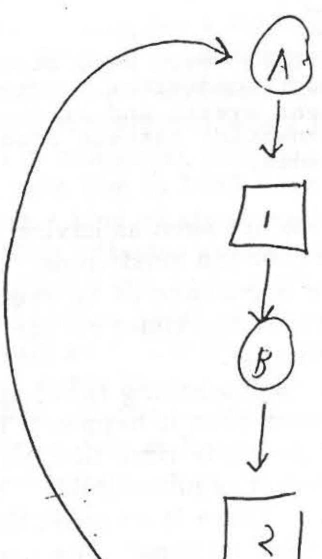
In a simple Petri net, circles represent conditions, rectangles represent events and arrows show the connection between conditions and events.

Conditions are seen as having duration. Events merely bound conditions. The firing of an event, the occurence of an event is not viewed as consuming time; rather it separates distinct conditions.

An event is something that happens. The question is when does it happen? The answer is that it happens any time that all of the conditions that it requires hold. That is when it can happen. There is no other definition of when. And what happens? The conditions that were required for it to happen cease to hold. There is another set of conditions which are the outcome of this event happening. They begin to hold. That is the firing of an event. What are the conditions? You can think of the conditions as representing the state of something.

But what is interesting is that a state in Markov theory, or in traditional computer science, is the total system state, that is the concatenation of the value of every interesting variable. In Petri's system, we are talking about local conditions, only local conditions. When the event can take place is determined strictly by those conditions that are input to the event, not the total state of the system. The total state of the system is like the universal clock. It is not accessible to an individual event. There would be no way of building a device in which the different individual events were all connected to an arbitrarily large number of state possibilities. That is just not physically realizable. You can only get so many things together close. No matter how hard you try you cannot squeeze more than so much, so why talk about the event being conditioned by a total state when you could never build such a device? Throw out that idea as a descriptive technique.

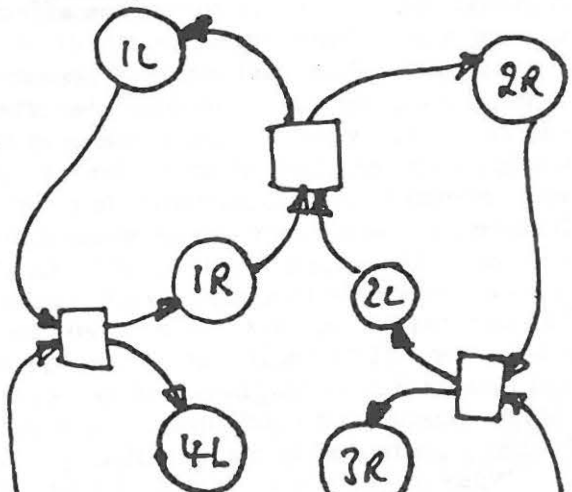
From Petri nets you can generate total descriptions but when you do that interesting things happen. One example is when you look at two events. In a Petri net you can ask the question are these events ordered? Does one necessarily come before the other? Here is Condition A. It is input to Event One; the output of Event One goes to Condition B. Condition B is input to Event Two which then produces as output Condition One. Imagine a single token travelling through this circuit.



A causal relationship between conditions and events means that the events are not able to fire concurrently.

First Condition A holds then Event One fires; as a result Condition A ceases to hold and Condition B begins to hold. Now Event Two can take place. There is no way Event One and Event Two can fire concurrently. They are strictly ordered, always in alternation. You can produce pictures that deal with the issue of whether events are strictly ordered or whether it is possible for them to occur concurrently. There are certain ways of representing the behavior of Petri nets called occurence graphs in which this is made clear.

You can get situations where two events are not ordered—one could happen first and then the other, or vice versa, or the two could happen at the same time. All of those behaviors are generatable. To do that in classical statement changes requires exploding the possibilities, somehow or other explicating: representing first this then that, or first that then this, or the two together. As if they were three distinct things. In Petri nets, that idea would be rubbish—they are not three distinct things; the point is that the relativistic description does not preclude any of the possibilities. In a way, in order to achieve the same things in a statement sheet as a Petri net, the process of description for certain classes of systems would explode enormously. Those are systems with a lot of concurrency.

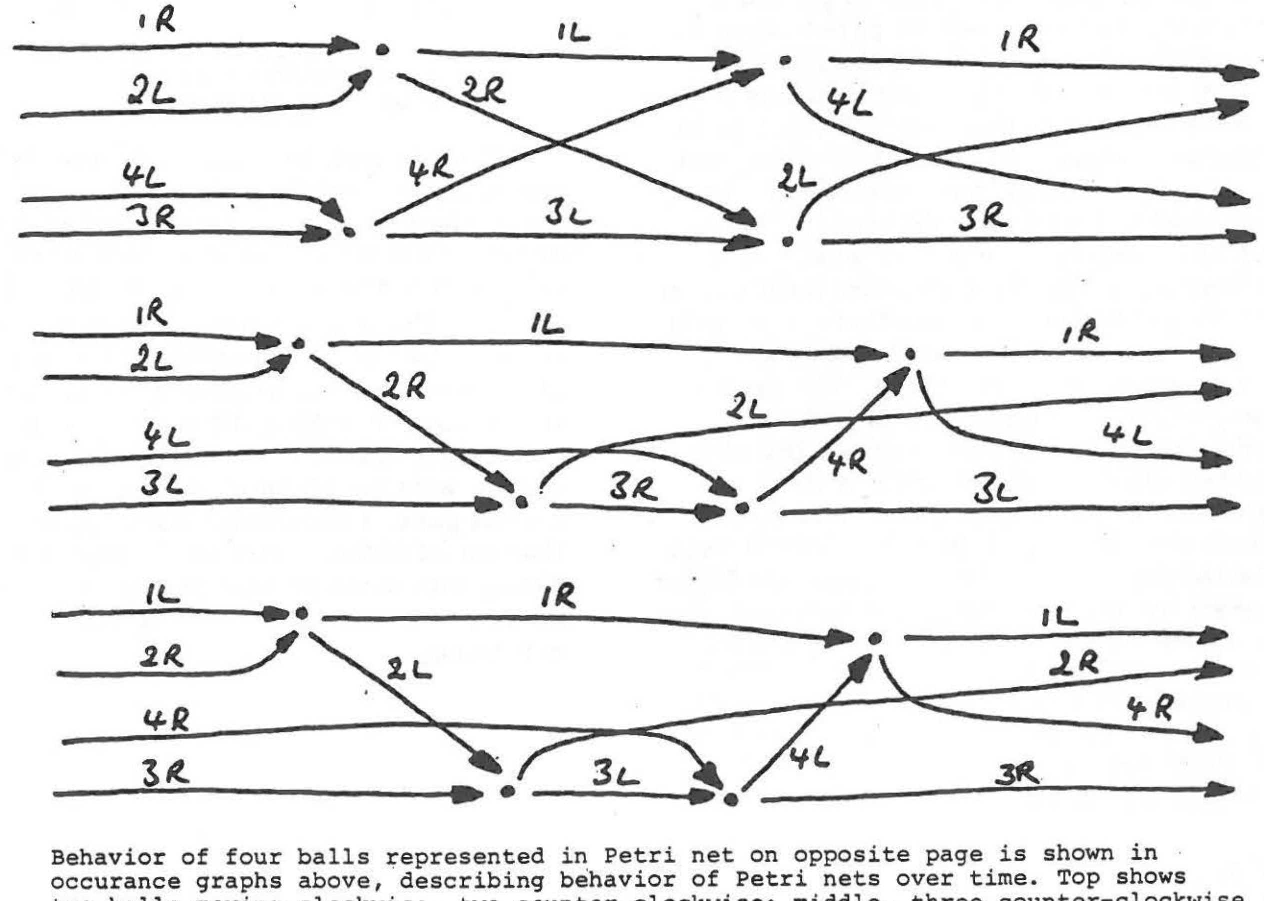


Four balls are moving and colliding on a single lane track. The two possible directions of each ball's movement--clockwise or counterclockwise--are represented by circles. The collisions which result in a change of the ball's direction of movement are represented by rectangles.

You are making a stronger statement when you say things are ordered than when they are not. You might say in general things are not ordered. This gets complicated when there are a lot of different subsystems when they are interrelated to each other. It gets interesting too because this is an area of computer science which has become very important with the advent of multiple systems in which the task of getting such systems to work together correctly is enormous. One reason is that there is no good way of describing or analysing the behavior of such systems. You have a bunch of separate asynchronous systems which send messages affecting the others' behavior. The design of such systems must include a meaningful way in which they relate to each other's messages so you don't get into a situation where A is waiting for B to send something and B is waiting for A to send something. That is called deadlock or deadly embrace. When it does happen you're stuck. If you have a formal technique for looking at a systems description and saying whether or not it contains a deadlock, that would be very valuable. That was one of the early promises of Petri nets.

It is kind of difficult to know if anyone has actually built a piece of hardware in which they started off with Petri net description of what they wanted. Even if they drew pictures of Petri nets, did they use any mathematical analysis or did they just use Petri nets as descriptive techniques? I have drawn Petri net pictures of things that then led to software designs. I've never used any mathematics on Petri nets tht resulted in anything that went into a design.

At the time I first heard of and became interested in Petri nets, I was working on compilers, on that area of compilers having to do with code optimization. In code optimization, you start off with the problem that someone has written an algorithm in a programming language. You want to get a realization of that algorithm on a particular computer. The language that was used had certain things built into it, some of which were important and some irrelevant. You write a statement, from left to right on a line all completely sequential. An optimizer wants to figure out what was essential in the ordering and what was not essential. When it finds something not essential, it has the freedom to rearrange things. It can explore that freedom to say which of the different orderings works better. I produced some papers on this topic which had to do with various machines where different ordering

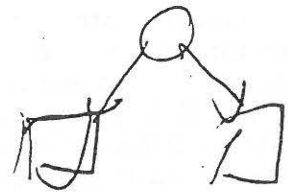


Behavior of four balls represented in Petri net on opposite page is shown in occurance graphs above, describing behavior of Petri nets over time. Top shows two balls moving clockwise, two counter-clockwise; middle, three counter-clockwise and one clockwise; bottom, three clockwise and one counter-clockwise.

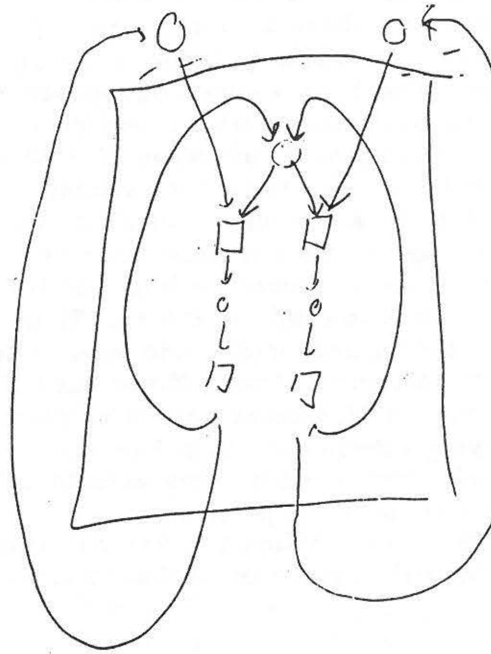
arrangements made a big difference. One of the examples is the CDC6600. One of the reasons that the different orders made a lot of difference is that the machine had a lot of concurrency in its operation. Especially in the context of a repetitive loop, you could get a speed-up of a factor of two or three by choosing one order over another. In principle, the language was serial and there was one fixed order. That was an accident of the fact that it was a linear language. You see what happened—I got interested in representing only the order that was critical. This is causality.

I used Petri nets as a descriptive tool. I described an algorithm with the accidental ordering constraints stripped out. I described the machine and the ordering relationships among its registers and functional units also as a net. There was a mapping of the algorithm onto the machine and an evaluation of each mapping and a choosing of one that worked better from the point of view of elapsed time. Of formal significance? I doubt it. From a practical point of view, evaluating the different choices was a combinatorially explosive project. If you had a piece of code that you wanted to work very well, then you could spend a lot of computer time using this technique.

The thing I liked then and still like, if you are faced with the problem of producing descriptions where you want to get rid of accidental ordering, —Petri nets have a way of expressing choice. It is not described as choice but as conflict. What it means it that if you have a condition and it is input to two different events, not causally ordered, and that condition holds, both events have what they need but only one can occur. That is a conflict. Petri's view is that what you are looking at is something that has been cut out of a larger system in which there were other conditions which resolved the issue about which event could take place. The proper perspective is to imagine this cut as expressing the boundary between this sytem and something larger which had the information which this system now needs. There is an input to this system which would resolve the confict. The cut from the larger system has created the incompleteness, the necessity for information to flow into it.



On the simplest level, conflict arises when a condition is input to two events.



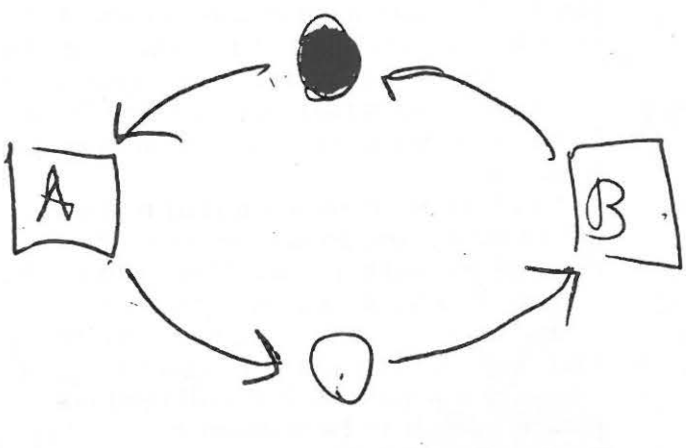
Conflict is resolved by information which comes from outside the boundary of the system.

You can imagine where two events flow into a single condition. After the events have taken place you can no longer tell which one of the two it was. This is a place where information would have to flow out of the system. There is a general idea about the conservation of information, in the same sense of the conservation of energy. You can make the analogy by taking the view that these incomplete systems are cutouts from the total system with no information loss, no information gain. I have never seen anyone utilize that set of ideas. Petri would talk about it fitting into some grander picture that he has never gotten around to writing down or explaining.

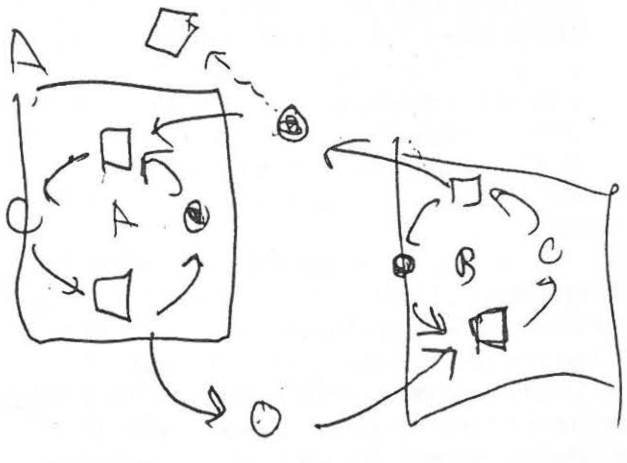
You never talk about the system as complete. It is not very interesting. A system is not quiescent. It is receiving messages and sending messages. In the classical, von Neumann view, you send the system a set of inputs, and the algorithm is a way of mapping the input set onto a set of outputs. That is a very static view of a system or process. It has nothing to do with a living system.

In all of Petri's examples, he did not deal with questions like: Can you imagine a Petrinet itself dynamiclaly changing in the sense of adding states and conditions, growing? He never talked about any of that. There are people who have tried to produce a level of description of Petrinets in which such things were thinkable. The level of analysis and expectation of what might sensibly be calculable excluded getting into nets that grew. In fact, the amount of progress in the mathematics of nets that do not grow is pathetic.

There were other graphical ways to represent conditions and events. Circles and squares are very primitive elements. If you try to use them by themselves to represent a complex system you may be in for an awful lot of boxes and circles. If you can not introduce levels of notation, you are in trouble. Petri developed a number of ideas that have to do with net morphisms, mappings between nets.



A simple representation of a deadly embrace.



Same deadly embrace, also detailing internal states of A and B.

Some subset of these morphisms produce relationships between levels of detail, a simple net that you can see exploded into something that has a lot more detail in it but in a very controlled rather than arbitrary way. If I show a picture where I have a condition as an input to an event, I could imagine this as a compound condition and this as a compound event. And if I blew up the picture what I would see is that inside that compound condition thre are really a whole bunch of simple conditions and inside that compound event there are a whole bunch of different events. There is wiring between those conditions and events which in effect act as a selector operation. On one level, I can legitimately represent that as a single condition and as a single event. From a simulation point of view, that is quite correct. I am not interested in the detail. At that level. But there is a lower level at which it is interesting. You can imagine again the lower level computer operation supporting some higher level computer operation. That is just one morphism.

If I take the case of one condition and I have it as input to two events that are in conflict, on one level I might be interested. On another level all I care about is here is this condition, it held and then this compound event could take place which happens in this case to be either one or the other. With a few mappings like that, you can then take a complicated net and squish it down. If you do this systematically, it becomes a top-down programming. I draw a big box, that is my complicated event. You then see there is a start-up event. Then there is this simple substructure that repeats itself. Then I say fill in more details and it descends to a lower level and then blow that up. You end up with a nice top-down system design where at each level it explodes into more detail. That is the kind of tools I have been working on, tools that are intended to make it possible to draw nets that way.

During the seventies, whenever I went to Germany, I would shout at Institute meetings thta it was the responsibility of the Institute to try to take the work and apply it to something practical. I thought they would benefit enormously. If you speak to theoreticians and present the argument that it is worthwhile to apply the theory to practice because that goes back into the theory, that is not a popular view. That is kind of a Marxist idea. It may be common sense too. But there are math theoreticians, who in general think that philosophically that is the wrong idea. Petri did not present a theoretical objection to that idea. He did not go into rhetoric about why it was a good idea or a bad idea; what he said was, he had an institute set up, licensed to do theoretical work he felt that the real results of this theoretical work would not begin to appear for 20 to 30 years. For the Institute to get involved in a practical demonstration that might easily fail at this stage was not a good idea. That was his argument.

It is also true that this whole thing requires maintaining momentum. You must continually generate an image that says this thing is a comer, this is where the future is. If you spend years studying Petri nets, you may not end up with a job. There may not be too many places that want to hire experts in Petri nets. In the US, the process was different. There was not someone to come to, but people did get involved and a number got disappointed with the outcome. People got involved at the level of doing Ph.D. theses and trying to do interesting mathematics in the context of Petri nets.

It has gotten complicated because other people have come up with ideas in computer science—Smalltalk and object oriented programming—which share at least some ways the ideas and messages that were in Petri's early work. People doing work in computer science in the early 60s laughed at this basic research but as the times changed some of those ideas were reinvented in specific settings. It could turn out in 20 years that you say, hey, look at all of these people who have adopted Petri's way of thinking—but in fact they never read any of his stuff.

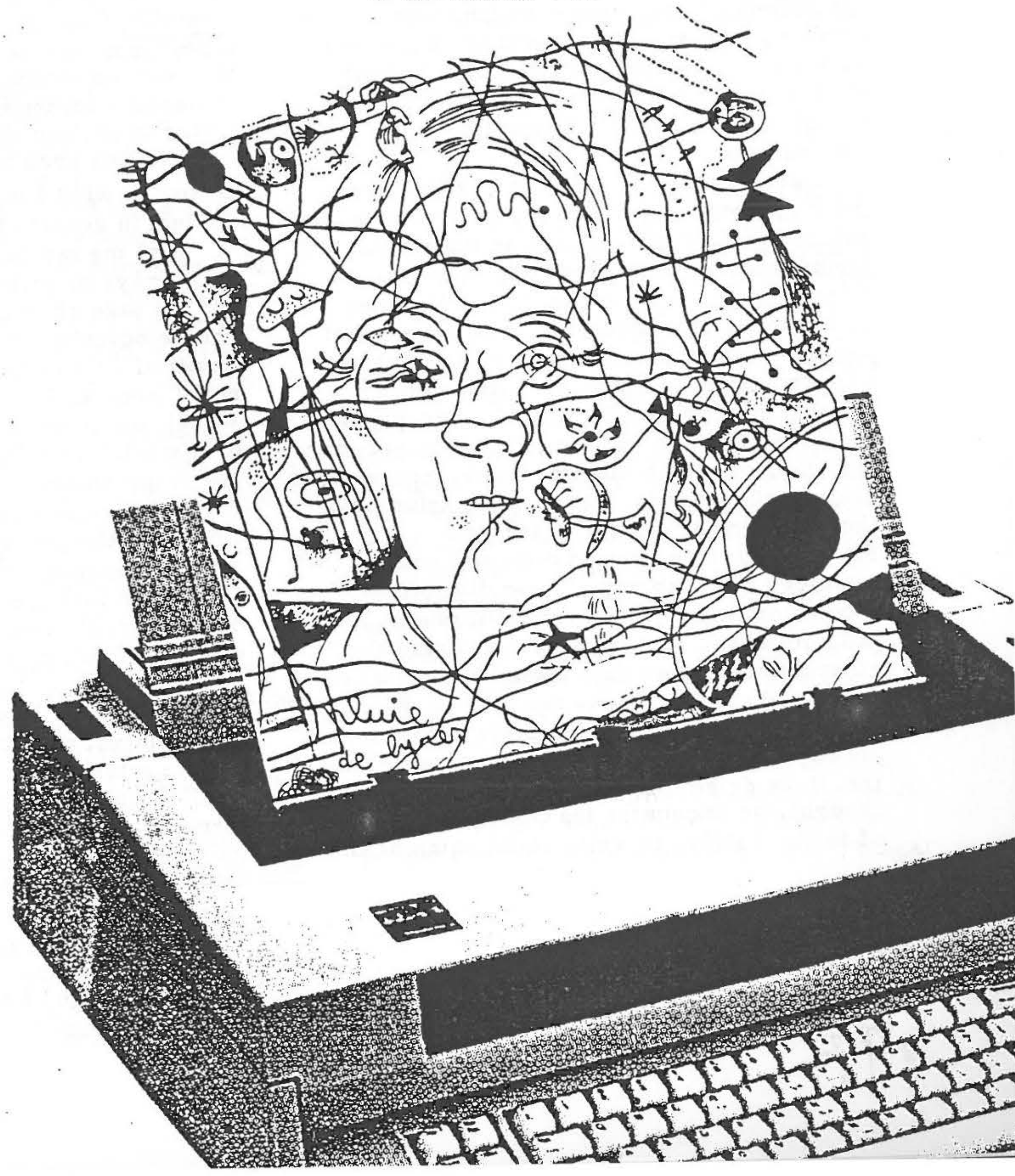
In the evolution of a science, the things that become possible as a result of the materials at a certain stage in time then become the forces in forming what kind of ideas emerge. Different people coming up independently with ideas that share things in common is not remarkable. As soon as you had a multiple processor view, as a serious reality, not just a few machines that could work that way, having systems co-ordinated over a network have all these problems. There is no clock that you can all count on. It takes time for messages to go between them which is an exaggeration only of the time it takes an electron to travel in the wire. A lot more things can go wrong. Different users trying to update a common database. These problems are all the same problems from a formal point of view but they were not problems of practical significance in the sixties. They were of theoretical significance. Now they are of practical significance everyday. There are a lot of ways that twenty years from now Petri could get to say that his ideas made their way.

Ultimately it requires skill to produce a good description, no matter what the description technique is. There can not be any magic. You have to have a perception that is clean, a way of organizing your own thoughts that is good. You can not expect magic to come from a good tool; it still requires the person using it to have clean vision. Trying to describe something complicated well is a hard task and Petri nets might make it possible to do a really good job.

Memory Revisited
By Sol Yurick

The author is a novelist (Richard A; The Warriors; and a forthcoming novel, The King of Malatesta, to be published by Doubleday) who has experienced life inside something like a Petri Net, actually an edge-notch card information retrieval system with Petri Net characteristics, designed for him by Robert Shapiro. "The experience was in some sense shattering," he recalled, "since, at least as organizing material was concerned, all items in the catalog did not necessarily relate to one another in the usual way. This had a curious effect on my mind."

I asked him to explain this, and the article is the result.—Ed.



Practitioners of what seem to be the ancient knowledge-arts (such as writing novels, epics, poems, interpreting dreams, rhetoric) must confront modern practice . . . the information world of program-run machines. Have we advanced significantly or have we leaped back into ancient times using computer-assisted, ancient visions? Past or present, primitive or modern, some subset of many populations have always been obsessed with the generation, processing (playing with) and ordering of language and information.

The new technology presents us with a sort of imperfect mirror in which we are forced to look at what we have been doing for thousands of years, but in a new way. But there's a problem in this new, informational paradise promised to us by the futurists: instead of saying the computer works like a (poor) version of the brain/mind, we reverse the terms of the statement and run into trouble. Like the ancients, we dream of controlling the universe with language and/or number . . . designating the universe, what's in it, and the relationship of its parts and—if one's language is generally accepted—organizing reality by information-manipulation.

I am a novelist. I choose to represent reality in certain ways. I try to deal with the unfathomable depths of human (individual and group) moitvation, philosophy, the social sciences, etc., in a certain context; drama and action in which passion becomes an integral part of what we like to think of as relatively pure thought. Intellectual systems do not develop in hermetically sealed, conceptual containers. While they think, people eat, have sex, confront the burden of many, inconsistent pasts in their minds, fight for the triumph of their thought over other thinkers . . . Remember: Newton was obsessed with astrology and alchemy. These disciplines require order, regularity, measurement, laws, predictability. Can we really separate the components of Newton's thought, save what we like, discard what we don't like? Which leads us to ask: what's the metaphysical, the cosmic-dramatical basis of modern physics, for, if we delve into the bottom of our thought, we encounter (as Godel implies) leaps of faith. I strive to write about some of this.

I became aware of this new world of information in 1966-67. At the time I was writing one of my novels, a complex work called The Bag. Published in 1968, it was not only involved with the events of the late sixties, poverty, welfare, civil rights, student rebellion, revolution, but theories of human behavior in that immediate period, and incorporating as well, their historical aspects. It's not that I wasn't thinking: I became aware of my thinking.

As I was writing this book, I began to face several problems. To do the topic justice, I would have to write a huge volume, indeed many volumes, perhaps in the style of Zola. Not wanting to do that, I had to think of methods of compression and allusion, how to organize the massive material I had gathered from a variety of disciplines, how to remember (retrieve) items, putting the pieces into the proper position at the proper time (which is not too different, if one is speaking formally, from the problems of putting together allocation-of-material schedules in, let's say, an automobile factory). I was forced to become conscious not only of what I was trying to do, and the way in which I was trying to do it, but even forced to generate a working theory of what I in particular and creative writers in general try to do.

(Let me say parenthetically that there are many ways to write novels. Let's narrow it, for the sake of discussion, to two: the chronologically arranged novel (such as the works of Zola or Balzac) and the 'modernist' novel (such as Joyce's Ulysses or Finnegan's Wake), the latter being a simultaneous display of materials, fundamentally achronological and fragmentary. I had chosen to write the chronologically arranged novel in which one simulates the procession of real time and arranges events from a beginning to an end

But in fact there is no such thing as the chronological novel . . . how many begin, as does The Iliad, in medias res, in the middle, and backtrack to the beginning and move forward again? How many novels must stop in many places, go back and explain something, or give some background? Think of the intellectual leap required by the simple formula: "meanwhile, in another part of town (or the world, or the universe"). How much must we know—that we take for granted—in order to even begin reading. How much constant checking against our biological-mental reference library goes on constantly. A consideration of this question indicates that one always begins, as it were, in the middle.)

What I was putting together were interviews, news clippings, readings in the social sciences, histories of how social theories came to be, philosophy, economics, politics and political theories, pieces of drama, psychological motivation (both theoretical—which I tended to reject--and personal), scenes, conversations, and the usual weapons out of the armentarium of the creative writer, rhetorical devices such as metaphor, simile, trope . . . My haphazard files grew exponentially. (Now the point of mentioning the different ways of looking at the same thing is that not only was I involved in what could be considered a public and shared endeavor, where knowledge was common, but an individual endeavor. In creative writing, succinct ways of expressing complex things do not begin as group activities, but are the activity of single minds--to be sure in a social context—in which the original, singular idea or image may or may not enter into the public domain. How new ideas are received is a political question, explored by Kuhn in The Structure of Scientific Revolutions, which applies to revolutions in fiction, poetry, science, religion, philosophy . . . etc.)

Ahh, you say, if only I had had a computer and the proper programs. Remember: this was 1966-67. There were no micros in general use and the world of computing and all of its disciplines was hardly known to the general public. I thought it would be a nice thing to have a mainframe in the house . . . all right, perhaps a mini.

Given the overwhelming complexity of material I was trying to handle and the way in which I saw that material, I was floundering. I had written a huge outline of some hundred pages, and a short outline which was a guide to the long outline, and a theme-map in different colors which stretched for some ten feet (and didn't have a wall on which to display that map). As the notes overwhelmed me, I began to look for a way of retrieving and organizing the pieces. My mistake had been to assign one key word, descriptor or indicator to each piece of information and sometimes I would forget under what designation I had filed it.

Looking around, I thought I had found a system, one outlined by C. Wright Mills in The Sociological Imagination. The system he recommended was index-cards; topics were flagged alphabetically in as many ways as you could think of them. Extremely clumsy. In time that might mean that my whole time might be spent in writing cards and finding them.

At this point in time, Robert Shapiro, a computer maven, came to my rescue. He suggested working with something called edge-notch cards. It more or less worked in the following way: each IBM-like card had a series of numbered holes running around the edge of the card. What one did was to create a designator for the item involved, assign a two or three digit number (taking the number from a list of randomly generated numbers) and, using a punch something like a trolly-car conductor's punch (does anyone remember trolleys?), clip the holes in such a way that they reached to the edge of the card. In this way one could assign multiple descriptors to one card, by inventing or using other relevant, associational descriptors (and what is relevant for me is not relevant for another). Thus, if you forgot to think of the item you were looking for in one way, you might retrieve it in another way.

One inserted the card into a deck of cards. The way one queried the deck was to insert two or three needles into the numbered holes standing for the descriptor you were looking for, lift the deck, and the piece of information dropped out.

The beauty of the scheme was that not only did the specific piece of information you were hunting for drop out, but everything that might be related and pertinent (which was to say other material which you saw in the same way and to which you had assigned the name descriptor), or even material that was not directly connected, except in the mind of the user of the system. This created some interesting resonances and intersections of thought. The ultimate problem with using this deck was that as the cards grew in number, there came a time when the operations that were required to find a specific piece of information became clumsy. In addition one might find oneself musing, and having a conversation, so to speak, with the deck itself.

To my knowledge, three novelists used this system: Marge Piercy, Robert Coover and myself. We all used it in different ways, which is to say that we all created different categories and descriptors, sometimes for the same material. One of our desires was that people could exchange materials, copy cards, have insights into the way our three, quite diffrent minds worked. The way in which we dealt with material makes it difficult, if not impossible, to in any way universally specify our descriptors. If I saw the world from, let's say, a marxist perspective, and Coover from—for the sake of argument—a religious-anthropological perspective (and even these should be qualified), we came up with different descriptors of the same material and thus were talking about different worlds using different metaphors.

The universal acceptance of a world view comes later when the individual's contribution becomes public. Example? Consider how many times you have seen the word 'wasteland' used? Yet the concept, 'wasteland' is the metaphorical contribution of one individual. Reflect on how many times a situation has been described as 'Kafkaesque'. Examples could be multiplied. People in our indicipline deal with resonances, fusions and associations, constantly hunting for new ways of describing the reality of the world and the way in which our imaginations intersect with and label that world. I will go further and say that specification itself is a convention . . . metaphorical in nature . . . an act of faith, a common agreement . . . at least if we are to believe the way the world is designated from Bertrand Russell on. (A metaphor is an imperfect but imaginative comparison which fuses the poles of the items to be compared, into a new term.) Indeed, when applied to the universe, mathematics is a metaphor.

At first I thought I should try and impose some larger organizational structure on this system to facilitate retrieval. For instance subdivide language into, say, the large, general, heirarchical categories that were imposed on the universe of words by Roget in his Thesaurus. Shapiro suggested, for a variety of reasons, some of them technical, that the best way was to keep the whole purely 'randomized;' each key word being 'equal' to every other key word for ease of retrieval.

One result of this way of thinking (which grew out of the actual practice of querying the deck) was that, as the deck grew, I had several insights. The first was a new and more heightened appreciation of comparison or matching. The universe can be matched up to a series of languages, for example literary, philosophical, mathematical, physical . . . or language to language . . . the thesaurus effect. The second was that—all descriptors being equal—everything in the universe and in the way our minds regard that universe is interconnected, and if interconnected, then in some sense simultaneous. Another result was that disciplines (psychology, sociology, anthropology, fiction, etc.,) lost their boundaries, allowing one to consciously view the world in this unified, interdisciplinary way. Yet another result was that the structure of cause-effect was weakened (leading to various meditations on the conventions of temporal arrangements). But these ruminations also led to some disturbing, psychological effects. For the dream world of simultaneity began to impinge on the conscious world.

As I would hunt through the cards for some appropriate item to put into the latticework of the structure of my novel (let me say, parenthetically, by way of example, Dante's Divine Comedy is a memory system with a variety of conical shapes upon which to hang a number of tales, personalities and gossip), I found something peculiar and disturbing happening to me: the disorienting—even psychotic—effects of synchronicity, simultaneity and interconnectedness was something like getting stoned on LSD, or dreaming . . . That is, the process of a form of intellectual thought had the effect of making me feel intoxicated.

I began to wonder: why did chapter have to follow chapter? Why did paragraph have to follow paragraph? Sentence follow sentence, indeed, word follow word? What I recognized in the system was something akin (something I felt) not only to the way in which the mind of the novelist and poet works, but the way in which the brain itself works. Everything is simultaneous; and conventional, mental and biological algorithms sort out the required knowledge for specific purposes: a high order of abstraction is required to describe—however imperfectly at present—the process of sequencing this array of simultaneous items into a chronological order. But, in the past, arranging material in chronological order was viewed as quite natural. Conversely, the works of the 'modernists' with their penchant for fragmentation and implied simultaneity had been considered artificial, a high order of abstraction.

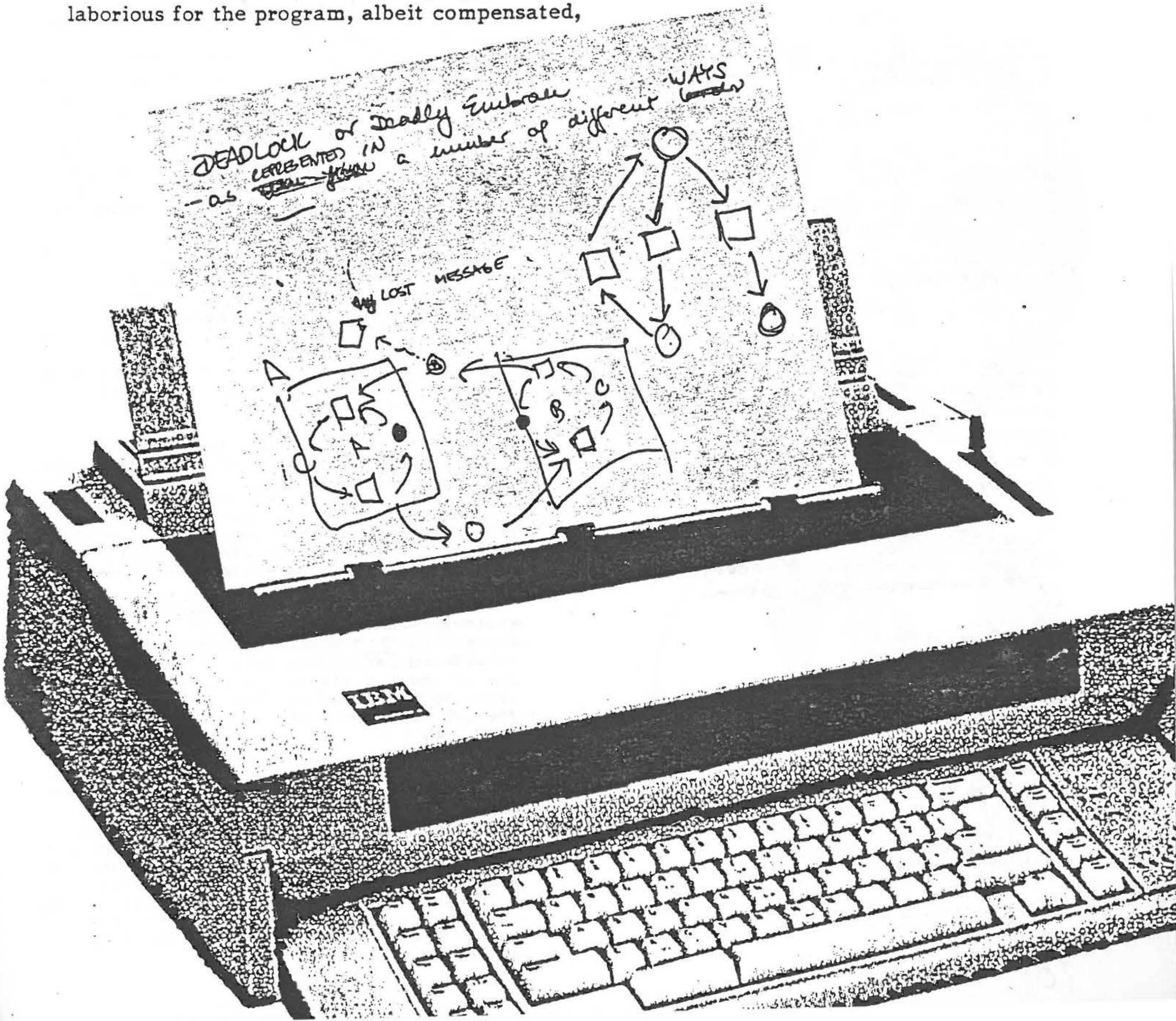
Why, I wondered, couldn't a work, a novel, be issued as a set of cards, such that the purchaser of the cards would have the task, perhaps the joy, of arranging the cards (and having the ability to add to them) into his own work? Of course I found there was no publisher willing to fund such a development.

Now it may seem that I am reinventing a wheel, since there have been many programming theoreticians devoted to the ordering and retrieving of materials stored in memory. Now that I have looked more closely into the matter and since I use a micro, I see that those devoted to the ordering of information are at the edge of a vast ocean, and that ocean is the brain itself. What is easy, and speedy for the mind—the generation of connections of detached item-fragments separated by vast, conceptual distances, indeed embedded in different disciplines with their mutually incomprehensible jargons—is laborious for the program, albeit compensated, up to a point, by programmers using Turing-Von Neuman machines, which, after all, are mere logic machines of a certain sort.

Clearly, the present machinery is all wrong.

Recently Shapiro and I sat down and began to wonder: what would be required to write a metaphor-generating program? Our talk ranged from languages to chips. I was not sanguine that it could be done. Shapiro was more optimistic. We agreed on one thing: we (in reality he) would have to design an entirely new kind of computer from the bottom up and he felt he knew how to do it.

Then, and only then, could I carry through a project I have been thinking about: creating a program that would generate endless and utterly new stories.



DIAMOND: A LOGIC OF PARADOX

by Nathaniel S. Hellerstein

Outline

The Problem Of Paradox
The Liar and variants; the Barber; Grelling's; Quine's; Russell's; Antistrephon; Berry's; interesting numbers; Richard's; gremlins

The Diamond System
Introduction; the buzzer; wobble; and, or, not, but; fixed-points

Productio Ex Absurbo
Self-Reference theorem; evaluate example

Using Diamond
The Liar; the Barber; Grelling's; Quine's; Russell's; Antistrephon; Berry's; interesting numbers; Richard's; Cantor; gremlins

Paradox And The Continuum
Continuous functions from $\mathbb{R}$ to diamond; embedding $\mathbb{R}$ in $\diamond^\omega$; continuous functions from $\mathbb{R}$ to $\mathbb{R}$ extend to $\diamond^\omega$; comment; Zeno's Arrow

Open Questions
Diamond computation; Gödel; games; unexpected exam; Dilemma

Conclusion

Technical Appendix
Tables of the truth functions; Equational laws; order and topology: two proofs of the Self-Reference Theorem

Bibliography

Afterword: Fractals

1. The Problem Of Paradox

"All Cretans are liars"
- Epimenides the Cretan
"I am not a Marxist"
- Karl Marx
"The statement I am making is false"
- Eublides
Forbidding Forbidden
- graffito

"This sentence is false."

This, the "liar paradox", is a simple yet profound problem; childishly easy to state, it seems to have no logical solution. If the paradox is true, then it is false; if it is false, then it is true. Which is it? It can't be either, so somehow it must be neither. But what is there that is neither true nor false?

If you believe in the Law Of The Excluded Middle (which says that any sentence is either true or else false) then you have to answer "nothing is," and then try to turn the paradox into nothing. This is difficult, because it seems to be something. Because the Law Of The Excluded Middle is a basic axiom of two-valued (Aristotelian) logic, many logicians have gone to a lot of trouble to avoid the liar paradox.

The usual approach is to create a "type theory", which forbids sentences from referring to themselves. However, all these type theories have turned out to be artificial, restrictive, and inelegant. They're also somewhat inhuman; after all, we humans love to self-refer. (At least, I do.) Finally, self-reference shows up quite often in mathematics. Here is a list of some famous mathematical paradoxes.

The Liar. "I am lying." "This is false." Its most compact form: "Not this."

Some variants of the Liar avoid direct self-reference. For instance, consider the "Jourdain card"; on one side it says "The statement on the other side of this card is true," and on the other side it says "The statement on the other side of this card is false."

There is another card which says "The statement on the other side of this card is false," on both sides. This need not be considered paradoxical; it is consistent for one of the two statements to be true and the other to be false; but which should be which? The two statements are identical, yet opposite.

The Barber. Legend tells of an small village with only one barber. Francisco, proud of his monopoly, boasted, "I shave every man in the village." His crazy painter friend Pablo asked, "What about the men who shave themselves?" "Good point," said Francisco. "I shave every man in the village who does not shave himself. Of this I am sure." Pablo replied, "Do you shave yourself?"

According to Francisco's second boast, Francisco shaves a man M exactly if M does not shave M; but then Francisco shaves Francisco exactly if Francisco does not shave Francisco.

Grelling's Paradox. Call an adjective "autological" if it describes itself. "Short" is short, and "polysyllabic" is polysyllabic, so "short" and "polysyllabic" are autological. Let "heterological" mean "not autological". "Long" and "monosyllabic" are heterological. Is "heterological" heterological?

Quine's Paradox. Let "quining" be the act of preceding a phrase by its own quotation. "Has been quined in this sentence," has been quined in this sentence. Now consider the following sentence.

"Is false when quined," is false when quined.

Russell's Paradox. This is a paradox of set theory. Sets are collections; they can contain objects, and they can contain sets. In "naive set theory", the "Complete Comprehension Axiom" says that for any property, there is a set containing just those objects and sets with that property. Some sets may contain themselves; some may not. Russell invites us to consider the set R of all sets which do not contain themselves. This means that for all sets s,

s is in R = s is not in s.

But then what of R itself?

Substituting, we get

R is in R = R is not in R.

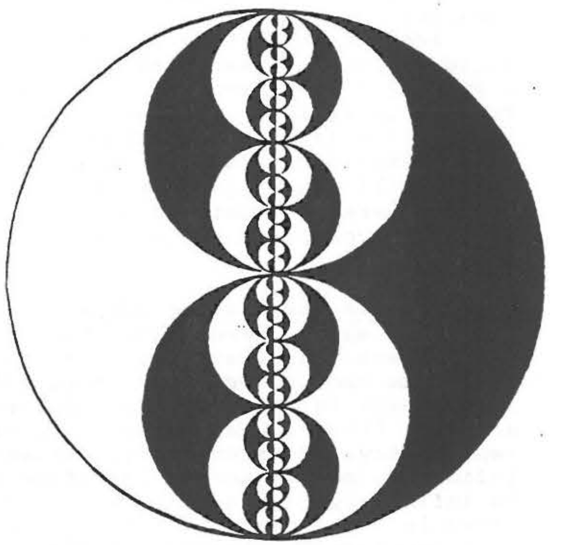
Paradox. The solution usually proposed to this is to restrict the scope of the Complete Comprehension Axiom; but this goes against the original naive idea of a set as an abstract collection; also, the paradox does not tell how much Comprehension should be restricted.

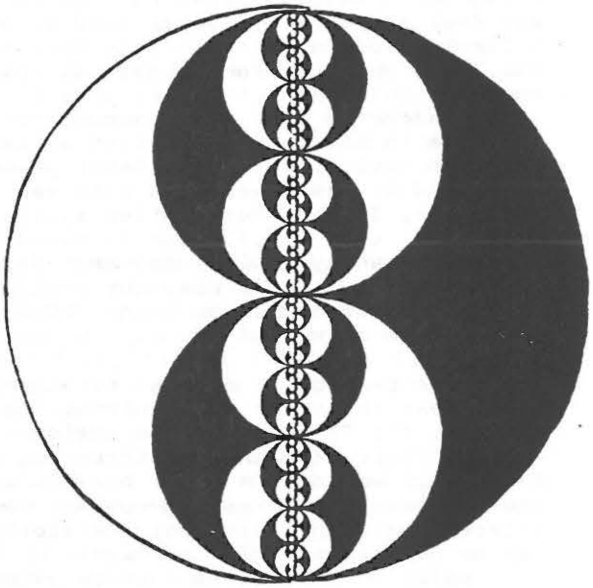
Antistrephon. That is, "The Retort." This is a tale of the law-courts, dating back to Ancient Greece. Protagoras agreed to train Euathius to be a lawyer, on the condition that his fee be paid, or not paid, according as Euathius win, or lose, his first case in court. (That way Protagoras had an incentive to train Euathius well; however, it seems that he trained him too well.) Euathius delayed starting his practice so long that Protagoras lost patience and brought him to court, suing him for the fee. Euathius chose to be his own lawyer; this was his first case.

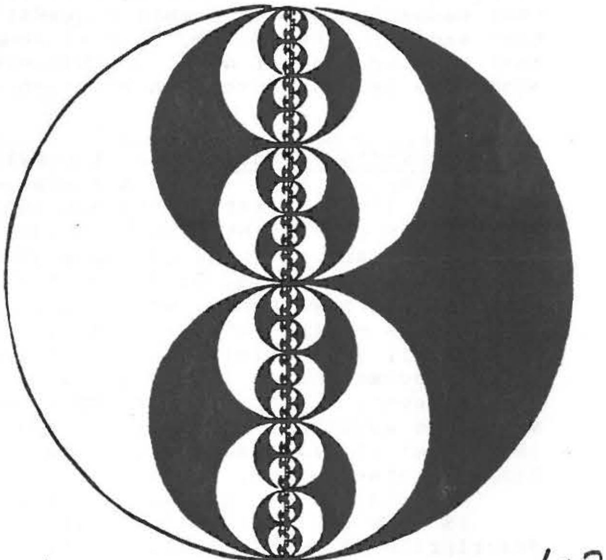
Protagoras said, "If I win this case, then according to the judgement of the court Euathius must pay me; if I lose this case, then he wins, and according to our contract he must pay me. In either case he must pay me."

Euathius retorted, "If Protagoras loses this case, then according to the judgement of the court I need not pay him; if he wins, then I lose, and according to our contract I need not pay him. In either case I need not pay."

How should the judge rule?







Here is another way to present this paradox:

According to the contract, Euathius will avoid paying the fee - that is, win this suit - exactly if he loses his first case; and Protagoras will get the fee - that is, win this suit - exactly if Euathius wins his first case. But this suit is his first case, and he will win it exactly if Protagoras loses. Therefore Euathius wins the suit exactly if he loses it; ditto for Protagoras.

Berry's Paradox. Consider numbers and their names. Some number names are longer than others; for instance, "one thousand" names the same number as "ten cubed", but the second name is one syllable shorter. There are only finitely many names of a given length (say, nineteen syllables) and infinitely many numbers; therefore there must be infinitely many numbers which cannot be named in fewer than nineteen syllables.

Consider the least such number; that is, the least number not nameable in fewer than nineteen syllables. It might be 111,777; using the usual naming scheme you can name any smaller number in fewer than nineteen syllables, but not it. This is uncertain; 111,777 might have some other, shorter name. Assuming that there is none, then 111,777 would indeed be "the least number not nameable in fewer than nineteen syllables."

But notice; that very description is a name, and it has fewer than nineteen syllables. If that description applies to 111,777 , then 111,777 can be named in fewer than nineteen syllables, and that description does not apply; if it does not apply, and no other short names can be found, then that description does apply.

This paradox is related to a proported proof that there are no uninteresting numbers. The "proof" goes as follows:

If there were any uninteresting numbers, then there would be a least one. It would be the smallest uninteresting number; how interesting! Contradiction; therefore there can be no uninteresting numbers.

Well, uninteresting numbers exist anyhow. The problem with the proof is that being the least uninteresting number would be that number's only interesting quality; if that made it interesting, then it would lose that quality, and it would be uninteresting again. So is that number interesting or not?

Richard's Paradox. Is it possible to make a complete list of all subsets of the integers? (In mathematical terminology; are the subsets of the integers "countable"?)

Any subset which we can know about is one which we can name. We can list all these names. That, presumably, would be a list of the subsets of the integers: S(1), S(2), S(3), S(4), ... , S(n), ...; S(n) would be the nth subset named in the list.

However, Richard invites us to consider a certain subset of the integers, called C; C is the set of all n such that n is not in S(n). In other words, for any integer n,

n is in C = n is not in S(n).

Is C on the list? We've just given a description of C, so it should be; but if it is, then it has some place number (call it c), so C = S(c). Is c in C?

c is in C = c is not in S(c) = c is not in C.

Gremlins. Avoiding paradox can force you to accept some very odd conclusions. Consider the following sentence:

"If this sentence is true, then gremlins exist."

The existence of this sentence, plus the law of the excluded middle, forces the existence of gremlins. Here is one proof:

Call that sentence G; so G says "If G, then gremlins exist." According to the law of the excluded middle, G is either true or else false. If G is false, then "G implies gremlins" is false. The only way for an implication to be false is for its first part to be true and its second part to be false; but its first part is G itself. Therefore if G is false then G is true; so G cannot be false, so it must be true.

G is true; so it's true that G implies gremlins. G is true, and G implies gremlins. Therefore there are gremlins.

Here's another gremlin proof:

Suppose that there were no gremlins. Then G says, "If this sentence is true then (falsehood)," which is equivalent to "This sentence is false," a paradox. Assuming that there were no gremlins leads to paradox, which is a violation of the law of the excluded middle; to avoid paradox, we must have gremlins instead.

In short, if there are no gremlins, then there is paradox; if there is no paradox, then there are gremlins.

The same argument can be used to prove anything else you want, including the nonexistence of gremlins. ("If this sentence is true, then gremlins do not exist.") Epimenides the Cretan said that all Cretans are liars; some people have claimed that this proves that some Cretans are honest. This is an example of the gremlin process at work.

By the way, gremlin-like sentences are quite common; people use them all the time. "The key's in the drawer, if I'm not mistaken."

Mathematics contains paradoxes. Since mathematics has insisted on the law of the excluded middle, it has remained incomplete. Lately, though, some logicians have proposed to turn this around; since paradox is a fundamental reality, they say, we must go beyond analytic Aristotelian logic.

Lately I have been working on a non-Aristotelian logic called "Diamond". It's a logic of paradox; therefore I now introduce it with one:

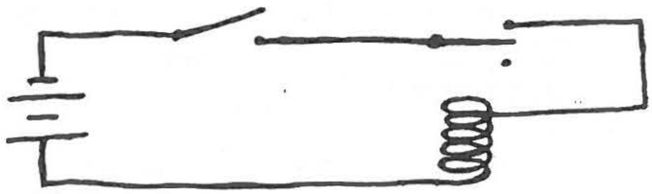
This sentence is false.

2. The Diamond System

This sentence is false.

Is it true or false? If it's one, then it's the other; it can't be either, so what is it?

The usual theory gives no answer, so let's resort to experiment. Consider the following electrical circuit:



When the switch is closed, the relay is in a paradox; whenever current flows in it, it pulls down the relay arm, shutting off its own power; and when current stops in it, the relay arm goes up again, starting the current flowing again. The relay can stay neither ON nor OFF.

Close the switch. Then listen; your apparatus will buzz. The relay arm vibrates. Since the relay cannot decide between ON and OFF, it oscillates between the two.

If relays can vibrate, why not sentences? Suppose sentence A obeys the paradox equation:

A = not A.

Our little buzzer suggests that A oscillates:

A = ...true/false/true/false/.........

The equation A = not A can be solved if "not" is a combination of 1) exchanging "true" and "false", and 2) a unit delay:

A = .../true/false/true/false/........

not A = .../false/true/false/true/...

In other words, negation takes a moment to occur.

In Diamond, there are four truth values:

...tttt... : call this "t/t", or t.
...tftf... : call this "t/f", or i.
...ftft... : call this "f/t", or j.
...ffff... : call this "f/f", or f.

t/t

t/f   f/t

f/f

"/" is pronounced "but"; i is "true but false". Negation has a unit shift, so the equation is;

not (a/b) = (not b) / (not a)

With this "twist" in negation, both i and j solve the paradox equation;

not(i) = not(t/f) = (not f)/(not t)
= t/f = i
not(j) = not(f/t) = (not t)/(not f)
= f/t = j.

Meanwhile, what of "and" and "or"? In ordinary logic, they don't cause the paradoxes that "not" does, so we might as well proceed conservatively. Let them operate on each side separately:

(a/b) and (c/d) = (a and c) / (b and d)
(a/b) or (c/d) = (a or c) / (b or d).

From "and", "or", and "not" we can build other logical functions; these are called the "harmonic" functions. For instance there are "if → then", "if and only if", "or else", and "but".

if A then B	=	(not A) or B
A if and only if B	=	(if A then B) and (if B then A)
A or else B	=	A if and only if (not B)
A but B	=	(A and i) or (B and j).

With these definitions, "and", "or", and "not" act as they normally do on the values "t" and "f". The mixed values "i" and "j" are complementary paradoxes: they equal their own negations; "i and j" equals false, and "i or j" equals true. We lose the law of the excluded middle:

i or not i = i or i = i
j or not j = j or j = j,

neither of which equal "true". Although they are complementary, i and j imply each other:

i if and only if j
= ((not i) or j) and ((not j) or i)
= (i or j) and (j and i)
= true.

Stranger still:

(i or not i) and (j or not j)
= i and j
= false.

This, then, is the Diamond system. Now on to its most important theorem; Self-Reference.

3. Productio Ex Absurbo

Diamond is a logic of self-reference and inter-reference. In it, sentences can talk about each other in networks of any degree of complexity. Such a network is called a system. For instance, the liar paradox

"This sentence is false."

is a system with one sentence. It obeys the equation

A = not A.

The sentences

"The following sentence is false."
"The preceding sentence is false."

form a system whose equations are

B = not C
C = not B.

In general, any system obeys a set of equations of the form

s1 = F1(s1, s2, s3, ..., sn)
s2 = F2(s1, s2, s3, ..., sn)
s3 = F3(s1, s2, s3, ..., sn)
....
sn = Fn(s1, s2, s3, ..., sn)

where F1, F2,....Fn are harmonic. We can abbreviate these equations as

$\underline{s} = \underline{F}(\underline{s})$

where $\underline{s}$ is the sequence of sentences (s1, s2, ... sn), and $\underline{F}$ is the sequence of functions (F1, F2, ... Fn).

A fixedpoint for a system $\underline{s} = \underline{F}(\underline{s})$ is a sequence of truth values $\underline{v}$ = (v1, v2, v3, is called a "fixedpoint" because it's left fixed, unchanged, by the functions $\underline{F}$.

A given system may have many fixedpoints. The system

A = not A

has two fixedpoints:

A = i; A = j.

The system

B = not C
C = not B

has four fixedpoints:

(B,C) = (t,f); (f,t); (i,i); (j,j).

Those two systems have fixedpoints, but what about in general? This question is answered by the Self-Reference Theorem.

The Self-Reference Theorem says that if $\underline{F}$ is harmonic, then the system $\underline{s} = \underline{F}(\underline{s})$ will have a fixedpoint. More than that, it tells how to find such a fixedpoint.

The method, called "productio ex absurbo", is as follows:

1) Start by giving all the sentences the "default value" i;

2) Plug these values into the equation to get new values;

3) Repeat step 2 til the values stop changing.

If the functions are all harmonic, the values will eventually stop changing, and you will have a fixedpoint.

Incidentally, a default value of j will also work. This method is called "productio ex absurbo" because it produces the fixedpoint by iteration from a paradox - that is, an absurdity.

To see productio ex absurbo in action, consider this system:

Alan:	"The key is in the drawer."
Bob:	"If I'm right, then Alan is right."
Carl:	"Alan is right or wrong."
Dan:	"Alan is right, but Carl is right."
Eli:	"Carl is right, but Alan is right."
Fred:	"Dan is right or wrong."
Gary:	"Eli is right or wrong."
Harry:	"Fred and Gary are both right."

If two-valued logic were controlling this situation, then Bob's gremlinish statement would make Alan right; and everybody else would be right too. However, when you look in the drawer, the key isn't there.

The equations are:

A = false
B = if B then A
C = A or not A
D = A but C
E = C but A
F = D or not D
G = E or not E
H = F and G

To solve these equations, first give all the sentences the default value i:

(A,B,C,D,E,F,G,H) = (i,i,i,i,i,i,i,i)

Then plug these values into the right-hand side of the equations to get a new set of values for the sentences:

(A,B,C,D,E,F,G,H) = (f,i,i,i,i,i,i,i)

Plug these values in again:

(A,B,C,D,E,F,G,H) = (f,i,t,f,i,i,i,i)

Again:

(A,B,C,D,E,F,G,H) = (f,i,t,j,i,t,i,i)

Again:

(A,B,C,D,E,F,G,H) = (f,i,t,j,i,j,i,i)

Again:

(A,B,C,D,E,F,G,H) = (f,i,t,j,i,j,i,f)

Again:

(A,B,C,D,E,F,G,H) = (f,i,t,j,i,j,i,f)

The values have stopped changing; we have reached a fixedpoint.

Notice how the values acted during this process. Starting from i, the "leftmost" value in the diamond, the values drifted rightward until they could move no furthur. If we had started from default j, the values would have drifted leftwards until stopping at (f,$\underline{J}$,t,j,i,j,i,f).

Some general comments:

"This sentence is false"; when this paradox appears, Aristotelian logic ends and diamond logic begins. Analytic logic operates by "reductio ad absurdum": reduction to the absurd. Reductio ad absurdum collapses any self-contradictory systems. Diamond logic operates by the reverse process: productio ex absurbo, or production from the absurd. Self-contradiction is the basis of its systems.

Yes, paradox is absurd. It is self-contradiction; literally nonsense. To the Aristotelian, this discredits it, but the diamond logician sees that some nonsense is inevitable and necessary when creating sense. Paradox is empty, information-free; it's a way to say nothing when nothing is all you can say. Paradox is vague, without meaning, and for that very reason does not interfere with meanings. It's the vacuum which contains substance, the chaos which creates order.

4. Using Diamond

With productio ex absurbo and the self-reference theorem, the classic paradoxes are no longer a problem; they can be resolved. Here are some examples.

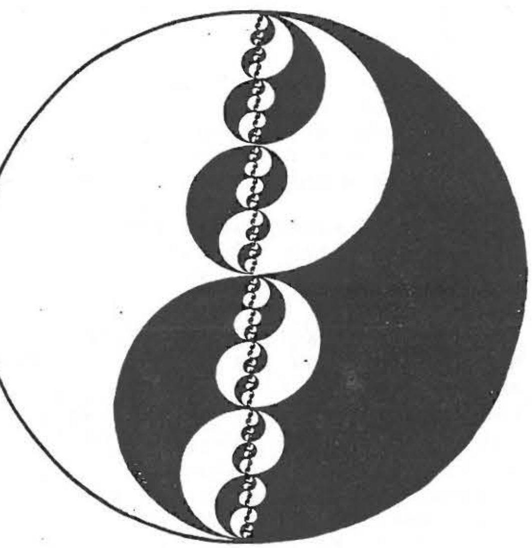
The Liar. "This sentence is false" can be true but false. Or, it can be false but true; either way works. (This uncertainty is appropriate, considering paradox's vague nature.) Epimenides wasn't entirely honest, but he wasn't entirely dishonest either; he told a half-truth, half-lie. He said nothing, and he said it.

The Barber. Francisco was so impressed by Pablo's sharp thinking that he offered Pablo half-partnership in the firm. Now they boast that together, as a team, they shave every man in the village who does not shave himself. As for themselves, Francisco shaves Pablo and Pablo shaves Francisco.

Grelling's Paradox. Is "heterological" heterological? Any answer to that question must be false, including this one. Yes but no. Or, if you prefer, no but yes.

"Is false when quined" is false when quined. That sentence is but isn't true. Or it isn't but is.

Russell's Paradox. In diamond set theory, the Complete Comprehension axiom applies; any property is a set, without restriction. Russell's set R of all sets which do not contain themselves is no problem; it contains itself but it doesn't. (Or vice versa.)



Antistrephon. In the next few paragraphs I take the role of judge and address the shades of Protagoras and Euathius.

Gentlemen, you have given me a dilemma. If Euathius is to win this case, he must show that he has no obligation under the contract; but the contract says that he need not pay just if he loses his first case - which is this one. He wins if he loses and he loses if he wins; the same goes for Protagoras. If I find for Protagoras, then the judgement should have gone for Euathius; if I find for Euathius, then the judgement should have gone for Protagoras. You wish me to declare sentence, but any sentence I declare would be an incorrect sentence, a false sentence. Therefore I declare:

This sentence is false.

Paradox, or half-truth. By the nature of this case, I can only be half-right; I can only half-satisfy you. I should take a position midway between yours, favoring neither side. Compromise is called for.

I reformulate this case. I say that it is actually two cases being simultaneously decided. The first case is about the second half of the fee, to be won only if the second case is lost; and the second case is about the first half of the fee, to be won only if the first case is lost.

This is a formal, artificial division of the original case which would make no difference if the original case had an inequivocal solution. But equivocation is necessary, and it works; for it is consistent for Protagoras to win the first case and Euathius to win the second. When these two cases are recombined, we see that Protagoras can claim half the fee, having won but lost, and Euathius can keep the other half, having lost but won.

One final legal note; in this case, as is usual, Protagoras won or else Euathius won. What is unusual about this case is that it's also true that Protagoras won if and only if Euathius won!

Berry's Paradox. Is 111,777 "the least number not nameable in fewer than nineteen syllables"? Assuming that it has no other short names, then it is that number, but it isn't. (Or vice versa.) The name only partly applies.

By the same token, the smallest uninteresting number is only vaguely interesting.

Richard's Paradox. Is c in C? Yes but no; or no but yes.

In two-valued set theory, Cantor produced a paradox like Richard's; he concluded that the subsets of the integers are "uncountable"; that they form a set of "greater size" than the set of integers. I consider Cantor's Theorem to be an example of the gremlin process, and just as dubious. How can one infinity be bigger than another? In diamond set theory, the subsets of the integers can be counted, at the price of paradox.

Gremlins. "If this sentence is true, then there are gremlins." One can, of course, believe in gremlins; otherwise, one can let "there are gremlins" be false, and "if this is true, then there are gremlins" be true but false. Or false but true. With paradox, you can eliminate gremlins - unless, of course, you think that paradox is a kind of gremlin.

People often unconsciously use gremlin sentences in ordinary life; "the key's in the drawer, if I'm not mistaken." If you say that, look in the drawer, and find no key, then it's best to admit to yourself, "I am mistaken." This indicates uncertainty, a change of mind, and (taken literally) is a paradox.

5. Paradox And The Continuum

Although I welcomed the above applications of Diamond, they did not surprise me; in fact, I started to investigate it with those in mind. It did surprise me, though, when it turned out that Diamond also applies to another entirely different subject - namely, the continuous real line (here, called R.)

Diamond and two-valued logic, in addition to being logics, are also "topological spaces"; that is, they have "topologies." A topology is a way to distinguish between continuous and discontinuous functions. Roughly speaking, a transformation is continuous if it never sends points that are "near" each other (as determined by the topology) to points that are far apart. In two-valued logic, the two values are completely separate and distinct; they are already far apart, so you can send them anywhere you wish without discontinuity; so in two-logic, all functions are continuous. In Diamond, the continuous functions are just the harmonic functions.

Because two-logic is a totally disconnected space, this makes it very different from R, which is a connected space. Any function from R to two-logic is either constant or it changes discontinuously. Two-logic allows only abrupt change; it must always miss the smoothness of the real line.

Like R, and unlike two-logic, Diamond is a connected space. The paradoxes allow smooth change from true to false. For instance, the following function is continuous:

```
t                     ------------------------

i                    *

f-------------------

                     0
```

In this application, paradox means boundary.

In standard math, a real number is identified with an infinite sequence of 1's and 0's - that is, with an infinite sequence of trues and falses. The topological space of such sequences (called 2^{ω}) is totally disconnected and therefore has 2-logic's problems with smooth transitions at boundaries. For instance, the number 1/2 has two representations in infinite binaries; as .1000000.... and as .0111111...

This trouble is avoided in the space of infinite sequences of diamond values. This space is called diamond$^{\omega}$, or D. R and D are very closely related; in particular, the following theorems apply:

1) R "embeds" in D.
2) In this embedding, any continuous function from R to diamond extends to a harmonic function from D to diamond.
3) In this embedding, any continuous function from R to R extends to a harmonic function from D to D.

The first theorem means that R, with its topology, can be put inside D, with its topology:

```
                               *
|                          *   |   *
|                       *      |      *
|     --------->     *         |         *
|                       *      |      *
|                          *   |   *
                               *
```

The second theorem means that any (diamond-valued) continuous property of real numbers is also a continuous property of points in the larger space D.

```
                               *
|                          *   |   *
|                       *      |      *
|     --------->     *         |         *
|                       *      |      *
|                          *   |   *
                               *

|                              |
|                              |
|                              |
|                              |
V                              V

*                              *
* *                           * *
*                              *
```

In this diagram, the horizontal arrow is the embedding and the vertical arrows are the continuous properties; if you start from the line and go down, you get to the same place as if you had gone right and then down.

The third theorem says that any continuous mapping of R into itself extends to a continuous mapping of the larger space D into itself:

```
                               *
     |                      *  |  *
     |                   *  +  |     *
     |    --------->   *       |        *
     |                   *     |  +  *
     |                      *  |  *
                               *

     |                         |
     |                         |
     |                         |
     |                         |
     V                         V

                               *
     |                      *  |  *
     |                   *  +  |     *
     |    --------->   *       |        *
     |                   *     |  +  *
     |                      *  |  *
                               *
```

Here, the horizontal arrows are the embeddings and the vertical arrows are the continuous mappings; if you start from the line (in the upper left hand corner) and go down and then right, you get to the same place as if you had gone right and then down.

If you combine the third theorem with the Self-Reference theorem, you get the following:

4) Any continuous function from R to R has a fixedpoint in D.

In the above diagram, each + indicates a fixedpoint.

So, according to these three theorems, the topology, continuous properties, and transformations of R all extend to D, diamond space. It seems that R, the continuous real line, is essentially paradoxical.

No discussion of paradox is complete without mentioning Zeno's paradoxes of motion. In Zeno's "Arrow" paradox, he says that an arrow is at rest in its position at any given instant; therefore it is at rest. To understand this cryptic statement, imagine taking a flash photo of the arrow in midflight. The resulting picture is supposed to "freeze" the motion, and indeed if the flash is quick enough, the arrow's picture comes out sharp, clear - almost indistinguishable from a photo of a motionless arrow.

Almost indistinguishable - but not quite. If we examine the photo through a magnifying glass, we will see a bit of blur. No camera flash is infinitely fast; some amount of vagueness, uncertainty, and ambiguity is inevitable, so long as the arrow is in motion.

Vagueness, uncertainty, and ambiguity are characteristic of paradox. Zeno's error was in assuming that arrows have definite positions, specifiable in a true-or-false manner to infinite precision. He assumed that there is no vagueness; he concluded that there is no motion either. We who move must deny the conclusion; therefore we must also deny the assumption.

For continuous change to exist, confusion must also exist. Life, unlike logic, is full of continuous change; maybe that's why life is confusing.

6. Open Questions

Diamond, a theory of open reasoning, is itself still open. This section is about some of its possible future applications. Naturally, these ideas are vague; I only have the intuition that Diamond will apply to these topics. Feel free to speculate about these yourself.

Diamond Computation

Every logic should have its own theory of computation. Diamond's contribution, once it is defined, should be threefold; 1) by allowing machines to begin from a state of genuine vagueness - that is, ignorance - where even distinctions have not yet been discovered, these machines should find it easier than two-valued machines to dispense with axioms and other forms of prejudice; 2) by allowing these machines to interact in a network, rather than in a linear hierarchy, diamond computation should be better suited than two-valued computation for parallel processing; and 3) by allowing those machines to stably self-refer, diamond computation should bypass certain limits to computation related to Godel's Incompleteness Theorem.

About Godel's Theorem: it results from constructing, in the language of number theory, a sentence which can be read:

"'Is unprovable when quined,' is unprovable when quined."

or in other words

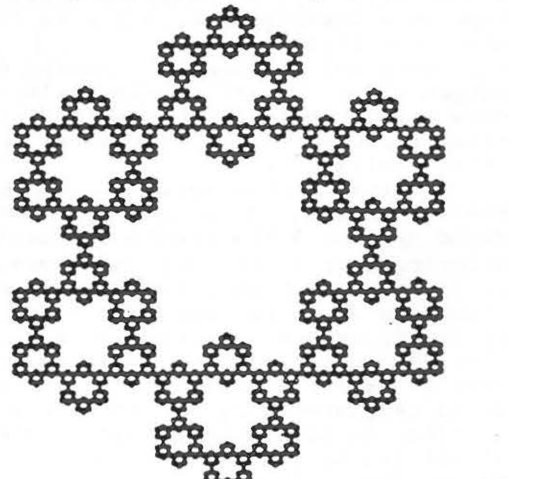
"This sentence is unprovable."

Godel points out that if proof equals truth, then that sentence is paradoxical; to preserve the law of the excluded middle, he concludes that proof does not equal truth.

In Diamond, though, proof can equal truth; then Godel's sentence becomes a genuine paradox - in fact, what we construct the fixedpoint out of. It seems, then, that Godelian limitations do not apply in Diamond.

One reason for this is that the limitations are built in from the beginning. Diamond logic is weaker than two-logic; without the law of the excluded middle, it can deduce fewer theorems. Maybe what it does should not be called "proof" but "construction".

To create a Diamond theory of computation, it's enough to create a Diamond theory of the integers. The question, then, is what are paradoxical integers?



Games

In any competitive game, each side wins if it can prove that the other side loses; they can't both be right; therefore, in any game, logic is pitted against itself. This is a situation ripe for paradox. And indeed, games have all the usual qualities of paradox; unpredictability, oscillation, negative feedback, and vagueness.

What, then, would be a Diamond theory of games?

The Unexpected Exam Paradox

In this logical puzzle, a teacher tells her class that there will be an exam on Monday, Tuesday, Wednesday, Thursday, or Friday, but they will not expect it. The students reply that then there cannot be any exam at all. Their reasoning is as follows; the exam cannot be on Friday because by then they will know that it didn't happen from Monday to Thursday, and therefore they would be expecting it. Therefore, if the exam is to be unexpected, then it would have to be on Thursday at the latest; but then by similar reasoning Thursday is also ruled out; and so on, eliminating Wednesday, Tuesday, and Monday. The exam, if it is to be unexpected, cannot take place. The teacher says nothing; but when she gives the exam the next Tuesday, her class is taken by surprize. What was wrong with their reasoning?

I think that they erred by trying to derive too precise conclusions from an inherently paradoxical assumption. They were trying to predict what will happen on the basis of the teacher's announcement, which was that they cannot predict what will happen.

If I were in her class, I would announce on Monday, "I expect the exam today." If it isn't given that day, then I'll make the same announcement on Tuesday; and so on until Friday. Obviously I am using the word "expect" rather differently from the other students; they use it analytically, which is falsified when shown to be wrong once, whereas I'm willing to be wrong several times, so long as I'm eventually right. I also use the word "today", which means a different day on different days. In short, my announcement is a vague one; this is in keeping with the vagueness of the teacher's announcement. It is also in accord with the teacher's obvious wish, which is that I be alert all five days.

Note one paradoxical quality of my vague announcement; the more often it's wrong, the more likely that it will be right the next time. Paradox, unlike precision, thrives on being contradicted.

If the teacher were willing to risk making her original announcement false, she could guarantee the exam's unexpectedness by flipping a coin each day and giving the exam if it comes up heads. There would be only 1 chance in 32 of no exam, and the exam would be truely unexpected. Or, she could dispense with the coin-flip on Friday if there had been no exam til then. In that case, the exam would be guaranteed, and there would be only 1 chance in 32 of its being expected. In this situation, paradox is resolved by letting it become random chance.

This is my informal analysis and solution of this paradox. What would be a formal solution?

Dilemma

Dilemma (usually known as Prisoner's Dilemma) is a non-zero-sum game with a payoff matrix like this:

(A's, B's) payoffs:		B for	B against
A	for	(1,1)	(-2,2)
A	against	(2,-2)	(-1,-1)

The "dilemma" comes from the fact that strong arguments can be made for playing either way. The "analytic" line of reasoning says that no matter what B plays, A gains one more point (or loses one less point) by playing "against". The "harmonic" line of reasoning says that B will reason the same way as A, and will come to the same conclusion as A; therefore if they are to benefit, they must both play "for".

The harmonic player does well when playing with another harmonic player, but the analytic player does poorly when confronting another analytic player; therefore harmonic play can be said to be superior; unfortuately, the analytic player is able to exploit the harmonic player.

If any line of reasoning leads to the conclusion that it's best to play "against", then that line of thought fails when two players both use it, and consequently both lose 1. On the other hand, if logic lead to the conclusion that playing "for" is superior, then a logical player could be exploited by a less logical player. In either case, it seems that any definite conclusion about Dilemma is flawed, precisely on account of being definite. There seems to be a paradox here. Note also the self-referentiality of the "narmonic" line of play, plus the fact that harmony does better than analysis when playing <u>itself</u>.

What does Diamond, with its built-in vague self-reference, have to say about Dilemma?

7. Conclusion

In this article I use a "solution in search of a problem" - multivalued logic - to discuss a "problem in search of a solution" - the logical paradoxes. The solution and the problem fit together nicely. Diamond has room for vagueness and equivocation, but seemingly no need for it; paradox needs vagueness but cannot find it in the context of the usual logic. The mixed values i and j serve as consistent solutions for the self-negating sentences; more than that, they serve as stable default values for any sentence whose value has not yet been determined. Rather than being a source of instability, breakdown and incompleteness, the paradoxes can be used as a <u>form</u> of stability and as a <u>source</u> of completeness.

There is a price to be paid for this; that is the failure of the law of the excluded middle. This is appropriate; for the law of the excluded middle is the claim that the subject under discussion is completely precise. The point of the paradoxes is to deliberately leave some areas vague; this is useful because there are some questions we are not yet sure about and others which are by definition vague. To insist on precision is to insist on partial vision.

This system can be applied to the traditional and modern logical paradoxes. By accepting paradox as it is, we can drop the need for type theory or other artificial limitations.

Paradox makes self-reference possible. It also makes continuous change possible. With the embedding of R in D and the extension of real continuous functions to all of D, we see that continuity is essentially paradoxical.

Diamond is a system for tolerating paradox, and I say that paradox is real. In both continuous and discrete math, it has its effect; any attempt to avoid or suppress it only makes those effects more obtrusive; whereas making an explicit place for it defuses it. In appropriately paradoxical fashion, paradox is less of a genuine problem the more you acknowledge that it is a genuine problem. I suggest that mathematics get rid of it by accepting it.

Paradox is a central topic of logic; perhaps the central topic. I therefore end this article as I began it, with the thing itself:

This sentence is false.

8. Technical Appendix

Truth functions and truth tables

	not	and t	and f	and i	and j	or t	or f	or i	or j
t	f	t	f	i	j	t	t	t	t
f	t	f	f	f	f	t	f	i	j
i	i	i	f	i	f	t	i	i	t
j	j	j	f	f	j	t	j	t	j

	but t	but f	but i	but j	if-then t	if-then f	if-then i	if-then j
t	t	i	i	t	t	f	i	j
f	j	f	f	j	t	t	t	t
i	t	i	i	t	t	i	i	t
j	j	f	f	j	t	j	t	j

	if and only if t	if and only if f	if and only if i	if and only if j	or else t	or else f	or else i	or else j
t	t	f	i	j	f	t	i	j
f	f	t	i	j	t	f	i	j
i	i	i	i	t	i	i	i	t
j	j	j	t	j	j	j	t	j

Note that (a/b)/(c/d) = (a/d).

With "but" we can define various "hybrid" operators:

And/or. a and/or b = (a and b)/(a or b).
Or/and. a or/and b = (a or b)/(a and b).
Lambda. lambda a = a / (not a).
Rho. rho a = (not a) / a .

	lambda	rho	and/or t	and/or f	and/or i	and/or j	or/and t	or/and f	or/and i	or/and j
t	i	j	t	j	t	j	t	i	i	t
f	j	i	j	f	f	j	i	f	i	f
i	i	i	t	f	i	j	i	i	i	i
j	j	j	j	j	j	j	t	f	i	j

(a and/or i) = a and (a and/or j) = j; i and j have the same roles in "and/or" that t and f have in "and". In a sense, and/or is "and" sideways; or/and is "and" sideways, the other way. I call "or/and" and "and/or" respectively the "i-attracted" and "j-attracted" connectives.

One connective worth mentioning at this point is the "majority operator" M:

M(a,b,c) = (a and b) or (a and c) or (b and c).

M is true on the left exactly if a majority of its three arguments are true on the left; the same applies on the right. Therefore M(a,t,b) = (a or b) ; M(a,f,b) = (a and b) ; M(a,i,b) = (a or/and b) ; M(a,j,b) = (a and/or b).

(if i then j) = (i if and only if j) = (i or else j) = t; clearly we no longer have that (a if and only if b) = not (a or else b) = (a equals b). In fact, to define true equality, we have to leave the system of functions defined from "and", "or", "but", and "not"; we must re-introduce connectives like those from two-valued logic. The basic one is termwise negation, or "non":

non t = f; non f = t
non(a/b) = (non a)/(non b).

non	t	f	i	j
	f	t	j	i

(not a) = (non a) for a = t or f.

(a or non a) = t for all a; non obeys the law of the excluded middle.

There is no solution to a = non a.

Diamond has two kinds of truth functions; "harmonic" and "analytic". The harmonic functions are those which can be defined from "and", "or", "not", and "but" alone; the analytic functions are those which need "non" to be defined. Here are some analytic functions:

*a = not non a = "star a"
= "the reflection of a"
La = a/(*a) = "the left side of a"
Ra = (*a)/a = "the right side of a"
(a implies b) = (non a) or b
(a=b) = (a implies b) and (b implies a).

	*	L	R	implies t	implies f	implies i	implies j	= t	= f	= i	= j
t	t	t	t	t	f	i	j	t	f	i	j
f	f	f	f	t	t	t	t	f	t	j	i
i	j	t	f	t	j	t	j	i	j	t	f
j	i	f	t	t	i	i	t	j	i	f	t

Equational laws

Diamond, as a logical algebra, is a cross between a boolean algebra and a de morgan algebra. Not is a de morgan negation and non is a boolean negation; the first allows paradox and the second obeys the law of the excluded middle.

Here are Diamond's equational laws:

```
associativity:
    (a and b) and c   =  a and (b and c)
    (a or b) or c    =   a or (b or c)
commutativity:
    a and b  =  b and a
    a or b  =  b or a
dominance:
    a and t  =  a    ;   a and f  =  f
    a or t  =  t     ;   a or f  =  a
distributivity:
    a and (b or c)  =  (a and b) or (a and c)
    a or (b and c)  =  (a or b) and (a or c)
double negation:
    not not a   =   a
    non non a   =   a
commuting negations:
    not non a   =   non not a
de morgan:
    not(a or b)    =  (not a) and (not b)
    not(a and b)   =  (not a) or (not b)
    non(a or b)    =  (non a) and (non b)
    non(a and b)   =  (non a) or  (non b)
excluded middle:
    a or non a    =   t
paradox:
    not i  =  i
    not j  =  j
```

Order And Topology

The "order", or "leftness/rightness", relation is of great importance in understanding diamond. Here is its definition:

a<b ("a is to the left of b" or "b is to the right of a") is true if

```
            a=i and b=i    or
            a=i and b=t    or
            a=i and b=f    or
            a=i and b=j    or
            a=t and b=t    or
            a=t and b=j    or
            a=f and b=f    or
            a=f and b=j    or
            a=j and b=j.
```

```
                t

           <         <

      i         <         j

           <         <

                f
```

a<b if a is at least as true on the left as is b, and b is at least as true on the right as is a; to put it another way, a<b if (a or/and b) = a.

Note that La = (a<t), Ra = (t<a), -La = (f<a), -Ra = (a<f). The order relation tells us about a truth value's "sides".

The importance of order arises from the following fact:

```
If
a<c and b<d
then
(a and b)  <  (c and d)
 (a or b)  <  (c or d)
  (not a)  <  (not c).
```

In other words, "and", "or", and "not" preserve order. "Non" doesn't; in fact, it reverses order. In general, harmonic functions preserve order and analytic functions do not.

With the order relation, you can define two topologies on diamond:

the "left topology", whose open sets are
{-}, {i}, {i,t}, {i,f}, {i,t,f}, {i,t,f,j}

and the "right topology", whose open sets are
{-}, {j}, {j,t}, {j,f}, {j,t,f}, {j,t,f,i}

In the left topology, an open set is one which contains every value to the left of an element; in the right topology, an open set is one which contains every value to the right of an element. The open sets of one topology are the closed sets of the other topology.

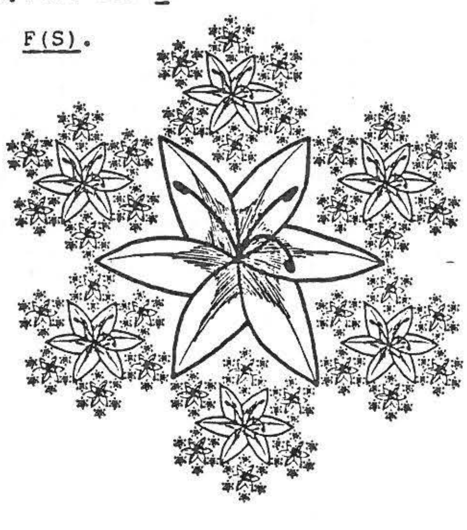
When Diamond has either of these topologies, the continuous functions are the ones which preserve order. This means that the harmonic functions (such as "or" and "not") are continuous, and the analytic functions (such as "non") are discontinuous.

A Proof Of The Self-Reference Theorem

* The Self-Reference Theorem *

If F is a sequence of n harmonic functions from diamond^n to diamond, then there is a sequence of n truth values S which is a fixedpoint for F:

S = F(S).



Proof

We are given $\underline{F}$, which is from n copies of diamond to n copies of diamond.

Let $\underline{i}$ be a sequence of n of the truth value i. Now

$\underline{i} < \underline{F(i)}$ (termwise)

because $\underline{i}$ < any truth value.

$\underline{F}$ is harmonic; harmonic functions preserve order, so

$\underline{F(i)} < \underline{F(F(i))}$

Applying $\underline{F}$ again, we get

$\underline{F(F(i))} < \underline{F(F(F(i)))}$

and so on:

$\underline{i} < \underline{F(i)} < \underline{F(F(i))} < \underline{F(F(F(i)))} \ldots$

In diamond, a truth value can only move two times strictly rightwards from i before fetching up against the value j, so one can move strictly rightwards only 2n times from $\underline{i}$ before reaching $\underline{j}$ and being obliged to stop. Therefore the above inequalities become equalities by F to the 2nth:

$$\underline{F}^{2n}(\underline{i}) = \underline{F}(\underline{F}^{2n}(\underline{i}))$$

Therefore there is a fixedpoint for $\underline{F}$; namely, $\underline{F}^{2n}(\underline{i})$. QED.

Comments.

$\underline{F}^{2n}(\underline{J})$ is also a fixedpoint. These two fixedpoints are the leftmost and rightmost fixedpoints; for any fixedpoint $\underline{S}$ of $\underline{F}$,

$$\underline{F}^{2n}(\underline{i}) < \underline{S} < \underline{F}^{2n}(\underline{J}).$$

In particular, if the two are equal, then they must equal any other fixedpoint.

-P.S.: I've discovered a new, elegant proof of the self-reference theorem. It's somewhat more sophisticated than the one given above, but more general. I've also discovered that the fixedpoints for a function form a distributive lattice. First, some definitions:

$$\boxed{\begin{aligned} \underline{a \times b} &\triangleq a \vee/\wedge\, b = (a\vee b)/(a\wedge b) \\ \underline{a + b} &\triangleq a \wedge/\vee\, b = (a\wedge b)/(a\vee b). \end{aligned}}$$

× and + are lattice operations: they distribute over each other. Also:

$$\boxed{\begin{aligned} &\sim(a\times b) = (\sim a)\times(\sim b) \\ &c\wedge(a\times b) = (c\wedge a)\times(c\wedge b) \\ &\text{and ditto with } +. \end{aligned}}$$

proof is by the definitions and formal work.

Therefore:

$$\boxed{\begin{aligned} &\text{If } F \text{ is a harmonic function} \\ &\text{then} \quad F(a+b) = Fa + Fb \\ &\qquad\quad\; F(a\times b) = Fa \times Fb. \end{aligned}}$$

Definitions. The left and right limits of a sequence a_n are:

$$\ell\text{-}\lim a_n = \Sigma_{N>0} \Pi_{n>N}\, a_n$$
$$r\text{-}\lim a_n = \Pi_{N>0} \Sigma_{n>N}\, a_n.$$

ℓ-lim and r-lim are like lim inf & lim sup.

Lemmas:

$$\boxed{\begin{aligned} \ell\text{-}\lim a_n &= \ell\text{-}\lim a_{n+1} \\ r\text{-}\lim a_n &= r\text{-}\lim a_{n+1} \end{aligned}}$$

by the definitions and formal work.

$$\boxed{\begin{aligned} &\text{If } F \text{ is harmonic,} \\ &\text{then} \quad F(\ell\text{-}\lim a_n) = \ell\text{-}\lim F(a_n) \\ &\qquad\quad\; F(r\text{-}\lim a_n) = r\text{-}\lim F(a_n). \end{aligned}}$$

because F commutes with + and ×.

Self-Reference Theorem
new proof

Given ANY initial values $\vec{a}_0$,

let
$$\boxed{\begin{aligned} \vec{a}_L &= \ell\text{-}\lim \vec{F}^n \vec{a}_0 \\ \vec{a}_R &= r\text{-}\lim \vec{F}^n \vec{a}_0. \end{aligned}}$$

Then
$$\boxed{\begin{aligned} \vec{F}\vec{a}_L &= \vec{F}\,\ell\text{-}\lim \vec{F}^n \vec{a}_0 \\ &= \ell\text{-}\lim \vec{F}^{n+1} \vec{a}_0 \\ &= \ell\text{-}\lim \vec{F}^n \vec{a}_0 \\ &= \vec{a}_L \end{aligned}}$$

and similarly, $\boxed{\vec{F}\vec{a}_R = \vec{a}_R.}$

All fixedpoints for $\vec{F}$ can be found this way, not just leftmost and rightmost.

Finally: **Fixedpoint Lattice Theorem:** if $\vec{a}$ and $\vec{b}$ are fixed by $\vec{F}$ then so are $\vec{a}+\vec{b}$ and $\vec{a}\times\vec{b}$.

proof:

$$\vec{F}(\vec{a}\times\vec{b}) = \vec{F}\vec{a}\times\vec{F}\vec{b} = \vec{a}\times\vec{b}$$
$$\vec{F}(\vec{a}+\vec{b}) = \vec{F}\vec{a}+\vec{F}\vec{b} = \vec{a}+\vec{b}.$$

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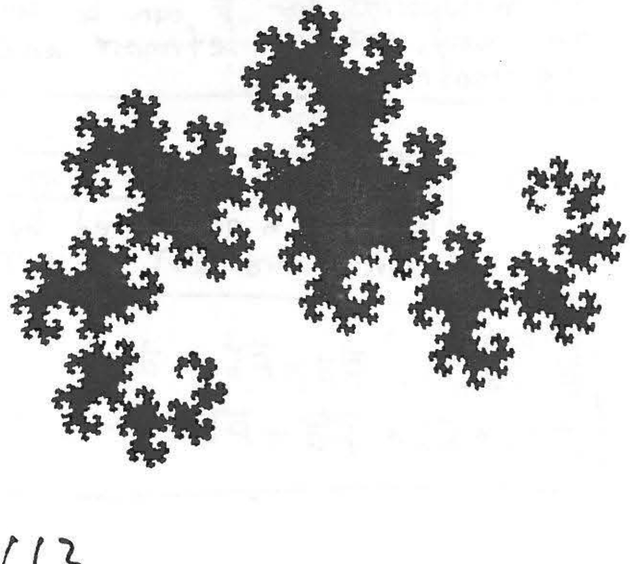
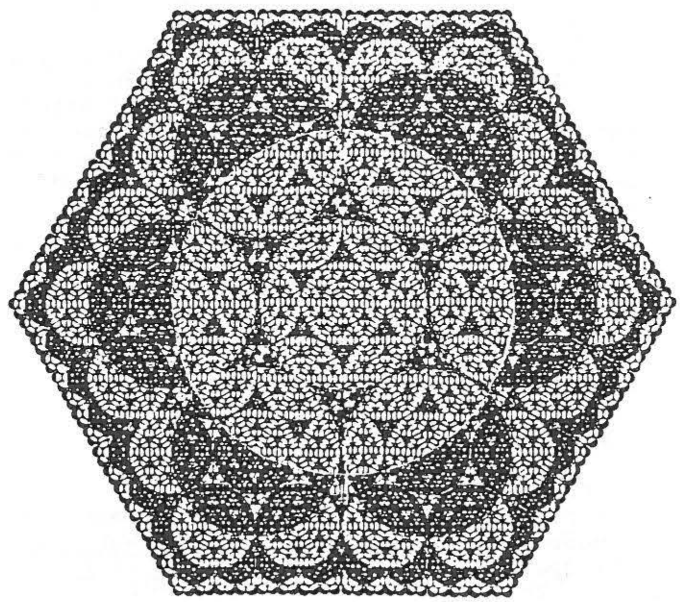
10. Afterword: Fractals

Fractals are self-contained forms, shapes which are made out of themselves. They are pictures of self-reference and paradox. I made these fractals by using a reduction xerox machine. Starting with a simple design only a few stages deep, I reduce it, cut and paste it into a design a stage deeper, reduce that design, and so on; the details become smaller and more numerous until finally they become too small for the machine to see.



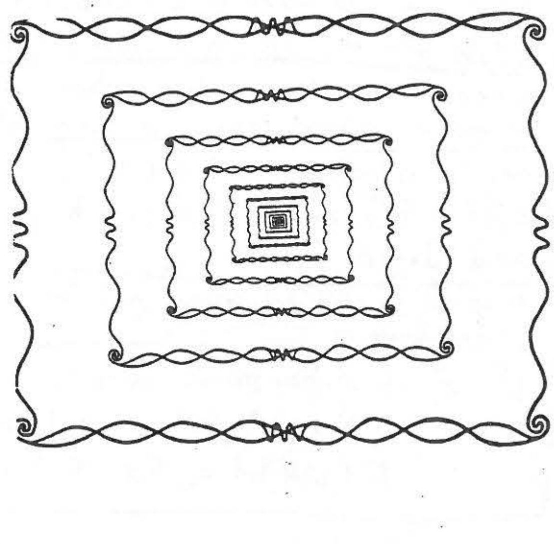
Limericks

There was once an old poet from Crete
Who performed a remarkable feat.
He announced to the wise
"Every Cretan tells lies"
Thus ensuring their logic's defeat.



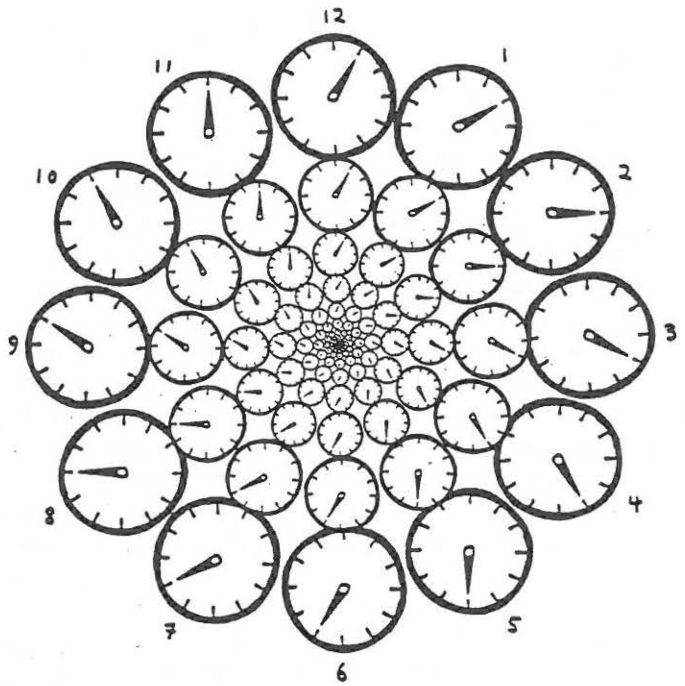
"What I'm telling you now isn't true."
Tell me, what's a logician to do?
For it's wrong and it's right
And it's black and it's white
This confusion is making me blue.

Bertrand Russell once dolefully thought
"Is set N in itself? Is it not?
If it's in, then it's out
If it's out, then no doubt
It is in. What on earth have I got?"



Mr. Godel, with ill-disguised glee
One day wrote down a sentence named G.
It said, "G has no proof"
And if proof equals truth
It makes truth equal falsity. See?

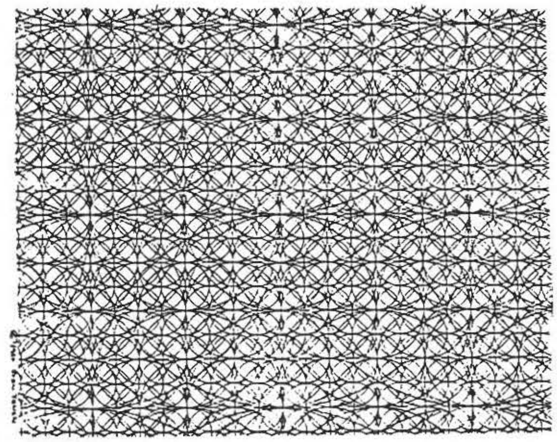
Said Zeno to archer, "A quiz.
Your arrow is moving? It is,
In its flight to the west,
Every instant at rest
So when is it moving?" "Gee whiz!"



An electron confessed to the fact
That its nature was not too exact.
"I'm a particle, yes
That is true, more or less
But I frequently like to diffract."

There was once an unfortunate ass
Who had stopped between two heaps of grass
At the midpoint. It tried
But it couldn't decide
Which was closer. It starved there, alas.

Doc Strangelove once angrily fumed
"These peaceniks have falsely assumed!
For we're safe if we're gambling
And safer if scrambling
And safest if certainly doomed!"



Said a monk to a man named Joshu
"Is that dog really god?" He said, "Mu."
This answer is vexing
And highly perplexing
And that was the best he could do.

The Logical Self Does Not Exist

This morning's scientific laws
By evening will develop flaws
Our models must admit defeat
Consistency is not complete
Our minds cannot unspin this twist
The logical self does not exist

From far to near, I search for me
So close and clear, so hard to see
Exact description can't be got
For I am I, but I am not
The central point is always missed
The logical self does not exist

Of what will be no one can say
But change will happen anyway
The tricks of time we can't avoid
We all must flow or be destroyed
Unending ending will persist
The logical self does not exist

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The Organ of Form
Towards a Theory of Biological Shape

Francisco J. Varela and Samy Frenk

Embodiments of Reality

For years I have searched for a powerful and yet graspable metaphor or image that could pithily convey the way in whch we and the world in which we live in—complete with space, time, tables, and wives—specify each other in an inextricable way. The minute dissection of this process of co-arising is my craft and life work, and one which I normally express in bits and pieces of technical journals, mathematical abstractions, or epistemological elaborations. But what is knowing like?

My latest preference is that that mind and world shape each other as our bodies shape themselves. Startling observation: Our bodies are the best metaphor of how we mind ourselves. In this paper with my colleague and friend Samy Frenk we describe how a shape shapes itself through the complementary actions of cells which secrete a space around them to stick together (i.e., define a body space) but a space which in turn shapes what the cells do and look like. In pondering and contemplating the wonder of this microcosmos of cells and organisms, suddenly I saw myself as a cell shaping and being shaped, embodying a reality...

Francisco

Francisco J. Varela is at the Max Plank Institute fur Hirnforshung, Frankfurt, Germany. Samy Frenk is at the Rolf Institute, Boulder, Colorado. This paper is in press in: Journal of Social and Biological Structures.

1. What is shape?

Living organisms have shape. This is so obvious a statement, that we take it for granted, and become oblivious of the fact that there is no adequate theory of living form and shape in contemporary biology. A theory of shape, for us, means not only an understanding of the principles which determine the spatial patterns of bodies, but also how do such patterns participate in <u>all</u> the dimensions of animal life such as movement, cognition, disease, and communication. Thus, we are concerned with form not only as geometric relations and proportions as developed in the tradition of D'Arcy Thomson (1), but beyond that, with shape as an integral component in the dynamics of a living system. In this paper we shall present an outline for such a theory of biological shape.

Our approach is based on current biological research. However, it is not a mere aggregate of current facts, but rather a conceptual scaffolding from a very specific vantage point about what is a living system altogether, and how the phenomena proper to life unfold from this peculiar organization. This framework has been presented in extenso elsewhere (2). Rather than recapitulate these ideas here, we shall put them to use in the context of shape, and let the reader understand them through their use.

2. The knife's distinctions

At a fundamental level, a living form is a collection of spatial <u>distinctions</u> in an organism. A distinction is the act of defining what constitutes the components of a given unity. The table's shape, for instance, is such a collection of spatial relations between the components (table top and legs) of the unity table. Hence, a discussion of shape must start by making explicit what are the distinctions we make in an organism as a composite unity and their spatial relationships.

tot 115

Traditionally, biological shape has been the province of anatomy (literally: separating the parts). Anatomical studies began in earnest with Vesalius and his monumental De Fabrica Corporis Humana in 1543. Since then, his observations have been refined substantially, to constitute a data base which most scientists would consider "stable" or achieved, in some basic sense, although a few minor details are continuously added. This, of course, applies to human anatomy. Animal anatomy is a more open field because of the immense diversity of species.

The spirit of Vesalius' work is present almost unchanged in the human anatomy a beginning medical student must learn today. What are the fundamental distinctions implicit in this venerable tradition? They are easily described: the parts of an organism distinguished (and related in space), are those which result from the actions of a knife. Vesalius started his own studies in a cultural context where hunting and butchery were widespread. Evidently, he drew from that context and, more importantly, from those distinguishing instruments. To be sure, the knife today has been refined to become a scalpel. The principle remains the same. The knife separates through its edge that which falls on both sides as the distinguished components. It separates bone from muscle, and muscle from viscera. Thus we end up with the separation between soft parts, muscles, and skeleton, which seems so familiar to our western minds.

What we have said so far concerns what most biologists would call classic human anatomy. Modern biology has developed further tools of dissections, and instruments whose implicit distinctions are radically different. These instruments penetrate into the cellular and molecular level, and belong to microscopic anatomy, cellular, and molecular biology.

Chief among these new tools for distinctions is the microscope which revealed, in the XVIIth century, a fundamentally different distinction relative to bodies: cells. The microscope, and later molecular separation tools, can distinguish units bounded by membranes which are fundamental components of every living organism.

What might not be so apparent, is to realize that delimiting cells reveals, by contradistinction, what is not bounded by cells in the body. This aggregate of non-cellular substance is the so-called connective tissue. It includes the space under a covering epithilium, the gaps between muscle bundles, the spacing between viscerae, as well as ligaments and fascia. The remarkable thing about this non-cellular component is that it is a continuum. (Fig. 1)

To make this point apparent let us consider a cross section through the neck of a human body (Fig. 2). Let us move through the tissue from the outside in. At the outer surface we find the skin which appears as a layer surrounding the entire cross-section. Immediately under it we find connective tissue, first in the form of a basal membrane under the epithelial cells, and then as a subcutaneous layer.

Figure 1:

A microscopic view of the network of elements within a small section of the loose connective tissue in the guinea-pig, stained with Bizzozero's method; X 800. A: bundles of collagen bundles. B,C: fibroblasts. F: elastic fibres. V: Blood vessel. Taken from Elementos de Histologia Normal, S. Ramon y Cajal and J. Tello y Munoz, Madrid, 1950, Fig. 193.

Notice that, although there are some cellular elements in this connective tissue, such as fibroblasts and blood cells, typically this is a non-cellular matrix of fibrous and viscous material. We shall return below to the constitution of the connective tissue. Moving a bit deeper into the cross section, we come in contact with muscle bundles, where cellular elements clearly predominate, although we see connective tissue in the form of fascia which surround the muscle. The degree of condensation of the connective tissue associated with muscular elements varies from extremely lax to a thick packet as in a tendon. Moving even deeper inside, we encounter bone, which is also in continuity with the rest of connective tissue. It differs from it by deposition of mineral elements, especially calcium, and th arrangement of precise geometrical patterns produced by a sparse but active population of cells. (Fig. 2)

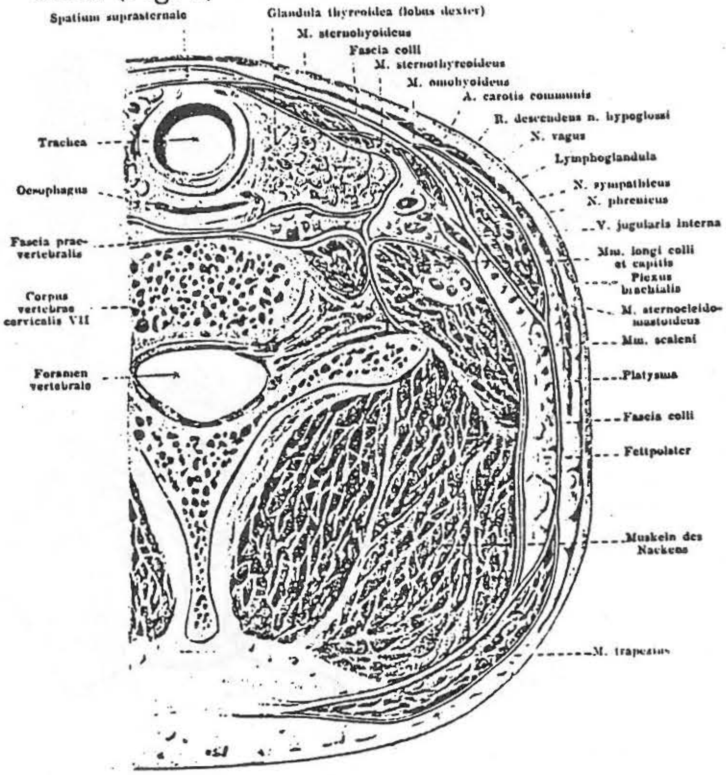

Figure 2:
A cross section through the neck of a human at the level of the trachea, as seen from above. Taken from Handatlas der Anatomie des Menschens, W. Spateholz, Leipzig, 1901, Fig. 307.

In short, from this brief journey through a cross section of a neck, we see that the usual anatomical descriptions, implicit in the knife's actions, produce separations in a connective tissue which amount to arbitrary distinctions of degrees of density, rather than qualitatively different constituents of the neck's shape. A more obvious distinction is between cellular aggregates (epithilium, muscle bundles, and so on), and the surrounding space filled with an extracellular matrix.

Let us now extend this point of view of the continuity of the space between cellular elements, beyond the two dimensions of the cross sections described above, to the entire three dimensions of the body. Thus, consider the shoulder beyond the forearm, then the trunk, until we encompass the entire body. It is perhaps easiest to evoke what we mean by yet another thought-experiment. Imagine we take the dead body of an animal, say a cat, and we dump the entire thing in a detergent which only dissolves cellular elements, leaving the extracellular matrix untouched. We leave it in the detergent long enough to extract every bit of cellular components, and then we pull the cat-minus-cells out of the detergent bath. What we would see is still a cat's shape, only in negative as it were, where only the space around the cells remain visible. This cat's shape is a continuum: there is no clear break point between the basement membrane of the skin, the muscle's fascia, the bones, or the connective between the viscera.

Our basic intention here is to show that the continuity of the extracellular matrix is the key to animal life: it constitutes an organ of form. The sections that follow discuss the adequacy of this designation and its consequences.

3. The Biology of the Extracellular Matrix

Studies concerning the extracellular matrix (ECM) have come mostly in the last 20 years, and still are not all that well known to biologists and non-biologists alike, although this is changing rapidly. In these years, techniques from biochemistry, ultrastructure, and immunohistochemistry, have revealed the fundamental universality of the ECM components (3).

As a first approximation, the ECM is a matrix of fibrous materials secreted by cells of various kinds, and bound together in intricate tangles. The most conspicuous, and first described, of these fibrous components is collagen, an ubiquitous protein which can exist in various degrees of aggregation. Next to collagen in abundance are polysaccharides, and combinations between polysaccharides and proteins or glycoproteins. There is also a rich variety of mucopolysaccharides, including hyluronate and chondroitin sulfate, collectively called glycosaminoglycans (GAG) (Fig. 3).

By and large, these biochemical characterizations have remained separate from cellular biology until recently. Interest in this area has increased because of the steady accumulation of observations pointing to the precise and extensive relationships between the ECM and the surfaces of all cells in the body. According to these observations, there are multiple ways in which collagen, glycoproteins, and GAGs can be arranged to form highly specific links to receptors located on cells' membranes. Thus, the ECM is in a clear position to exert specific and dramatic changes on the cellular dynamics, just as much as, a hormone or a neurotransmitter (Fig. 4).

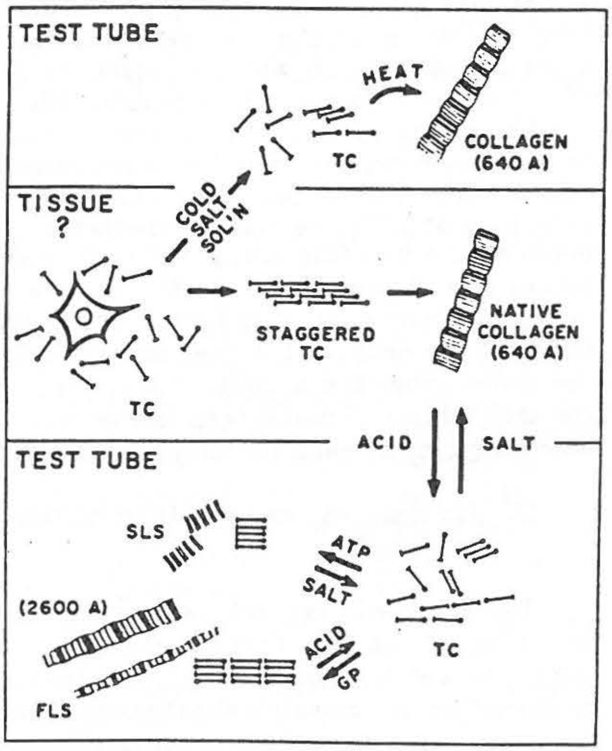

Figure 3:
Collagen is a protein which can take many different forms depending on conditions. Trocollagen (TC) is the building block which polymerizes in various ways described in the diagram. Taken from Hay (3).

In brief, the intimate milieu of every cell in our bodies is not a bland and homogeneous soup of nutrients. Instead, this intimate milieu has a precise architecture given by all of the intricacies of the ECM components, with an ongoing dynamic exchange with the cell surface.

4. Morphocycles and the organ of shape.

Having introduced the basic questions about shape, and having introduced the key qualities of the ECM, we can now turn to the core of the present proposal. It consists of considering simultaneously the local and global qualities of the ECM. The link between global and local is given by realizing the cyclic or self-referential nature of the interactions between cells and their surrounding space containing the ECM. Let us clarify.

At every location the ECM is produced by cellular elements of that particular region. But, it is also the case that the local ECM can influence the cell dynamics, thus constituting a cycle of reciprocal interaction between cellular and non-cellular constituents. But this local reciprocity is not the entire story, for whatever local action occurs is necessarily conditioned by the continuity of each local ECM with the adjacent ECMs, and, through them, to the entire body. As in the notion of a field and its corresponding particles, there is

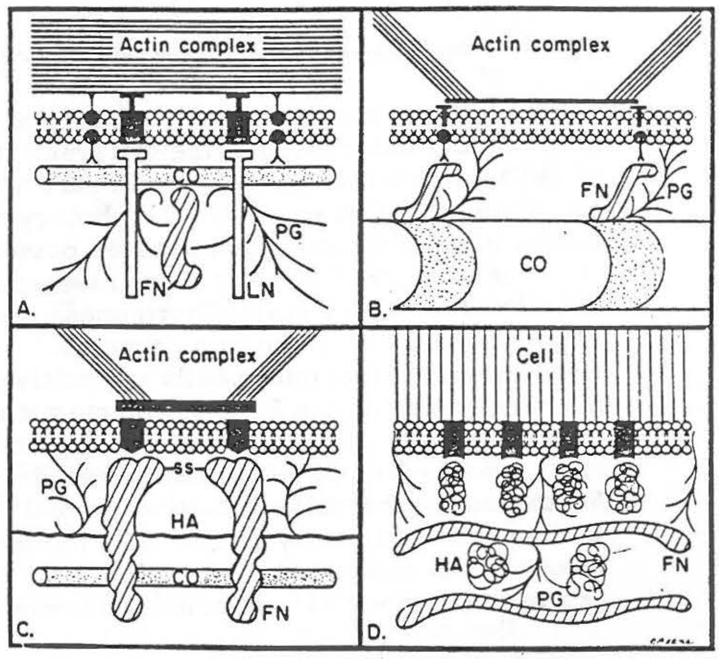

Figure 4:
Diagrams of several models depicting the possible relationship of ECM molecules to the cell surface. All models assume specific cell receptors for various fibrillar components of the ECM. Taken from Hay (3).

in living shape a dynamic complementarity: the entire global shape of the body affects the local conditions for ECM/cell relationship, but at the same time the local dynamics conditions how the entire body is actually built.

To this reciprocal determination between cellular elements of a multicellular animal and the continuous extracellular matrix we call a morphocycle. Thus, a morphocycle is a process, viz. an ongoing bootstrapping, whereby a shape is produced by the body's cells, but which shape in turn conditions (through its organ of form, the continuous ECM) what the cells do. Or, in other words, a morphocycle is the process whereby a local action between ECM and cell surfaces produces the global effect of shape, and is in turn constrained by it.

In this kind of dynamics of mutual and complementary reciprocity, the temptation is to put one side of the process as dominant (4). However, it is clear that at any given time, a body is the result of a very prolonged history of uninterrupted morphocycles, and what is due to cells and what is due to shape is inseparable. In fact, even if we retrace the steps of a body's shape back in time, the problem is not solved, for even the zygote did not exist in a vacuum, but already inside another shape.

5. Cases

Let us consider some examples which illustrate the above ideas in action.

A. Developmental morphology of organs.

The way in which a specific (i.e. local) kind of ECM can condition the differentiation of cells, and further be an integral part of specifying the characteristic morphology of an organ, is a recent and much debated possibility (5). For instance, for many years researchers have tried to induce normal hormones. Such attempts met with little or no success. However, when mammary cells are cultivated in the presence of the ECM of the mammary gland, adequate differentiation takes place, and produces functional mammary glands. Furthermore, this differentiation is possible with just the mammary stroma (i.e. the isolated fibrous components of the local ECM), and in the absence of any inducing hormone. If the flexibility of the ECM is inhibited by various means (such as accessibility to oxygen), the capacity for differentiation is correspondingly lost (6). Thus, the ECM is capable of acting back onto cells, by mechanisms which involve genetic repression and derepression, giving rise to change in the cells they enclose which, in turn, produce an ECM peculiar to their configuration. Also, the role of fibroblasts, the cell class found sparsely in the extracellular matrix, is beginning to be more clear. They have been found to have remarkable traction properties through their secretion of a collageneous matrix, capable of dictating much of the structure of the skeleton, location of the muscles, routes of nerves, and patterning of the skin (7). Thus, morphocycles are centrally involved in the differentiation of the function and shape of organs.

B. Cancer and connective tissue.

One of the most devastating aspects of cancer is the capacity of tumors to grow far from their primary site to other organs. Part of the difficulty of understanding this process, which is the key for the preventive treatment of cancer, is the diversity of cells in the primary tumor, and the way in which metastatic tumors are selected accordingly. Various different locations in the body select different cellular classes upon which to start the growth of a malignant tumor. Predictably, this selection occurs with the concourse of the cells of the target organs. Further, such selection also occurs with the participation of the specific kind of ECM, because it mediates between the invading malignant cells and the future site of tumor growth (8). Thus, a malignant tumor might not grow in the lymph nodes of the neck, but it does so actively in the nodes under the armpit. Thus, one key to the mechanism of metastasis is the ongoing morphocycles at each location.

C. Do muscles act by pulling on the tendons?

The standard textbook interpretation of how a muscle acts, is that it pulls on the tendon in which it terminates. The traction produced by the muscle's shortening is directly transmitted through the tendon to the bone, which is thus mechanically displaced. We may ask however, what is the source of evidence for this accepted view. If it were true, we would expect some kind of mechanical continuity between muscle cells and the surrounding collagen. From the ultrastructural point of view, such continuity is not all that clear. Muscle fibers are surrounded, but not directly linked, to their surrounding ECM (9). This raises the possibility of an alternative interpretation of muscle action, one that puts further emphasis on the continuity and integrity of the organ of form. In fact, when a muscle contracts, it not only shortens, but also thickens. The diameter of the fibers is correspondingly increased, which leads the connective sheath to be pulled perpendicular to the line of sarcomere shortening. If there is a strong continuity in the connective sheath, the increase in diameter will also result in a pull on the tendon and bone. Recent experiments show, in fact, that weakening the continuity of the connective tissue around the muscle belly, also weakens its capacity for action (10). It is possible, of course, that both mechanisms act in unison. But it is only if we think about the organ of form as a continuum that the second, and perhaps predominant mode of action of muscle action, is properly understood.

The cases mentioned in this section, range from the very detailed to the suggestive, and from molecular to macroscopic. They are intended as a showcase of how the present perspective can be projected into specific problems and contribute fresh new alternatives.

6. Natural history of the organ of shape

From the point of view presented here, the organ of shape is the specific structure which makes possible the spatial co-existence of cells in an aggregate which operates as a unity, as a whole organism. Thus, shape is synonymous with the very existence of metazoan or multicellular animal (11). Furthermore, the biochemistry of the ECM is surprisingly universal throughout the entire range of vertebrate, and perhaps invertebrate life (3). This universality is also present in other fundamental living dynamics such as the genetic code, membrane transport, or metabolic pathways. Like these, the mutual effects between ECM and cell dynamics, tend to be very conservative mechanisms throughout evolution, as fundamental building blocks which are rarely, if ever, subject to modification.

This is a very interesting fact when considered in the light of the universal nature of multicellularity. Contrary to traditional views, cellular aggregates constituting an organism with a distinct shape exist not only amongst the macroscopic creatures, vertebrates and invertebrates. Multicellularity is present through all of the five kingdoms: monera (i.e. bacteria like), protysta (i.e. protozoa-like), fungi, plants, and animals (12). In all of these kingdoms, one can find individuals which are multicellular, although in the case of vertebrates this is an obligatory feature. Amongst the first three kingdoms, in contrast, many members lead a life as independent free-living single cells (Fig. 5).

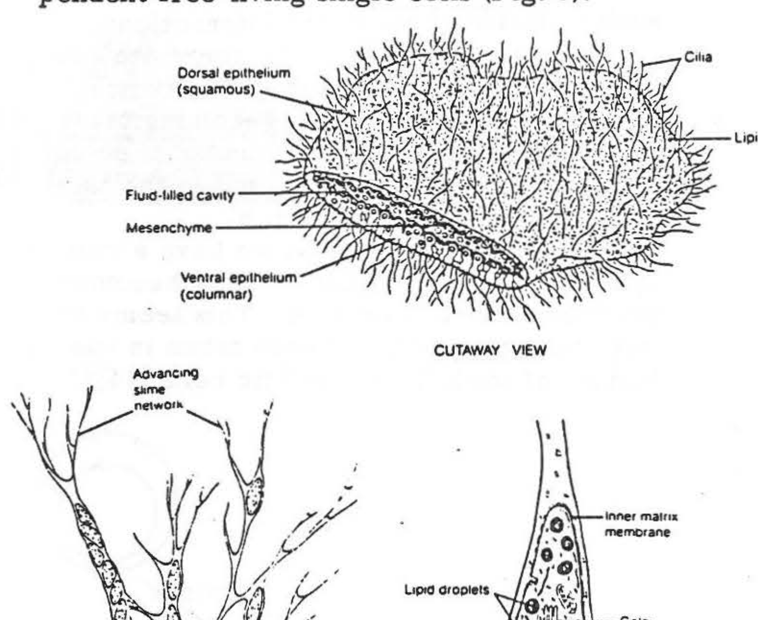

Figure 5:
Above, a drawing of Trichoplax adhaerens, one of the simplest of all living multicellular animals. Below left, Labyrinthula cells forming a slime net. Below right, the structure of a single Labyrinthula cell, showing slime matrix surrounding it. Taken from Margulis and Schwartz (12).

There is evidence for the presence of multicellular animals back into the Edicarian period, at the beginning of the Phanerozoic eon some 3 billion years ago, the period to which the oldest known living fossils have been traced (13). Shape, in the sense understood here, is almost as old as life, since multicellularity is. Bodies and shapes did not begin with fishes or lizards.

Life must have arisen by the constitution of minimal autopoietic units, self-producing units capable of generating their own boundaries (2). But once populations of such autonomous units arose, at the same time arose for these units the possibility to be factors of reciprocal selective histories. In such histories of recurrent interactions between two primitive cells, there are two possible logical outcomes: either their boundaries dissolve by one becoming contained in the other, or else their boundaries do not dissolve but become juxtaposed in the same space with each other. (Fig. 6)

In the first possibility, we have a case of symbiosis, where one kind of cell becomes a permanent host of another. This seems to have been precisely the path taken in the history of modern, eucaryotic cells (14).

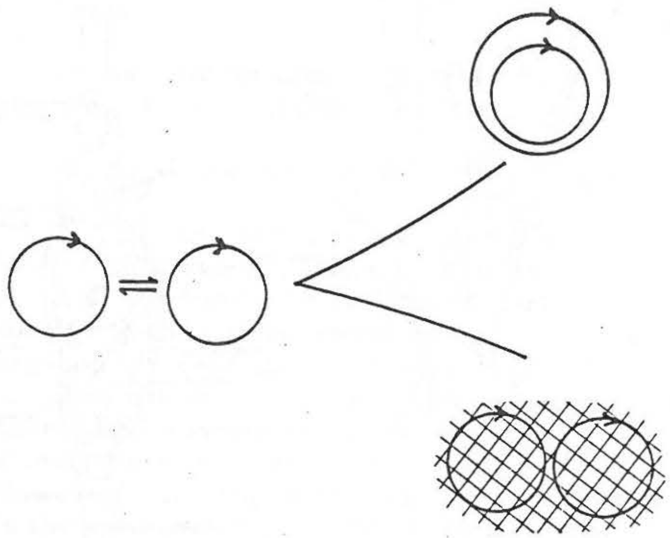

Figure 6:
The history of reciprocal coupling between two autopoietic units symbolized here by a circular arrow, can have two possible outcomes: containment or juxtaposition. In one case one has a history of symbiosis; in the other, the secretion of a common space, i.e. a shape.

However, the logical dual of this symbiosis is that cells become strongly bound by the specification of a common space produced by the joint dynamics of the participating cells. This is tantamount to saying that the participating cells secrete their own surrounding space: an extracellular matrix whch delimits precisely what is, and what is not part of it. Stated yet another way, crossing the boundaries (as in the origin of eucaryots) could be described as endo-symbiosis. Preserving the cellular boundaries while sharing a mutually specified space, could be described as exo-symbiosis, which becomes another word for shape. Endo- and exo-symbiosis have been present from the very beginning of the natural history of life, since these were options open to the very first populations of autopoietic systems. Further, the dual option of endo- and exo-symbiosis can operate not only between cells, but also between multicellular organisms themselves. A lichen and a parasite are examples of this principle applied at a higher level of recursion.

7. Conclusion.

The organ of shape and its morphocycles are token names for an entire context in which to understand biological shape, its material substrate, its natural history, and the way in which it can participate in various aspects of an animal's life. This proposed perspective consists basically of bringing into alignment a number of results from current research with a specific perspective about living systems. The intuition behind our framework is that space altogether is a constitutive element in the dynamics of the living, just as much as the solidity of their molecular constituents. The importance of this mutual partnership between cellular dynamics and specified/specifying space is only beginning to be realized.

In the light of the present perspective the understanding of biological phenomena is enriched and unified. Beyond such an aesthetic reward, the present hypothesis does lead to interesting new questions which can be addressed experimentally, such as those outlined above in Section 5. It is also interesting to consider the usefulness of this perspective as a foundation for the whole array of disciplines and techniques collectively known as "body work", where shape and posture are seen as inseparable from consciousness itself and the wholeness of human experience.

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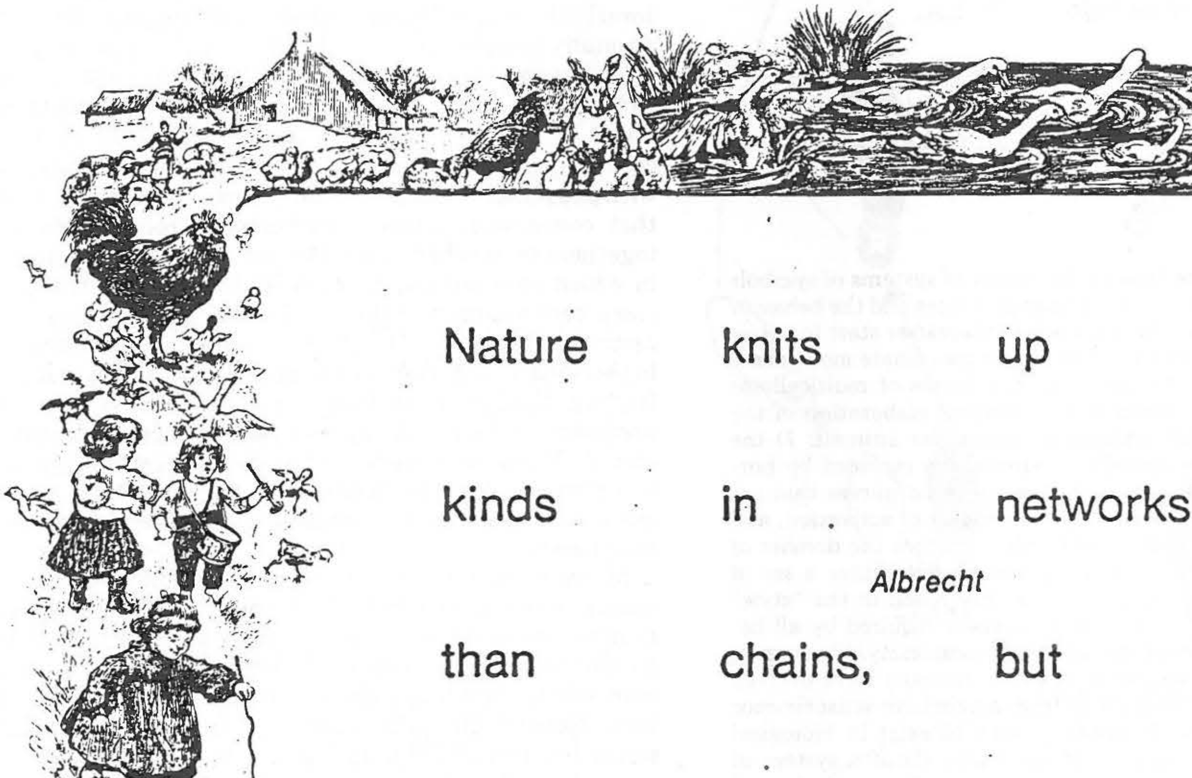

Nature knits up her
kinds in networks rather
than chains, but we
follow her in chains
because our language can't
handle more than one
thing at a time.

Albrecht von Haller.

Common origin of linguistic and movement abilities

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We start with the view that development of systems of symbols is rooted in the regulation of cellular processes and the behavior of unicellular animals. Animals would thereafter start to externalize these internal symbol systems, to coordinate movements with each other. We propose that the brains of multicellular animals can be understood as a continuing elaboration of the early chemical symbol systems of unicellular animals: *1)* the labile symbols of the unicellular animal are replaced by hormones, more stable chemical compounds, and nerves that are seen as more stable and more specific routes of activation; and *2)* brains developed layers of symbols such that the domain of a symbol is not a set of bodily processes but rather a set of brain processes. Human language is very much in the "style" of the rule-governed symbol manipulation required by all behaving animals, although unique in its complexity. We suggest that the essential question is not how humans have evolved symbolic and linguistic abilities from a primitive sensorimotor brain but rather how do symbols come to exist in biological systems and what is useful and necessary about a system of symbols for the coordination of action within animals and among animals.

It has always seemed to me extreme presumptuousness on the part of those who want to make human ability the measure of what nature can and knows how to do, since, when one comes down to it, there is not one effect in nature, no matter how small, that even the most speculative minds can fully understand.

Galileo Galilei (1632)

WE WISH TO RAISE the following question: What kind of thing is the brain and why does the brain lend itself so readily to linguistic and motor abilities? We will argue that language and movement abilities have been associated necessarily from the beginning of living organisms and that the reasons for this close association have also been the impetus for the development of brains.

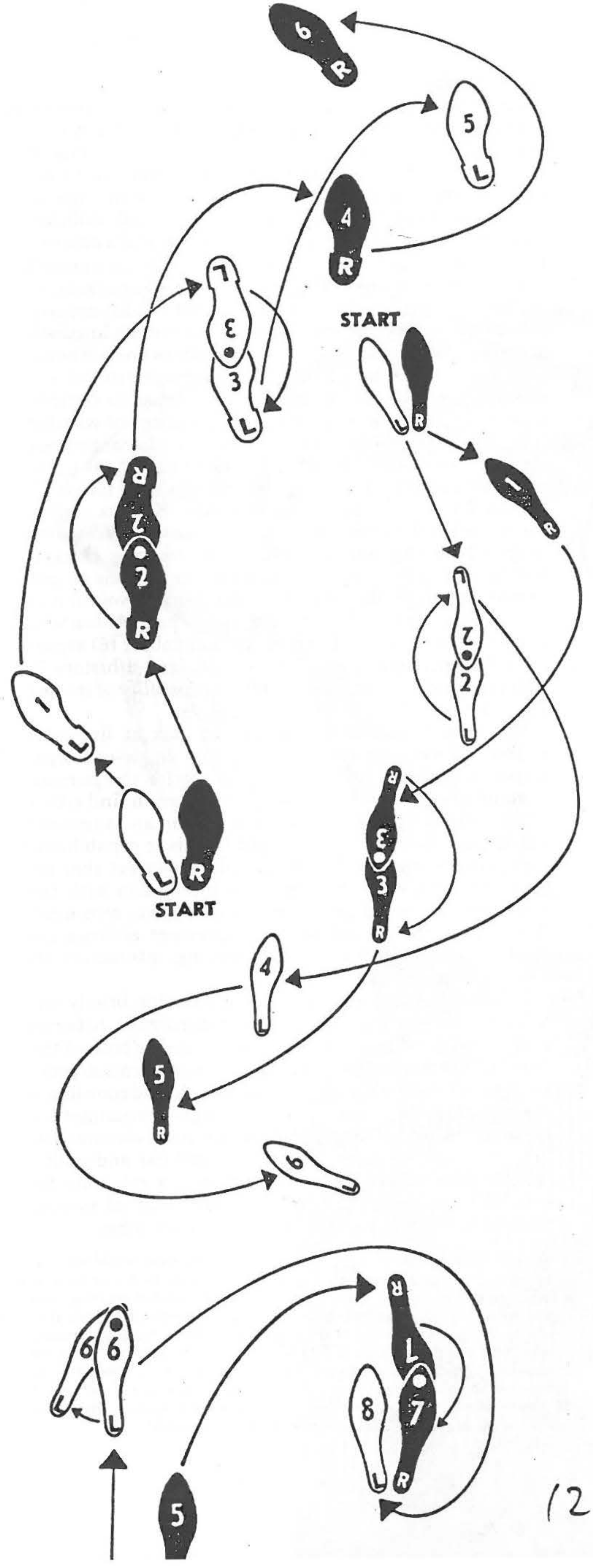
Previous research on the evolution of certain behavioral abilities, particularly speech and language, has given us many insights into the neural correlates of language and movement processing; however, it has scarcely addressed the question of why language and movement share so many qualitites in common. It is obvious that communicative-linguistic abilities are always associated with movements. Rather than examining the possibility that communication and movement processes develop together, researchers have tended to focus on examples in which communication abilities evolve from the processes controlling movement (7). We will challenge two assumptions here. *1)* Communication is somehow a higher-order function than movement skills, such as feeding; this assumes that one could have a behaving organism that secondarily evolves into a communicating one. *2)* Movement processing is concrete, primitive, and a matter of stimulus-response linkages that do not require the sophisticated cognitive abilities associated with language.

Many questions in the research on the evolution of speech have been directed to the differences between human communication skills, such as speech, and the communication processes so readily observed in subhuman species and lower animals (10–12). These questions have focused on differences in functions, pragmatics, structure, trainability, and so forth. This has led to a great deal of debate on whether primate vocalization is the evolutionary relative of human speech (1, 13). However, this emphasis in the research ignores the following, more fundamental, question: What is the purpose of communication and language-like processes in the maintenance of an individual organism and for the survival of the species?

For very good reasons scientists focus on "how" questions that yield descriptive answers. Many argue that evolution is mainly a historical process not amenable to analysis in terms of principles. Undeniably, evolution is a history of how individual characteristics in different species were adaptive to particular times and places and led to the extraordinary variety of talents we see today among living organisms. It is also true, however, that what is *adaptive* for any species is based on the then extant geophysical and biological world and the principles that govern the operations and interactions of these worlds. It is in this context that we can study how

Researchers have argued that the structures used for communication were adapted from the nervous control and physical structures underlying existing movement patterns. Hence stridulation in grasshoppers is argued to have derived from flight (rhythmic wing movements); human oral speech made use of the feeding apparatus (rhythmic jaw movements and flexible tongue movements). Although such cases are interesting in their own right, we reject the implication that communication functions always 'came after more basic' movement patterns. For many species, communication abilities are as essential as breathing. An infant animal which did not communicate appropriately may not get parented; an adult animal may not be able to mate. As difficult as it is, we must start to confront the issue of having several levels of a system or several subsystems being selected for at the same time. When the antennae of the ant population is being selected for, it is being done so on the basis of sensory abilities, cost as a physical structure and efficacy as a social instument.

In the accomplishment of some goal, the behavioral system is constantly adjusting the form and sequence of movements as it monitors the effects of its prior movements and changes in the environment. Most movements can be combined with other movements to form a large variety of acts. Movement is structurally coherent in the assemblage of elements and also generative in the combinations used at the moment to adapt to a given circumstance. In our thinking we have been overly dependent on prewired patterning. This concept places the emphasis on the coherence and the "fixedness" of patterns. It largely ignores the means of introducing flexibility and variability into the combinations of elements used in the assemblages. Furthermore a given instance of behavior can reflect several motivations and work towards several goals at once. Contrary to the usual emphasis in behavioral studies in which an animal must choose between mutually exclusive acts, an animal in nature is rarely in the situation where it must engage in one behavior to the exclusion of other behaviors. Rather an animal's movements frequently show behavioral merging in which several motivational goals and action patterns are combined into one coherent pattern. (see Additional References.)



animals adapt within the constraints imposed by these basic principles. The basic constraints will of course be the laws of physics. Although we as yet do not know how to extend physics adequately to biological phenomena, it is clear that the formation of inhomogeneous fields, fluctuating energy sources (3), and so forth is an impetus for the development of animal movement and abilities. These constraints are unifying: all of an animal's abilities must conform to these requirements; all of an animal's abilities can be seen in the context of these requirements.

Most of the researchers in this area will readily concede that there has been an evolution toward human linguistic abilities. The debate starts with the names one wishes to label the dimensions along which language evolved and whether there are few or many such dimensions contributing to the development of human language or whether these dimensions are continuous or discontinuous. Hence, Steklis and Raleigh (13) supply important information on continuities in the brain areas used for vocalization for both humans and primates. Kimura (5), on the other hand, argues that the most relevant dimension in speech development is a praxic-gestural one. Hockett and Altmann (2) point out that many dimensions go into human language abilities and argue for an evolution of each ability separately with the happy happenstance of convergence of them all in humans. Lenneberg (6) argues for a discontinuous evolution of language—a history in effect in which we have absolutely no capability of tracing any dimension from animals to humans.

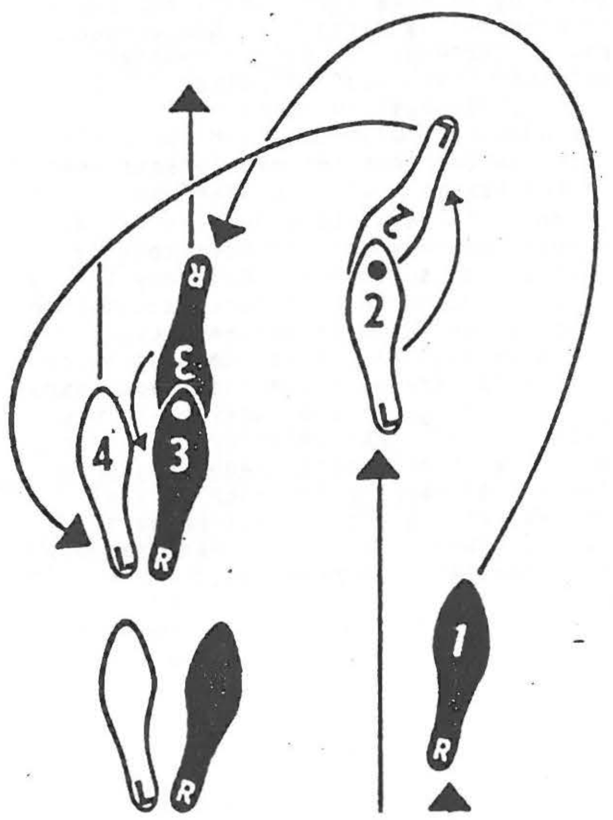
We suggest that it is essential to look at linguistic abilities as evolving continuously from single-cell organisms to humans. However, this is not for the purpose of going into the world of the ape or lizard to find either human-like language or the roots of human language.[1] Rather, our purpose here is to put linguistic capabilities, cognitive abilities, and movement in a context that relates the complete organism to its interaction with the environment, including other creatures of its own kind. We propose that linguistic and movement abilities are essential capabilities that any behaving, interactive organism must possess.

In the following section, we will examine briefly the behavior of unicellular organisms to distinguish between what we will call interaction (in which one or both of the participants gain information) and communication processes (in which the participants cooperate and coordinate their actions). In the course of defining our meanings for these terms, we will argue that the internal communication processes necessary to both unicellular and multicellular animals are linguistic and offer a rationale for why animals would start to use their internal symbol systems to coordinate movement with each other.

[1] It is appalling in an ethological sense that humans would attempt to study the linguistic abilities of a chimp or gorilla by trying to raise it in a human middle-class environment or in an isolated cage and then talk to it. Several researchers have been disappointed with the fact that all the chimps or apes want to do is talk about food or hugging. Frankly what else could the ape possibly discuss with its keepers? Have we allowed it any real task of survival? Can it talk to us about how to organize the hunting party or warn us of serpents in the trees? Can it even compete with us for dominance in an appropriate display of adolescent aggressive behavior without being punished?

Starting with Aristotle's search for principles, physics originally included inorganic and organic systems. (The words for physiology, physics, and physicians all derive from "natural things", the title of Aristotle's treatises.) Locke even included God and angels as among the objects of physics. It is a fascinating story in the history of science as to how physics becomes associated with only the lawful behavior of inorganic systems -and even beyond that, only passive systems. (In the 18th century, chemistry started to separate from physics.) Now among the 'avant-garde', one hears exciting breaches of this self-imposed gap between the biological sciences and the 'physical sciences'. Nonetheless, we are encouraged by progress in the applications of the qualitative theory of differential equations to both traditional physics topics, such as fluid mechanics, and biological topics, such as growth and decline in animal populations or the stability of physiological systems, and other areas of thinking, such as allometric studies, or Iberall's homeodynamics. (See Additional References.)

One tends to think of language and cognition as non-concrete because we cannot 'see' the exchange of molecules or the changes that underlie it. Similarly 'social functions' appear to be less concrete than the 'social' interaction of cells because we literally excrete our symbols into "thin air" and not into the acqueous solution between cells.

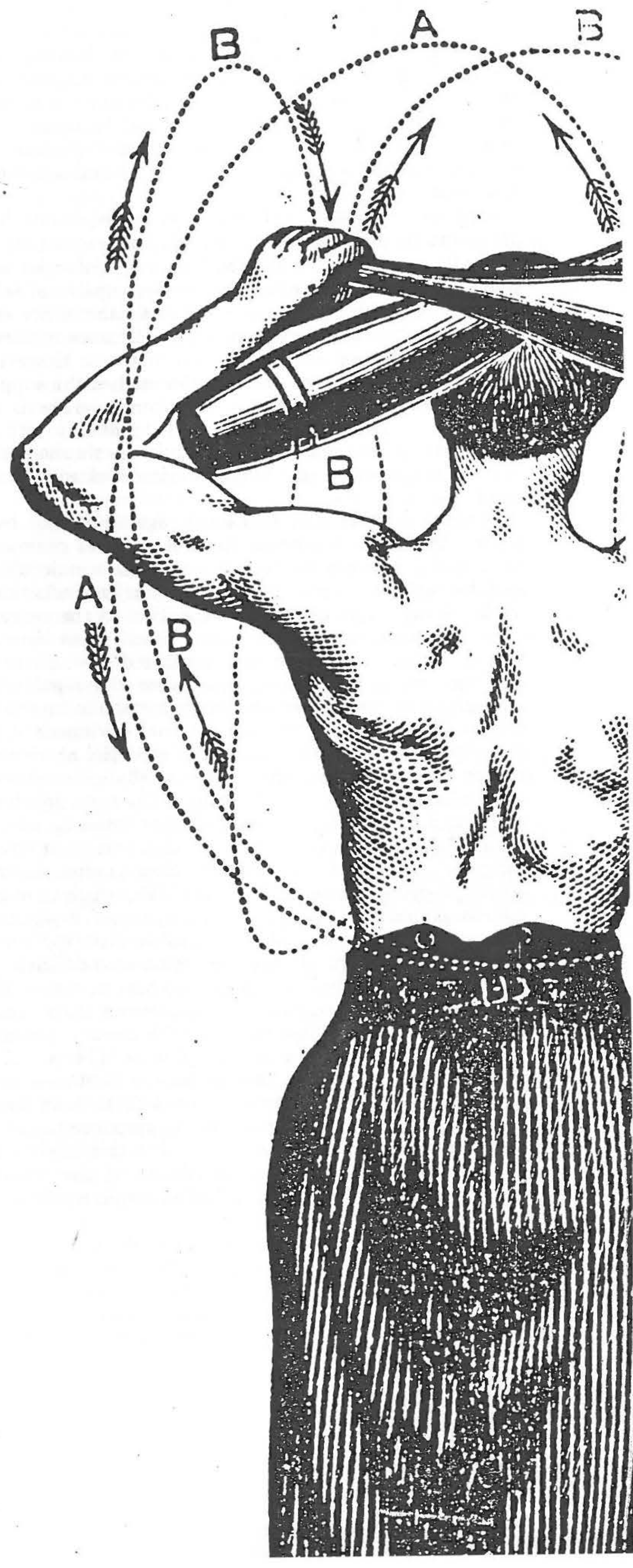


As Jennings (4) has argued so elegantly, unicellular animals are capable of many of the complex and adaptive behaviors of multicellular animals. According to Jennings, they respond to all the classes of stimuli to which humans do, and they have specialized receptive areas (although not yet specialized for different senses) and frequently specialized contractile parts whose action is coordinated. They have spontaneous behavior ["changes in activity induced without external stimulation" (4, p. 261)], trial-and-error behavior (in the sense of methodically running through a behavioral repertoire), habituation (and hence some memory), and the ability to change their response to a stimulus depending on the context. As Jennings concludes, "We do not find in the nervous system *specific qualitites* not found elsewhere in protoplasmic structures. The qualities of the nervous system are the general qualities of protoplasm" (4, p. 263).

Looking at these abilities, we see that even at the unicellular level, organisms cannot exist without internal communication. By internal communication processes we mean that different locations within the organism and different subsystems cooperate, interact, and coordinate their activities. This coordination is necessary to permit the organisms to perform a great variety of behaviors. We wish, further, to assert that communication among the various parts of a coherent system such as that found in a unicellular organism is linguistic. That is, these communication processes perform the following functions: *1*) they coordinate individual elements; *2*) they have a grammatical structure, by which we mean rules about what the combinations and interactions of individual elements can mean and how they take place; and *3*) they make use of a system of symbols. (This last point we will expand on in a moment.)

In addition to these internal processes, unicellular organisms interact with the environment and with each other. One example is the predator-prey relationships among infusoria, such as *Didinium* and *Paramecium* (4, p. 186). At what point does interaction with the environment evolve into the cooperative interaction among organisms that is essential to what we call communication?

The critical difference between interaction and what we call communication is that there is little coordination and cooperation between the participants in interaction. Hence, by this definition, *Didinia* and *Paramecia* do not communicate with each other. Like all animals, we get information from the environment; we interact with it; we even have rules that govern our relationship and response to it, but we do not converse with it. We cannot agree and coordinate with it; we cannot form a common goal with it. So at the point that interaction is not communication, we are saying that the animal is treating another biological object like an inanimate fact of its existence.[2]



[2] An interesting question is whether any prey-predator relationship is communicative and whether to kill another we cease communication, in other words whether we now treat the other biological creature as an inanimate fact—a piece of information about energy sources in the environment—and cease any cooperative behavior with it.

We have argued that unicellular animals have a rich repertoire of behaviors resulting from the coordination of body parts and internal structures. This internal coordination requires communication among the internal structures. We would like now to bolster our claim that this internal communication is linguistic by examining in detail Tomkins' (14) model of biological regulation by the use of internal symbols in unicellular and multicellular animals.

Symbols are physical and their origin derives from the critically important role they play in controlling physical systems. The example we develop here is the inseparability of movement and symbols. It takes movement to symbolize and symbols to coordinate movements.

If we ignore for a moment the biochemical details, his argument on the evolution of biological regulation is elegantly straightforward: even "ancient molecular assemblages" possessed cellular properties capable of self-replication. Nucleic acid and protein synthesis are endergonic reactions; hence primordial cells were required to capture energy from the environment. However, changes in the environment that diminished the supply of monomeric units necessary to polymer synthesis or altered the formation of ATP were probably lethal. Therefore survival would require regulatory mechanisms that maintain a relatively constant intracellular environment.

Tomkins divides this biological regulation into two modes. In simple regulation there is a direct chemical relationship between the "regulatory effector molecules" and their effects. As examples, he cites enzyme induction, feedback inhibition of enzyme activity, and the repression of enzyme biosynthesis. The critical point here is that in simple regulation, the control of the internal environment is tenuous at best, since the regulatory molecules are themselves important metabolic intermediaries. Therefore the animal's internal environment is still closely tied to the availability of essential nutrients. In complex regulation, there are metabolic "symbols" and "domains." To quote Tomkins, "The term 'symbol' refers to a specific intracellular effector molecule which accumulates when a cell is exposed to a particular environment" (14, p. 761). As two examples, he cites adenosine 3′,5′-cyclic monophosphate (cAMP), which in most microorganisms is a symbol of carbon source depletion, and guanosine 5′-diphosphate 3′-diphosphate (ppGpp), which is a symbol of nitrogen or amino acid deficiency. Importantly, "metabolic symbols need bear no structural relationship to the molecules that promote their accumulation in a nutritional or metabolic crisis ... cyclic AMP is not a chemical analog of glucose" (14, p. 761). Tomkins also points out that metabolic lability is another attribute of intracellular symbols that allows their concentrations to fluctuate quickly in response to environmental changes. However, note that this lability is different from the troublesome lability of the simple regulation mechanisms. In the case of simple regulation, since the regulatory molecules are themselves metabolic intermediaries, they (and hence the internal environment) will fluctuate in a direct manner according to the supply of external nutrients and conditions. However, in the case of complex regulation, the symbols will respond rapidly to the external environment, leaving protected for some time the metabolic processes they control. This protected time is exactly the time in which the organism has the chance to make some adaptive response to the environment (e.g., swim away from the carbon-depleted region), and this, it turns out, is exactly what bacteria do. For example, carbon-starved *Escherichia coli* develop flagella, which allow the bacteria to be motile. cAMP is critical to the development of the flagella. The point we wish to make here is that by incorporating a symbol "level," the animal gains time in which it can protect its metabolic processes from external conditions.

In Tomkins' terminology, the domain of the symbol is all the cellular processes controlled by the symbol. Hence in Tomkins' examples of the necessity of cAMP to the development of flagella in *E. coli*, we see that the effects controlled by the symbol are not all metabolic but also include adaptive behavioral responses that will protect the metabolic processes. He also points out that many symbols may share in the control of a given process. One begins to see how a system of symbols would build up and control the organism.

Tomkins does not end his argument at the levels of single cells; he points out that the mammalian and bacterial responses to cAMP and other symbols are quite similar. He then proposes the slime mold *Dictyostelium discodium* as a model of transition of intracellular symbols to intercellular symbol use. In the slime mold, the cells exist as independent myxamoebas until starved. At this point, cAMP accumulates in the cells, similarly to *E. coli*, as a symbol of carbon depletion, but unlike *E. coli*, it is also released from the cells into the external medium where it acts as the attractant that causes myxamoebas to aggregate into one multicellular slime mold. As Tomkins states, "Cyclic AMP thus acts in these organisms both as an intracellular symbol of starvation and as a hormone which carries this metabolic information from one cell to another" (14, p. 762).

But as noted earlier, cAMP is labile and therefore, Tomkins argues, not suitable for the long distances required for intercellular communication in large metazoa.

He proposes that hormones, more stable chemical compounds, took over the role. As he emphasizes, the process in intercellular communication always begins and ends in the internal primary codes of individual cells. "Specifically the metabolic state of a sensor cell represented by the levels of its intracellular symbols is "encoded" by the synthesis and secretion of corresponding levels of hormones. When the hormones reach responder cells, the metabolic message is "decoded" into corresponding primary intracellular symbols. Thus hormones apprise responder cells of the concentrations of intracellular symbols in the sensory cells, allowing relatively protected internal organs to respond coordinatively to external perturbations" (14, p. 762).

Just as in the case of the internal communication processes of unicellular animals, the intercellular communication processes of multicellular organisms are linguistic. Note how these internal linguistic communication processes, in both unicellular and multicellular animals, make possible behavior or coordinated goal-directed movements. Movement is a cooperative phenomenon. Movement requires communication among the organisms's parts. As we saw in the example of motility in *E. coli*, even the most primitive movement is controlled and mediated by the use of symbols.

We come now to a difficult issue; how, and to what advantage, did cooperation develop between organisms, because it is in the cooperation between organisms that we traditionally recognize the existence of language. For a living organism to persist it must be able to utilize and acquire the energy sources necessary for the running of its engine processes. All living organisms exist in a heterogenous energy field. For animals, the strategy adapted to access these fields was to pursue them, search for them, and act on them. This obviously required mechanisms for sensing the sources in the fields and for developing a machine that could move the organism to the source and devour it. This still does not give us the answer to the question of how and why cooperation between organisms developed, but it does give us an understanding of the conditions under which there was and is the need for an individual to move and hence, as discussed above, the development of internal language processes.

An equally compelling reason for the development of movement capabilities of individual organisms was the advantage to be gained for the persistence of the species from the mixing of genes. In the same way that an individual's movement allows an adaptive response to fluctuating energy sources within its lifetime, the mixtures of genes allows an adaptive response, by the species, on a longer time scale to environmental changes in energy sources. Movement of an organism in its own lifetime permits it to access and utilize energy sources and material requirements in its field. Given an environment in which the field is constantly in a state of flux, the persistence of the progeny of living organisms requires the ability to modify its sensorimotor apparatus and strategies for the location and devouring of energy and matter in a future environment that is likely to be dissimilar to the present one.

Therefore, obviously, a cornerstone in the development of both movement and communication between organisms is the need for living creatures to feed, in the broadest sense, and to locate and merge with other like organisms for procreation. Procreation is the result of a coordinated interaction among two organisms, and the means of that coordination is both the result of movement and communication and the genesis of increasingly complex movement and communication systems.

The impetus for the development of communication also stems from the advantages it provides organisms in extending the field of their perceptions and actions. Let us take the following hypothetical example: two conspecific unicellular organisms, separated physically, excrete a particular substance in a carbon-depleted environment. Let us now place one in a carbon-depleted area of this inhomogeneous field and one in a carbon-rich area. There will now be added to the field a gradient of this excreted substance that will produce changes in the internal chemical state of all the organisms in the field, if the substance can be taken up by these organisms.

We now have a situation in which an organism, occupying a fixed position in space with respect to the field, has effectively added to the range of the field in which it can perceive carbon lack. This is due to the gradient in the field that is produced by the ensemble of organisms and the diffusional characteristics of the substance through the medium. If the substance diffuses through the medium faster than the flux of carbon source, then the organisms in a local carbon-poor field can detect the onset and location of the development of carbon-rich fields.

In addition, if the substance enters the internal machinery of the organism and participates in the electrochemical processes that determine its structure, then one can begin to get an idea of how organisms in a chemical gradient field generated by others of its own kind can be deformed by that field so that movement away from energy-poor zones and toward energy-rich zones in the field can occur along the gradient.

This is an elementary form of communication by the use of symbols of an organism's internal state with respect to the external environment. This communication has extended the external space from which the organism can obtain information concerning geophysical or biophysical processes of significance to it, and it has modified its internal processes with respect to the processes of others like it in its environment. In more advanced animals, this externalization of symbols of internal state and subsequent coordination will lead to such things as mating, sharing of energy sources, and increasingly complex means of communicating advantageous perceptions and coordinating advantageous actions. To support these ever increasingly complicated movements and modes of communication, we have increased and elaborated our internal system of symbols. We propose that these elaborations led to the formation of brains which we now discuss.

We start with truisms; the brain is soft; it does not move; it does not engage in sex; it does not feed. The electrochemical language of brains is analogous to the set of symbols in unicellular animals. The same central issue remains for us now as it did for the first animal billions of years ago—the location and utilization of energy sources. What becomes different with the advent of the collection of cells we call a brain is that we now have an organ in which symbols act on layers of symbols.

In other words, in the unicellular animal, we have a collection of symbols, like cAMP, which together with the way they affect the processes under their control, and the way this collection of symbols affects each other, constitutes a primitive brain without nerves. This primitive brain without nerves is elaborated in multicellular animals in two ways. *1)* The labile symbols of the unicellular animal are replaced by hormones, which are more stable chemical symbols, and by nerves, which provide more specific routes of information than chemical diffusion. *2)* Layers of symbols develop to the point that the "domain" (in Tomkins' sense) becomes not a set of body processes but rather a set of brain processes.

What purpose does this increase in symbols and the use of symbols serve? If both we, and unicellular organisms, face and solve the same fundamental problems, then why should there be an increase in complexity? As mentioned before, an increased use of symbols dissociates the intracellular processes of unicellular organisms from the environment. This means that an event which occurs in the receptive space of the organism does not produce an immediate response. What it produces is an internal reaction that symbolizes the event in the environment.[3] These symbols of external events then become part of the internal processes of the organisms. The more an organism has the ability to symbolize external events and the greater its capacity to manipulate those symbols internally, the more it is freed from nonadaptive, direct responses to fluxes in the energy and matter surrounding it. It begins to have the capability to organize delayed actions which give it the freedom to plan, simulate, and act when its own internal processes deem it appropriate; such actions can take place at greater and greater distances in time and space from the initial external event.

When we apply this understanding of symbols to the development and advantageous properties of nervous systems, we see some immediate differences between this view and more traditional views. In the traditional view,

[3] We would like to emphasize at this point that a symbol is never a representation of an external event alone; it is always a representation of the organism in relationship to the external state or event. Hence, in Tomkins' example, cAMP is a symbol of carbon deprivation in the organism. It at once says something about the lack of food in the environment but also about the response and state of the organism. For a simple example, I am not necessarily hungry each time there is a lack of food around me; my hunger is at once a symbol of my state of food deprivation and the lack of available food in the immediate environment.

Eventually we will be able to ask how the physical embodiment of symbols (chemical exchanges or neuronal pathways) leads to differences in the symbol manipulating system. We see one hint here -chemical symbols decay quickly and neurons can't be left as a marker. Chemical symbols can cover a large area; neurons can overlay each other in interesting mapping architectures.

This is a great question and to address it we need an understanding of the rewards and costs of increased complexity. There is a price to increasingly complex organization. One cost is the increased demand on internal communciation among body parts and within the population of animals. A related cost is the need for long gestation periods and parental care for the young of a species. One way of viewing this is as increasing investment in the individual organism (perhaps leading to more complex roles within the group and to additional requirements for symbols among organisms.)

the nervous system is a set of slightly elaborated connections between a stimulus and a response. The nerve connects causally, and as immediately as possible, the stimulus with its appropriate response. By this view we are left contemplating how the marvelous variability of responses occurs to the marvelous variety of stimuli and perceptions and how such extraordinary processes as intention, planning, prediction, and symbolism evolve. However, if we adopt the view here that all animals, including our most primitive unicellular predecessors, have used symbols, we have inherited the advantageous characteristics of all symbol users noted above: symbols increase the time delay between the stimulus and the response and by doing so allow one to break the one-to-one correspondence, the immediate causality implied by connectivity alone. This lack of correspondence leads to an increase in flexibility; that is, a variety of responses can become associated with a single stimulus, and a single response can be elicited with a variety of stimuli.

We have thus far argued in this paper that language, as rule-governed symbol manipulation, has been an integral aspect of all life from the outset. Therefore we view human language as clearly being on a continuum of language capabilities in all organisms.

It will be useful first to discuss a capability of humans that we also consider to be on a continuum in the sense that we wish to argue here. Humans can play Rachmaninoff on grand pianos. This is an awesome skill. We do not argue, nor would anyone, that creatures other than humans can do so. Chimpanzees have fingers, dexterity, memory, auditory skills, and learning abilities; we do not contemplate their ever competing with us on the concert stage. However, the performance of any concert pianist is still rooted both in the structure of human hands and in their manipulation by a human brain. Clearly, to explain the performance of this motor task, one is not required to postulate that the human has suddenly acquired motor skills not directly related to those skills the chimpanzee possesses. Piano play is still fundamentally a motor act, maybe a wonderfully complex act, but a motor act nevertheless.

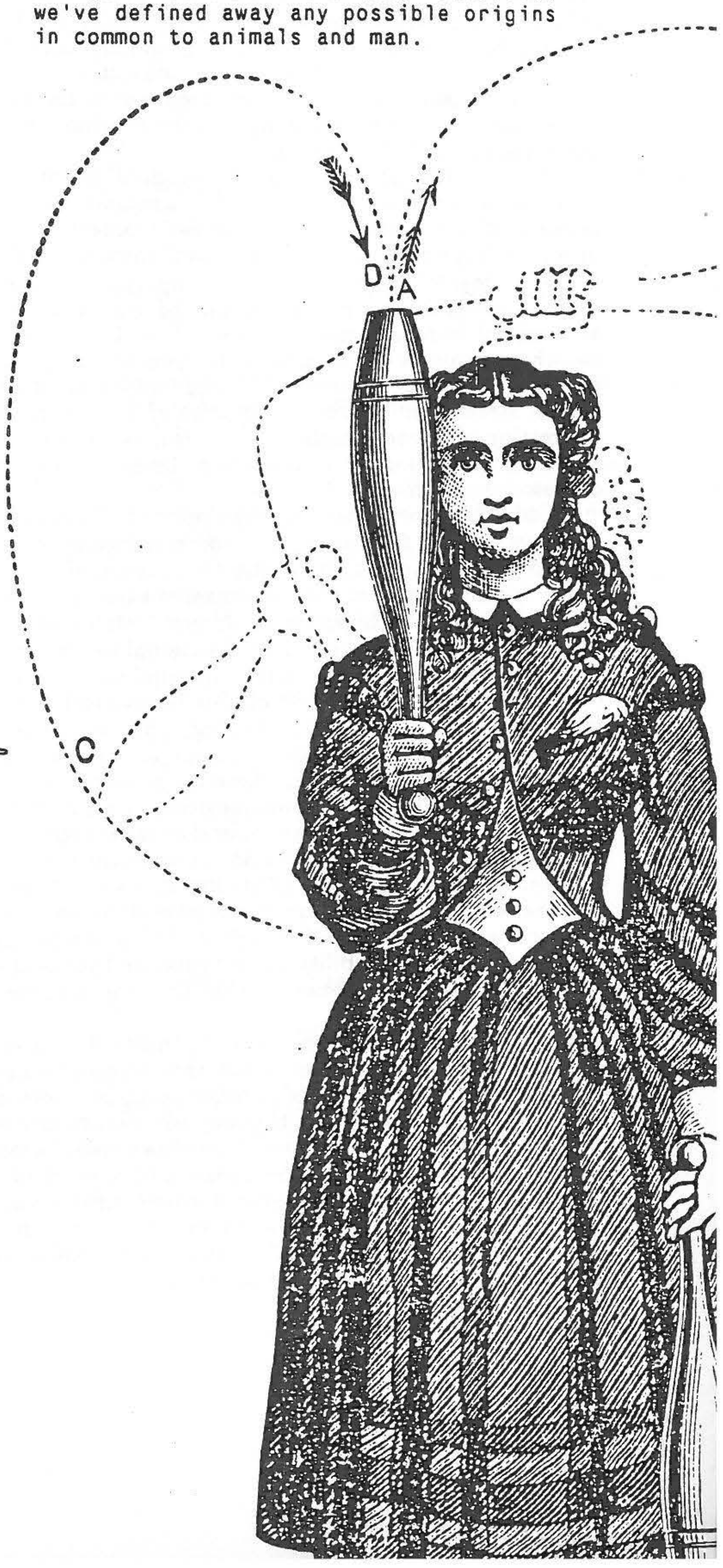
Similarly, speech, when it became the vehicle of language in humans, did not become other than a motor skill any more than piano playing did when it became the vehicle of whatever is embodied in the musical nature of human beings.

The repertoire of symbols and symbol manipulation abilities of the brain required for piano playing or speech in humans is certainly more extensive and complex than that for any motor skill of the chimpanzee. Hence we would agree with others that the human is *unique.* The qualities that come from this complexity remain a fertile area of study; we see in human linguistic abilities large numbers of symbols, formal grammars, a relative freedom from the channel of expression, and so forth. Apparently these qualities of human expression prompt some to conclude that humans not only possess unique linguistic abilities but, in fact, are the exclusive possessors of what they are willing to call linguistic processes. That is, they would claim that human language is unique not only in complexity but in its fundamental nature (6).

It is this last opinion on human language with which we disagree. In the earlier sections of this paper, we rooted symbol manipulation and the development of systems of symbols in the basic regulation of cellular processes. We then argued that internal coordination compelled the use of these internal symbols and was necessary therefore to any external behavior. We also argued that cooperation among animals requires both symbol systems and movement systems, which gives rise to the intimate relationship between linguistic and movement processes from the earliest forms of life. Lastly we proposed that brains could be understood as a continuing elaboration from the early symbol systems of unicellular animals. Therefore, to us the same basic quality of animal organization is continuing in human rule-governed symbol manipulation.

There appear to be two basic arguments that people use to assert that human language is a kind of symbol system fundamentally different from all others: *1)* in human language, we have the capability of creating an infinite number of meaningful combinations of symbols; and *2)* there are an infinite number of symbols that the human can generate and make available for their use.

At the onset, one could define language as the symbol manipulation and communication done by humans period! However, the search for the 'origins' or roots of language is a sham unless we allow the possibility that language occurs in other animals too. Otherwise we've defined away any possible origins in common to animals and man.



Presumably one can construct theoretically an infinite series of sounds resulting from the fingers of the human hand striking piano keys. However, in no way does this possible infinite repetition of motor acts eliminate the constraints of the form of the hand, the muscles that move the hand, and the physical elements in the brain that control the act. In the same way, any animal's movement could be theoretically constructed into an infinite series. Most would agree that infinity in this sense is nonsensical and meaningless. Similarly an infinite linguistic series would result in a nonfunctional (and probably institutionalized) human being, just as the perseveration of orginally meaningful animal behaviors is abnormal and self-destructive.

If it is not true that humans can produce an infinite series, is it perhaps true that we have available to us, because of the nature of our linguistic processes, an infinitely large pool of meaningful combinations of linguistic elements? If this is true, the important question here is whether or not this would be *exclusively* an attribute of human symbol systems. That is, are there no other examples of an apparently open-ended system in which the set of elements, fulfilling various functions in that system, can increase indefinitely? It remains an interesting question whether or not this is the case in certain other biological systems (e.g., immune, genetic, or memory systems)?

An additional constraint must be pointed out. Human language, or any form of animal communication, when it is meaningful, can signify only two classes of conditions: *1*) some aspect of the environment external to the brain, including both perceived internal states of the organism and perceived conditions external to the organism; or *2*) perceived variations in internal states of the brain itself. Neither of these classes is mystical. They represent states of matter and energy that are, at any moment in time, in existence within or without the organism. Within our brains, there is apparently a tremendous capability for the juxtaposition of signs. Such a capability is by itself as nonsensical or meaningless as playing C,D,C,D,C,D on the piano for an infinite length of time. What is meaningful is the juxtaposition of symbols that allows us to make use of the laws of the universe in which we happen to find ourselves. As human beings we are unique in our ability to recognize and make use of our rule-governed behavior and the rule-governed behavior of the universe.

As shown so clearly in the study of thermodynamics, the mystery of the universe is not that human beings have escaped the constraints of other animals, imposed by physical laws; rather it is that any physical reality is constrained. For to be constrained is to have laws, forms, structures out of what, in the absence of constraints, could conceivably be a homogeneous energy field, a vacuum. The marvelous symbolic abilities of humans do not help us explore "other worlds"; they are remarkable in helping us explore a little more of our own.

Language appears open-ended to us because we both accumulate bits of language (words and phrases) and develop language (convey increasingly complex meanings) throughout our lives. One reason why language may so surprise and delight us is that we see and do these adaptive creations within our human time scale. However sensorimotor systems, on a evolutionary time scale, have shown a similar ability to adapt, to accumulate novel elements, to respond creatively to novel circumstances.

The biological system does not just 'handle' experiences with the environment and with itself, it builds upon them, incorporates them into its organization and structure and develops from them. This means that in many biological functions, we see a quality of being able to indefinitely acquire new elements in some sense (the open-ended aspect) and yet we see the resulting organism as dependent and constrained by its personal and species histories. The family of processes which we call memory, the family of processes which we call development, and many others share with language the sense of rules which constrain additions and yet a structure that permits them.

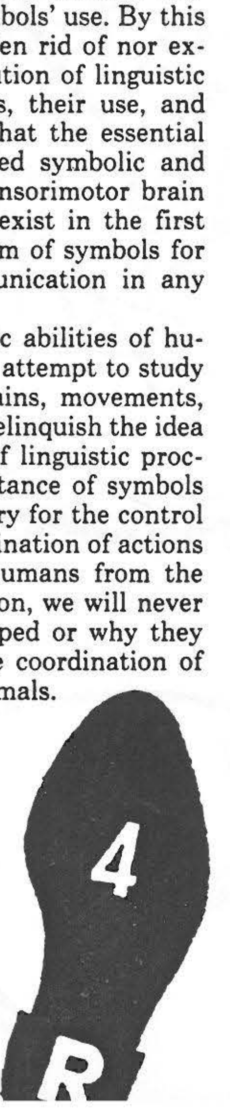
Language is the voice of our souls. More than any other quality humans possess, it makes us feel special as individuals and as a species. The researcher as scientist and as human is pulled in two often contradictory directions: our curiosity and scientific integrity causes us to explore the history of every human ability and to formulate principles that link us to all other creatures; our anthropocentricism and our ego cause us to emphasize the differences between ourselves and other creatures, to seek the exceptions, and to look for the uniquely defining characteristics of being human. We bring up this conflict between our antropocentricism and our science, because it directly affects our perception of the origin of language and movement. The last fifty years have recorded an amazing change in the attitudes of scientists: humans have now been placed on numerous continua that link us to beasts. Also many traditional indices of human uniqueness, for example, tool making, cognition, memory, creativity, social obligation, and even altruism have been acknowledged to exist in animals—and now language.

The first inroad into our attitudes about language is represented by imaginative researchers like Kimura (5), Steklis and Raleigh (13), and Noback (8). Although they argue the evolutionary roots for language, they agree on one issue: speech has its anatomic, functional, and physiological roots in animals. It is part of an orderly evolution in the brains of animals that vocalized, performed rapid manipulation and sequencing of fine movements, and communicated with one another.

However, researchers who do emphasize the similarities of speech to other behavioral systems often do so by excluding the linguistic, symbolic, and cognitive qualities of movement systems. Hence, like Kimura (5), they apparently accept the assumptions that movement processing is somehow concrete and therefore fundamentally different from the abstract, symbolic abilities of language which later come to make use of these movement systems. Hence, although these researchers would argue that the control of the laryngeal, pharyngeal, respiratory, facial, and tongue movements which underlie speech has not risen de novo, language apparently has.

One insightful critic of the research attempting to relate human and animal communication is Lenneberg (6). His well-taken criticisms react against the tendency to reduce human language to human speech to draw continua between animals and humans. These criticisms rightly force us to acknowledge the linguistic and sophisticated cognitive abilities of human speech. In this paper, on the other hand, we wish to claim that perhaps the most important continuum linking all brains of all animals was linguistic. Hence, even though Passingham (9) and Steklis and Raleigh (13) appropriately emphasize the cognitive continua of animals and humans, they do not recognize that all these cognitive abilities (e.g., memory, categorization, and intermodal transfer) are manifestations of a representational system that slowly evolved more symbols to represent more complex internal states and an increasing awareness of external conditions and the rules to govern the symbols' use. By this reasoning we have clearly neither gotten rid of nor explained away the problem of the evolution of linguistic abilities—the development of symbols, their use, and their grammars. We have suggested that the essential problem is not how humans developed symbolic and linguistic abilities from a primitive sensorimotor brain but rather how did symbols come to exist in the first place and what is useful about a system of symbols for the control of movement and communication in any animal.

To focus on the distinctive linguistic abilities of humans is important. However, when we attempt to study the evolution and development of brains, movements, and communication, it is necessary to relinquish the idea that humans are the sole possessors of linguistic processes. We have emphasized the importance of symbols to the internal communication necessary for the control of animal movements and for the coordination of actions among organisms. Without shifting humans from the ultimate intent and creation of evolution, we will never understand how or why brains developed or why they form such a fertile substratum for the coordination of action within animals and between animals.



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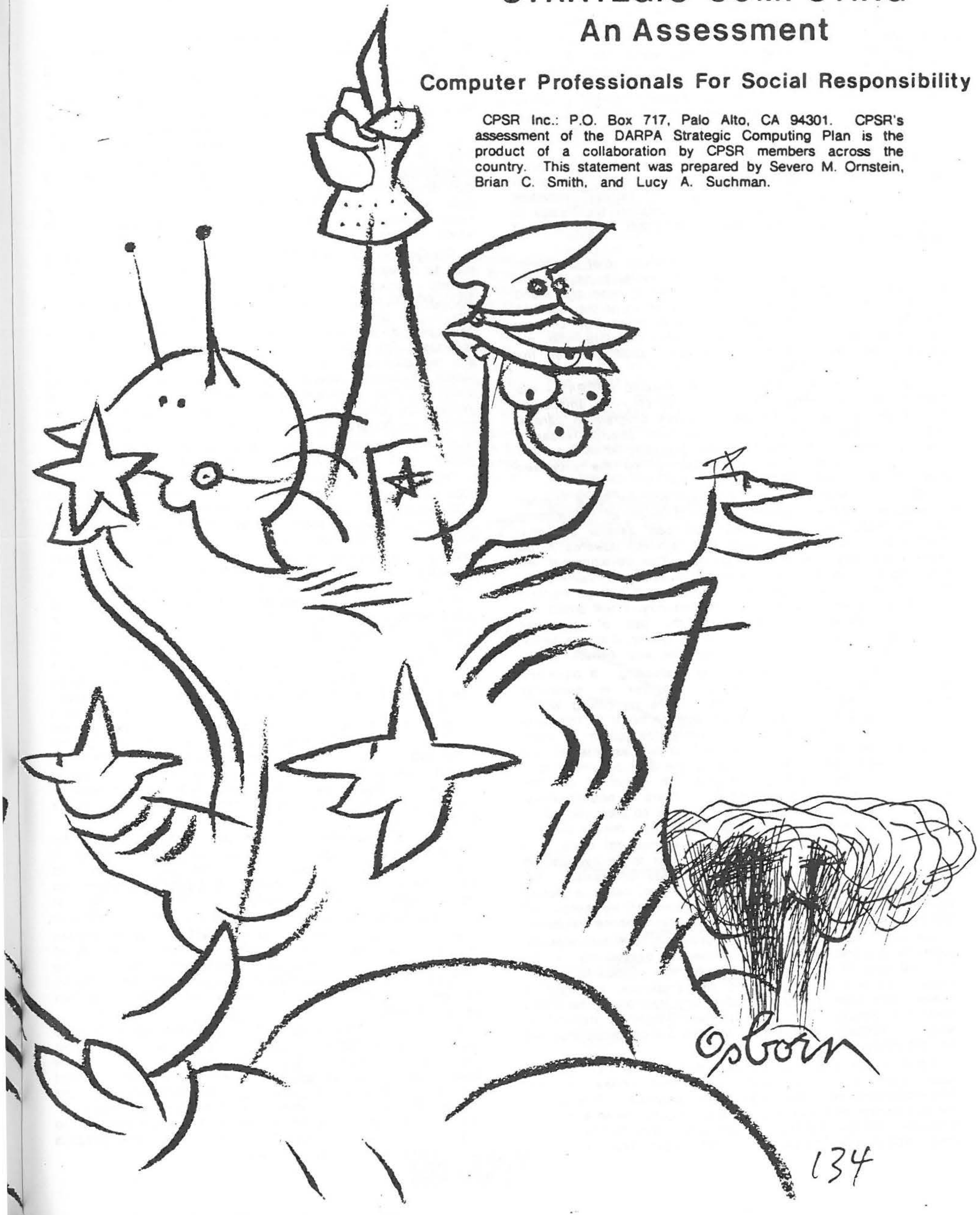
STRATEGIC COMPUTING
An Assessment

Computer Professionals For Social Responsibility

CPSR Inc.: P.O. Box 717, Palo Alto, CA 94301. CPSR's assessment of the DARPA Strategic Computing Plan is the product of a collaboration by CPSR members across the country. This statement was prepared by Severo M. Ornstein, Brian C. Smith, and Lucy A. Suchman.



When the Soviet Union launched the first satellite into orbit in the 1950's, the event provoked widespread concern about the state of scientific research in the United States. As part of its response, the government established the Advanced Research Projects Agency (ARPA) within the Department of Defense, with the mission of promoting basic research in areas potentially relevant to military problems. Since computer science was recognized as one such area, an Information Processing Techniques Office (IPTO) was established within ARPA.

Over the years, IPTO, headed by distinguished computer scientists, has established itself as the principal sponsor of computer research at universities and various industrial laboratories. The advanced state of computer technology in this country is in large measure a direct result of that leadership and support.

It is in the nature of computer systems that particular applications, whether missile guidance systems or hospital information systems, rest on a large common base of generic hardware and software. For this reason, much of the research that ARPA funded was directed towards technology of very general applicability. Most researchers, therefore, did not concern themselves with the intended application of the products of their labors.

Last fall, however, ARPA (by then renamed DARPA — the Defense Advanced Research Projects Agency — to emphasize its mission) decided to embark on a new program in parallel with its ongoing program of basic computer science research. The document describing this new program, known as the Strategic Computing Plan (SCP), clearly ties the proposed research to military applications.

We believe that the SCP is of grave concern for a number of reasons. Having gained control of much of the leading computer science research over the past several decades, DARPA now proposes to direct that research towards much more specifically military applications. This development will have serious repercussions within the research community. More importantly, because DARPA funds such a large fraction of computer science research in this country, it will direct our national priorities with regard to the use of computer technology. Such a strong hand on the rudder, it seems to us, should be subjected to public scrutiny and debate.

Moreover, the SCP is dangerously misleading. It blurs the distinction between straightforward progress in computer science and mere wishful thinking. There is nothing wrong with trying to achieve difficult goals, but the client (in this case the Congress and the public) should be given a clear understanding of how feasible the various aspects of the proposed work really are. In reading the SCP document, one cannot avoid the impression that it was meant to sell the program as much as to describe it. There is nothing novel about that, but because the implications are so profound (at an extreme the document suggests that a strategic missile defense would be handled almost entirely by computers) there is a special responsibility placed on the authors to be exceedingly conservative with regard to promises made or implied. Far from manifesting such caution, the document paints a picture suggesting that its goals are within easy reach if we merely pull together the various threads of computer science research.

Because computer science has achieved so much over the past few decades, people are inclined to believe that it can solve all sorts of problems. Admittedly, the troubles facing the world today are both perplexing and desperate, and help is needed from every quarter, including any technology that might contribute usefully. But if policy makers begin to depend on what is essentially technological fantasy, the consequences will be extremely serious.

Recently the Union of Concerned Scientists has taken it upon itself to make public a critical review of the Administration's so-called "Star Wars" proposal. This seems the appropriate response to such a technically flawed and naive proposal. We feel that the Strategic Computing Plan is similarly irresponsible and misleading. This paper explains why.

Introduction

In the 1940's, atomic physics was about 25 years old. Building on the discoveries of the new field, scientists of the day were able to produce a weapon more powerful than had ever before been conceived. In the 1980's computer science — which also happens to be about 25 years old — has taken over as the critical field underlying modern weapon systems. This fact isn't yet widely recognized; when we imagine nuclear weapons, for example, we tend to think just of the warheads and the explosions, forgetting about the complex computer technology that supports the decision to fire the missiles, and that directs them to their targets. Computer systems are by now used throughout the military, for early warning, communications, weapons guidance, and in the simulations with which targets are selected and battles are planned.

On October 28, 1983, DARPA issued a Strategic Computing Plan to develop a new generation of computing technology for military applications. The SCP initiates a five-year, $600,000,000 program, and there is good reason to believe that this is just the beginning. The proposal contains plans for developing an underlying technology base of new hardware and software. The hardware emphasis will be on microelectronics and multiprocessor architectures, from which DARPA hopes to obtain at least a thousand-fold increase in net computing power. The software component focuses on artificial intelligence (AI) — particularly on what is known as expert systems — to provide machines with "human-like, intelligent capabilities"[1] including natural language understanding, vision, speech, and various kinds of automated reasoning.

On top of this technology base, three specific military applications are to be developed. For the Army, the SCP proposes a class of "autonomous vehicles," able not only to move around independently, but also to "sense and interpret their environment, plan and reason using sensed and other data, initiate actions to be taken, and communicate with humans or other systems." For the Air Force, the SCP plans a "pilot's associate" to aid aircraft operators who are "regularly overwhelmed by the quantity of incoming data and communications on which they must base life or death decisions," in tasks ranging from the routine to those that are "difficult or impossible for the operator altogether" and that require the "ability to accept high-level goal statements or task descriptions." Finally, the Navy is offered a "battle management system," "capable of comprehending uncertain data to produce forecasts of likely events, drawing on previous human and machine experience to generate potential courses of action, evaluating these options, and explaining the supporting rationale." These three applications are intended to illustrate the power of the technology; we are also asked to imagine "completely autonomous land, sea, and air vehicles capable of complex, far-ranging reconnaissance and attack missions."

Two facts about the SCP stand out. First, it proposes the use of artificial intelligence technology in military systems in order to provide a radically new kind of flexibility and adaptiveness. Referring repeatedly to the increasing speed and unpredictability of modern warfare, the SCP promises that computing technology can be developed capable of adapting to "unanticipated enemy behavior in the field."[2] This will require "a new generation of military systems" that could "fundamentally change the nature of future conflicts." The change involves not only increasing the *amount* of computation, but also enlarging its role to include automation of military decision-making.

Second, the SCP makes specific proposals about how to direct computer science research. Rather than letting researchers follow their own course, the plan aims to focus them on military objectives. Various mechanisms are provided to do this, such as a close coupling of fundable research goals and military needs, adherence to strict development timetables, and the selection of specific development projects intended to "pull the technology-generation process" (the three projects cited above are the first examples).

In assessing the SCP, our concern is not with the underlying technology base or with military projects *per se*. Nor do we question the power of AI as a new and important technology. Our concern is that increased reliance on AI and automated decision-making in critical military situations, rather than bringing greater security, leads in an extremely dangerous direction. Specifically, in suggesting such a role for AI, the SCP creates a false sense of security in the minds of both policy-makers and the public. Like all computer systems, AI systems may act inappropriately in unanticipated situations. Because this limit on their reliability is fundamental, we argue against using them for decision-making in situations of potentially devastating consequence.

Automation and Uncertainty

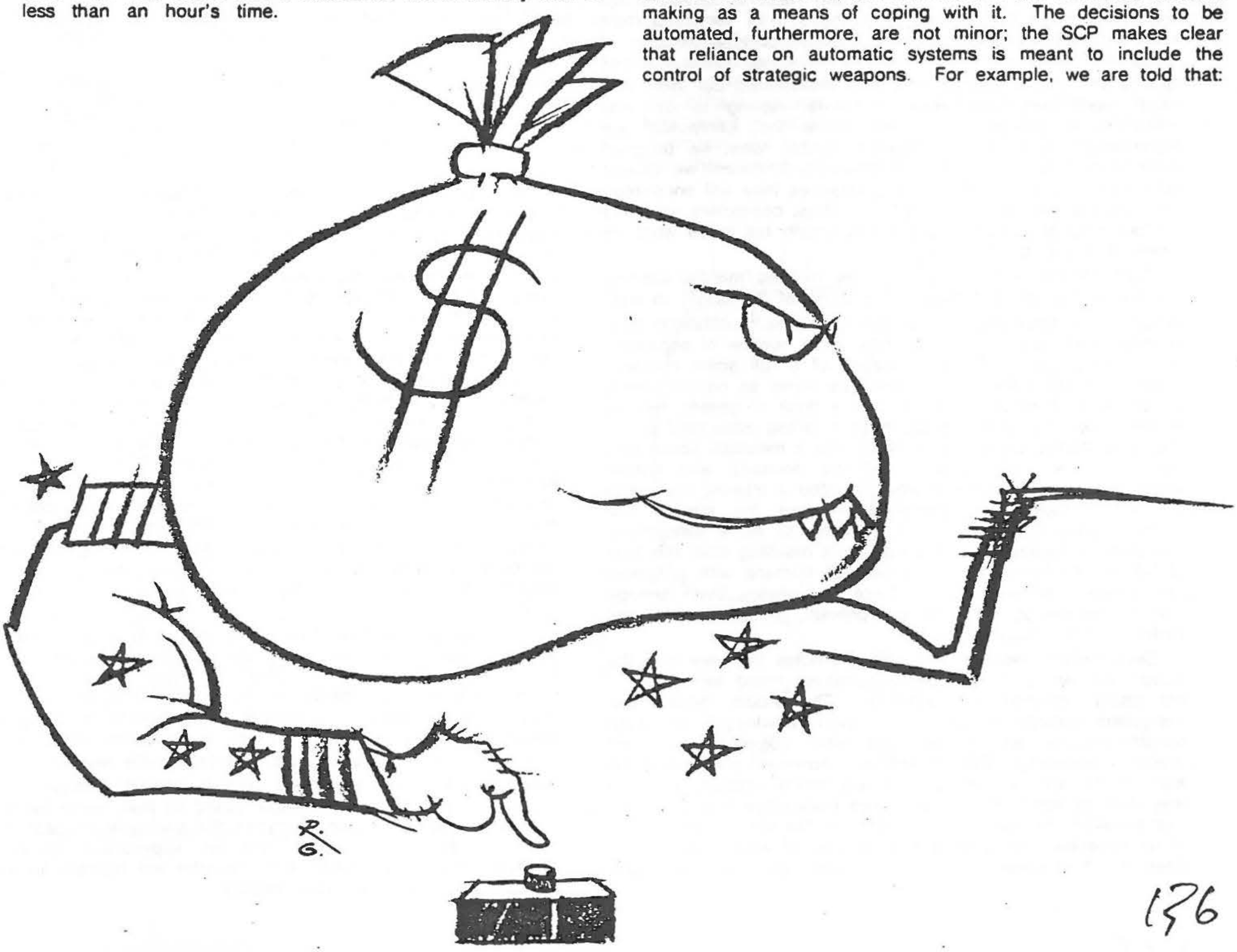
Modern warfare is marked by three interacting trends: increasingly powerful weapons; more separation (in both time and space) between planning and execution; and a faster and faster pace. The first trend means that the consequences of our actions, whether intended or unintended, can be greater than ever before. The second means that we rely on increasingly large, complex, and indirect systems for command, control and communication. The third means that any miscalculation can quickly lead to massive ramifications that are difficult, or perhaps impossible, to control. It is easy to see the dangerous potential of the three in combination. They are all the direct product of technological developments in offensive and defensive weapons systems. And they have brought us to the situation that we live with now: two nations confronting each other with forces that, if unleashed, would destroy both in less than an hour's time.

This danger is recognized on all sides; people differ only in what they think we can or should do about it. But if anything is universally accepted, it is that the current state is precarious — to be disturbed only with extreme caution. Into this situation the SCP proposes to introduce AI as a new ingredient:

> "Improvements in the speed and range of weapons have increased the rate at which battles unfold, resulting in a proliferation of computers to aid in information flow and decision making at all levels of military organization. ... A countervailing effect on this trend is the rapidly decreasing predictability of military situations, which makes computers with inflexible logic of limited value. ... Confronted with such situations, leaders and planners will ... be forced to rely solely on their people to respond in unpredictable situations. Revolutionary improvements in computing technology are required to provide more capable machine assistance in such unanticipated combat situations. ... Improvements can result only if future computers can provide a new 'quantum' level of functional capabilities." [pp. 3 – 5]

What this means in plain English is this: Faster battles push us to rely more on computers, but current computers cannot handle the increased uncertainty and complexity. This means that we have to rely on people. But without computer assistance, people can't cope with the complexity and unpredictability, either. So we need new, more powerful computer systems.

In observing that increased uncertainty and confusion are critical problems of modern warfare, the SCP accepts the situation as inevitable, and embraces AI and automatic decision making as a means of coping with it. The decisions to be automated, furthermore, are not minor; the SCP makes clear that reliance on automatic systems is meant to include the control of strategic weapons. For example, we are told that:



"Commanders remain particularly concerned about the role that autonomous systems would play during the transition from peace to hostilities when rules of engagement may be altered quickly. An extremely stressing example of such a case is the projected defense against strategic nuclear missiles, where systems must react so rapidly that it is likely that almost complete reliance will have to be placed on automated systems. At the same time, the complexity and unpredictability of factors affecting decisions will be very great." [p. 4]

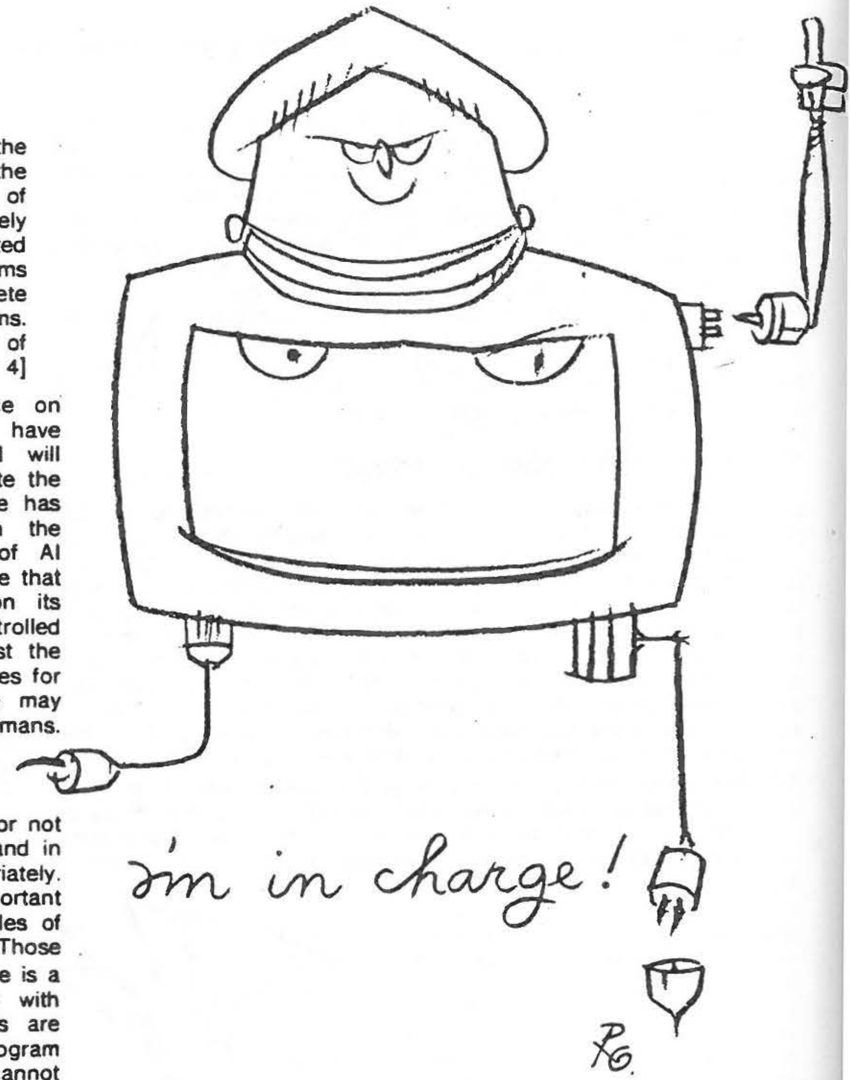
The SCP offers no argument to warrant this reliance on automatic decision making. Although computers have contributed to more effective weapons systems, and will continue to do so, it doesn't follow that we can automate the complex processes of assessment and judgment. There has been a long-standing and unresolved debate within the computer profession about what we should expect of AI systems, and when. If nothing else, everyone would agree that AI is still in its infancy; the first systems based on its technology are just beginning to be used, in highly controlled and delimited circumstances. But the problem isn't just the field's lack of maturity. The problem is that the SCP hopes for reliable decision making in circumstances where there may simply be no way to achieve it, with computers or with humans.

The Limits of Reliability

Any computer system, however complex, and whether or not it incorporates AI, is limited in the scope of its actions and in the range of situations to which it can respond appropriately. This limitation is fundamental and leads to a very important kind of failure in reliability — beyond the obvious troubles of transistors shorting out, or systems breaking down. Those failures are serious enough in and of themselves, but there is a much more intractable kind of failure, having to do with limitations of design. The problem is that computers are maddeningly literal-minded; they do exactly what we program them to do. Unfortunately, except in trivial cases, we cannot anticipate in advance all the circumstances they will encounter. The result is that, in unexpected situations, computers will carry out our original instructions, but may utterly fail to do what we intended them to do.

Such failures are very real. The ballistic missile warning systems of the US (and presumably those of the USSR as well) regularly give false alarms of incoming attacks.[3] Although most of these alerts are handled routinely, on a number of occasions they have triggered the early stages of a full scale reaction. These false alerts stem from causes as varied as natural events (in one case a moonrise, in another a flock of geese), failures in the underlying hardware (such as a failing integrated circuit chip that started sputtering numbers into a message about how many missiles were coming over the horizon), and human errors (such as an operator who mounted a training tape onto the wrong tape drive, thereby confusing the system into reacting seriously to what was intended to be a simulation). The primary insurance against accidents resulting from this kind of failure has been the involvement of humans with judgment and common sense. So far, there has always been enough time for people to intervene and prevent an irretrievable, and perfectly real, "counterattack."

Despite these lessons, the SCP promotes the view that the human element in critical decision-making could be largely, if not totally replaced by machines. This would require that computers embody not only the "expert knowledge" for which expert systems are named, but also common-sense and practical reasoning. Such capabilities, however, are beyond the state of the art. Expert systems are called "expert" because they capture some of the specialized knowledge that an expert has acquired, not because they surpass the abilities of the rest of us generally. In spite of a great deal of work, there hasn't been much progress in automating plain old common sense.



What distinguishes common sense reasoning is the ability to draw on an enormous background of experience in the most unpredictable of ways. In directing a friend to your house, for example, you don't have to give instructions about all the possible things that might happen along the way: fallen trees, accidents, flat tires, etc. Similarly, if you were to say *The city council didn't give the demonstrators a permit because they feared violence*, you would expect your audience to know immediately that the word 'they' refers to the councillors, not to the demonstrators, because in that kind of situation the council members would likely be afraid. The point is that an extraordinary range of knowledge and experience may be relevant; we never know what we'll need, or when we'll need it. Nor do we usually even notice that we are using this background knowledge. Both of these facts undermine any attempt to codify common sense knowledge and practical reasoning. This is one reason why computer errors so often violate common sense (as is clear from popular stories about computer billing errors, inventory mix-ups, and so on). Current expert systems don't have the common sense of even a small child.

In terms of their fundamental limitations, AI systems are no different from other computer systems. What computers do is to carry out, with lightning speed and unparalleled accuracy, rules that a human programmer has coded in advance. It is the job of programmers and system designers to anticipate ahead of time, as best they can, the range of situations that a computer system will encounter, and to provide recipes for the full array of possible actions that it should take in those situations. All this planning is designed so that, when the time comes, the computer can recognize the particular situation that does in fact arise, and select an appropriate response. Because of its great speed, the computer will typically be able to select a response very rapidly.

This all sounds very promising: designers plan carefully in advance, so that the computer can respond instantaneously when it matters the most. And it often works very well, as in the case of the computers that control the phone system, help to land aircraft, and provide guidance for missiles. The problem, however, is that the behavior of the system depends entirely on the structure of the programs — on the rules and the ways in which they are put together. Classical computer systems not only have rigidly pre-specified rules, but put them together in brittle and inflexible ways. What distinguishes AI and expert systems, and gives them the "flexibility" so touted by the SCP, is that they faciliate more productive interaction of the rules. But they continue to rely on the programmer's ability to state the rules ahead of time. And to state the rules, the programmer must first develop a conceptual structure that is appropriate to a given problem area.

The rules on which all computer systems are based, in other words, treat the world as if it were built from a stock of pre-defined building blocks, put together in carefully prescribed ways. AI systems are particularly good at dealing with very complex configurations of these building blocks, often better than more traditional computer programs. But they are ill equipped to respond appropriately to new kinds of block. As one might expect, they work best in areas that are well understood, highly constrained, predictable, and easily controlled (such as arise in manufacturing, scheduling, etc.).

In more complex environments, unanticipated events are liable to trigger anomalous reactions. That is why the radar reflections off the rising moon fooled the NORAD system; moons were not among the building blocks in terms of which that program categorized the world. The system had no way to say *Oh, yes, I forgot about the moon*, because it had no common sense to underlie its set of domain-specific rules. Even worse, computer systems don't "know" that they are encountering an event outside the scope of the assumptions on which they were built; they merely sort every event into the pre-specified set of categories. Not only was the moonrise not recognized as such; it was mistaken for something quite different.

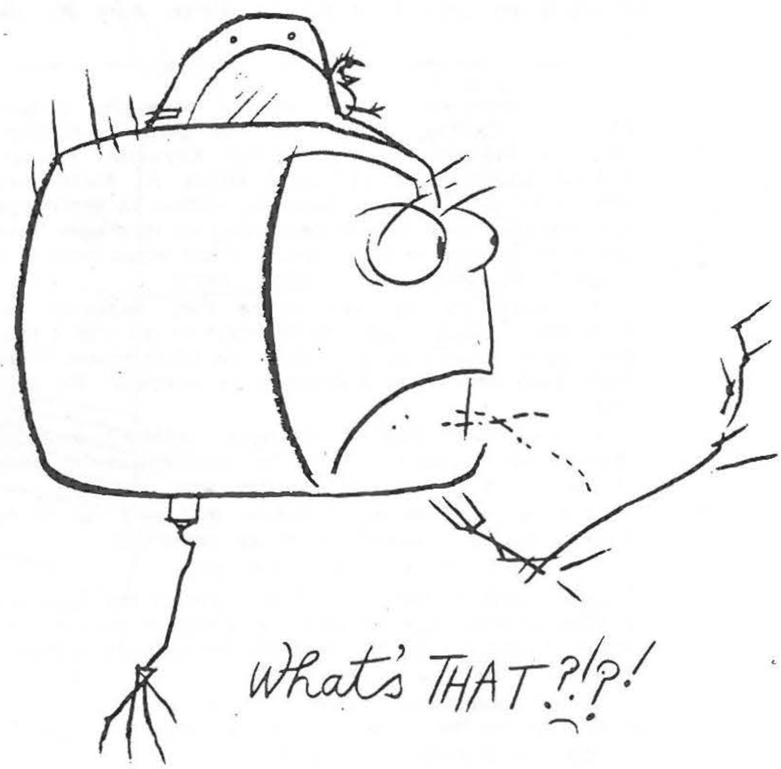
All complex systems, including AI systems, have to evolve for a substantial period before they are reliable enough to be used. The first version of such a system will invariably contain flaws, some of which will be obvious as soon as it is installed. Other more subtle problems will surface only after the system has been used over a period of time in a wide variety of situations. During this evolutionary period, the system makes many, often serious, errors, some of which require substantial modifications to correct. These errors, furthermore, may interact; the "fix" to one problem will often introduce another problem of greater subtlety. In this process, perfection is never achieved: the best one can hope for is to reduce the rate at which new flaws reveal themselves to an acceptable level. At that point the system will be described as "reliable," and may lead us to a sense of security. Even in the most reliable systems, however, residual flaws, although improbable, may nonetheless surface with dramatic effects.

The Northeast power failure of 1965 demonstrates how a large system containing hidden design flaws can run trouble free for years, and then suddenly collapse when confronted with unexpected circumstances. In that case the problem stemmed from a protective backup relay on a transmission line in Ontario, Canada, operating just as it was designed to do, that set in motion a chain of events resulting in loss of power over an area of some 80,000 square miles of the Northeastern United States. In 1980, in the nationwide computer communications network known as the ARPANET, a similar problem brought all communication to an abrupt halt.[4] Though they usually have less dramatic consequences, problems of this sort arise in all computer systems.

Computer systems that achieve a sufficient level of reliability to be used in real applications do so because they are heavily tested *in situ*. After being installed in their particular domain, they are observed, extended, and corrected to meet real world conditions. No amount of testing under simulated conditions can replace the testing that comes from embedding the system in the actual environment for which it was designed. The reason is quite straightforward: simulated tests exercise exactly those circumstances that the designers expect the system to encounter. It is the designers, after all, who build the simulators, based on the same understanding of the problem area used to build the system in the first place. But all experience with complex systems indicates that it is the circumstances that we totally fail to anticipate that cause the serious problems.

One obvious solution to the problem of unexpected events is to provide ways for human operators to intervene and override the default system behavior. But this too is a problem; we just don't know yet how to build large systems with substantial human interactions such that the combination is reliable. Given a person capable of perfectly adequate performance in a domain without machine assistance, and a supporting machine capable of adequate performance on its own, the combined "system" is often capable of quite poor performance because of problems in the interaction (Three Mile Island is perhaps the best known example).

Finally, when a computer system is intended to be used under crisis conditions, all of the standard problems are likely to be highly aggravated. The behavior of any system is only as predictable as the behavior of the people and technology that make it up. Yet human behavior in situations of fear and confusion is notoriously unpredictable — imagine the unpredictability of two countries at war. Systems designed for use under crisis conditions should be thoroughly tested before one begins to rely on them. And yet it is an inescapable fact that military systems — especially nuclear systems — cannot be fully tested in advance, nor can crisis conditions ever be fully simulated. As the SCP points out, it is the unpredictability of war that poses the gravest threat.



The Myth of Technological Solutions

If the uncertainty of battle is so serious a problem, and if computer systems are so unreliable in the face of it, why should the SCP propose computer technology as a solution? The easiest explanation seems to be a version of "If we can do it, we should do it": if there is some possibility that we can build new military systems, especially powerful new computing systems, we should press forward and try to do so.

There are also more subtle answers. Sophisticated AI computer systems are scientifically intriguing; they enable us to explore areas of human capability in which we have enormous interest, including those areas that are relevant to coping with uncertainty. The hope that AI systems could cope with uncertainty is understandable, since there is no doubt that they are more flexible than traditional computer systems. It is understandable, but it is wrong, because in the end the increased flexibility is limited by the same inexorable facts that limit all computer systems.

Over the years, the lure of AI has led to a growing appetite for research funding. The appetite in turn has led the professional community to make numerous promises, many of which have turned out to be more difficult to fulfill than was originally anticipated. For example, it was widely believed in the 1950s that we would soon have fully automatic machine translation, an accomplishment that still eludes us. These unfulfilled promises are frequently a combination of ordinary naivete, unwarranted optimism, and a common if regrettable tendency to exaggerate in scientific proposals. Shortcomings are often masked by subtle semantic shifts. When we fail to instill "reasoning" or "understanding" in our machines, we tend to adjust the meaning of these terms to describe what we have in fact accomplished. In the process, we obscure the real meaning of our claims for the power of AI.

When claims are taken literally, without appropriate qualification, they give rise to unrealistic beliefs about the power of AI technology. Policy makers, even those close to the profession, are not immune to such misconceptions, as illustrated in the following discussion of the Defense Department research on space-based weapon systems (from an AP article on page 4 of the LA Times, April 26, 1984):

... The fireworks began when a panel that included Robert S. Cooper, director of the Defense Advanced Research Projects Agency, George Keyworth, Reagan's science adviser, and Lt. Gen. James A. Abrahamson, director of the Strategic Defense Initiative, acknowledged that a space-based laser system designed to cripple Soviet long-range missiles in their "boost" phase would have to be triggered on extraordinarily short notice.

To strike the boosters before they deployed their warheads in space would require action so fast that it might preclude a decision being made in the White House — and might even necessitate a decision by computer, the panel said.

At that, Sen. Paul E. Tsongas (D-Mass.) exploded: "Perhaps we should run R2-D2 for President in the 1990s. At least he'd be on line all the time."

"Has anyone told the President that he's out of the decision-making process?" Tsongas demanded.

"I certainly haven't," Keyworth said.

Sen. Joseph R. Biden Jr. (D-Del.) pressed the issue over whether an error might provoke the Soviets to launch a real attack. "Let's assume the President himself were to make a mistake...," he said.

"Why?" interrupted Cooper. "We might have the technology so he couldn't make a mistake."

"OK," said Biden. "You've convinced me. You've convinced me that I don't want you running this program."

Mr. Cooper's final comment betrays a belief that computers are competent to take over critical decisions, and might correct deficiencies in human judgment as well. As the discussion shows, common sense suggests that these claims are implausible. It might have been that common sense was wrong — that the underlying science had advanced beyond the layperson's expectations. But we believe that the skepticism is in fact well-founded.

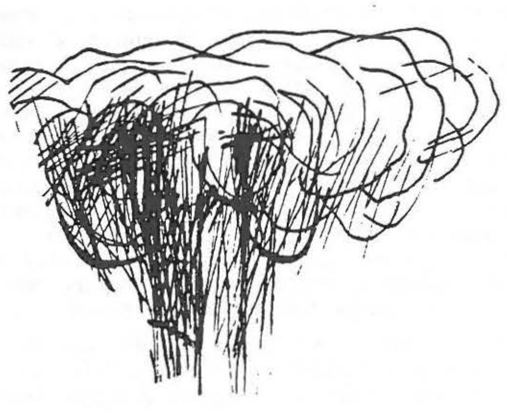
To cope with problems of complexity and speed in modern warfare, the Strategic Computing Plan proposes a quantum leap in computer technology, comparable to the advent of nuclear weapons technology in the 1940's. Ironically, the problems arise in part from the very technology that is proposed as a solution. The situation is like that of a debtor who, in order to pay off past debts, has to borrow ever larger amounts — a strategy that almost invariably ends in bankruptcy. Past attempts to achieve military superiority by developing new technology, rather than increasing our security, have brought us to the present untenable situation. The push to develop so-called "intelligent" weapons as a way out of that situation is another futile attempt to find a technological solution for what is, and will remain, a profoundly human political problem.

1. Unless otherwise noted, all quotations are from *Strategic Computing, New-Generation Computing Technology: A Strategic Plan for its Development and Application to Critical Problems in Defense*, Defense Advance Research Projects Agency, October 28, 1983.

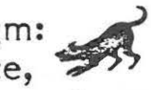
2. Electronic News, March 19, 1984, p.18.

3. See, for example, the Hart-Goldwater report to the Committee on Armed Services of the United States Senate, *Recent False Alerts from the Nations Missile Attack Warning System*, U.S. Government Printing Office, Washington, October 9, 1980 and "Accidental Nuclear War," Newsletter of Physicians for Social Responsibility, Inc., Vol. III, No. 4, Winter 1982, p.1.

4. This incident, which occurred on October 27, 1980, is described in an article by Eric Rosen in the ACM SIGSOFT Software Engineering Notes, Vol. 6, No. 1, January 1981.



Notes from a session on The General Systems Paradigm: Model for a Changing Science, held at the 143rd Annual Meeting of the American Association for the Advancement of Science, Denver, Colorado, February 25, 1977



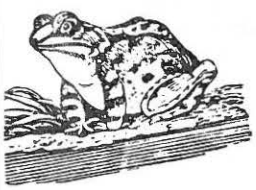
By **Kenneth Boulding**

Ernst von Glaserfeld:

From Plato to Boulding philosophers sweat
About how much reality images net,
So we roundabout roundabout roundabout go
On how do we know that we know that we know.
And in between long philosophical pauses
We think about causes of causes of causes.
But you stand in a great intellectual bog
If you cannot distinguished a leaf from a frog,
And when I look into a mirror at me
I cannot experience the thing that I see,
So nothing of this makes a great deal of sense
Without the new logic of self-reference.

Joseph Gouguen:

Ethnomethodology hopefully fits
The problem of subjective-objective splits;
If we listen for ever to talk that is taped
We finally catch things that might have escaped.
But if I become what I partially see,
I worry about what has happened to me.



Francisco Varela:

The world that is seen in the eye of a frog
Is different from that seen by man or by dog,
But any old image will lead to survival
If each will behave just as well as its rival.
And so we can prove with experiments neat
That kittens can see with the soles of their feet.
And no matter what glasses we wear, we will train
Ourselves to be King of a Knowledge Domain.
So Knowledge will mostly turn out to be crap
Unless we can learn how to walk on our map.

Margaret Mead:

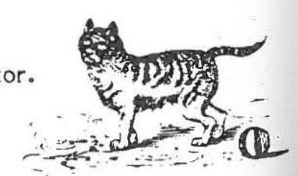
If we think of the moon as the wife of the sun
A proper astronomy <u>never</u> gets done;
But think of your wife as a kind of a moon,
You can bet Dr. Freud that you'll be divorced soon.
And a fact that creates a wide difference of view
Is that women feed babies and men seldom do.

James Miller:

If science is seen as a big living system,
It comes from our cells, and unless we have missed 'em,
We find 19 pieces that come right up through
And finally end up in me and in you.
Then nine information types tie us together
And help us explain both the why and the whether,
And so science fruits into succulent kernels
That end up as papers in technical journals.
And from these a sweet emanation arises
That finally falls out as big Nobel prizes.

Margaret Mead:

A scientist caught out in the telling of lies
Will never get back in the club till he dies,
And a scientist guilty of mishandling data
Will be found out in time by some dull replicator.
And so by the shaving of error, in sooth,
What's left has a larger percentage of truth.



Oliver Heaviside and the ATandT

The spectacle of a single poor, deaf man negotiating with equal strength with a company greater than many nations and successfully defying it

A movie proposal by Norbert Wiener

South Tamworth, N.H.
June 28, 1941.

Orson Welles, Esq.

c/o

Hollywood, California.

My dear Mr. Welles:

I recently attended a performance of your CITIZEN KANE, and was very much impressed with the ating, writing, photographic and sound technique, but particularly with the directing, and the way in which it gave verisimilitude to the entire career of Kane and the other characters, with their rise, culmination, and their fading into inactivity and oblivion -- except in K's own case -- as they grow old. In the past, I have had to collect the facts about a man's life for a series of feature articles, and the reconstruction of a character from the reminiscences of friends and associates is entirely as you picture it. Besides your own acting, I was particularly impressed by the medically accurate picture of senile cerebral arteriosclerosis given by the actor portraying Kane's old associate in the hospital on Welfare Island, and by the performance of the part of the cynical, vulgar, sharp, loyal little Jewish business manager. These characters are not stencils: they are taken from real life, and they stand on their own feet, three-dimensionally.

I am writing to you, not only to express my appreciation, but to call to your attention a very dramatic piece of history which may lend itself to your techniques of narration and performance. I am fully aware that a technique which is revolutionary on its first introduction, may become conventional on its second repeitition and a cliche on its third. Nevertheless, you have been so prodigal of innovations in your picture that I cannot think that you have intended to lock the door on their future use.

The events which I wish to suggest to you as raw movie material, though I have been born too late to participate in them, are well known to me, through my perusal of the documents, my personal conversation with the minor figures, and my professional activities. In this latter connection, I am professor of mathematics at the Massachusetts Institute of Technology, have done a certain amount of electrical engineering design work, and have spent much time in exploring the mathematical justification of the work of Heaviside, the chief figure of the events I shall relate. I regard him as one of the really great figures of his generation, and this is the general opinion of those competent to judge.

These events concern the foundation of the American Telegraph and Telephone Company (or is it Telephone and Telegraph). The chief figures are:

OLIVER HEAVISIDE, 1850-1925. Born in poverty, lived in poverty, died in poverty. Englishman, protege of the engineer Wheatstone. Came from a petty bourgeois family, so quarrelsome and unappreciative of him that at his death two different groups quite illegally tried to grab his personal library and correspondence from one another, and to sell them, with the result that part of the collection was where it belonged, in the library of the Institution of Electrical Engineers in London, while the rest was bought up finally by B. A. Behrend, the American electrical engineer, who finally presented it to the IEE.

Heaviside was self-taught, excitable, bitter, quarrelsome, and quite deaf. As a young man, he worked as an operator on the lines of the Great Northern Telegraph Company, in the Newcastle office, where many uncollected written memoranda of his remain. Later he was an employee of the Post Office, I believe, until his deafness caught up with him. He lived in a respectably sordid part of Camden Town in London, attended meetings of the Electrical Society (I am not quite sure of the name), where he scarified those—and there were many—who lacked his engineering and mathematical acumen, and sent profound and unintelligible papers to the Electrician, which without fully understanding his genius, at least understood that he was a genius, and on the whole gave a good-natured tolerance to his eccentricities. These papers, completely unreadable to his contemporaries, constituted the mathematical Magna Charta of the modern telephone. They were published privately by Appleton in two three-volume collections—Electromagnetic Theory, and Electrical Papers. These books occupied so much warehouse space to so little purpose that the firm destroyed them, with the result that they have become collectors' items, and that the needs of the working engineer have caused the reproduction in zinc-plate of at least three pirated editions—one in China. Copies of the reproductions are a necessary nucleus of the library of every communication engineer of the present day.

Heaviside was undersized, bearded, of slight physique, and except for his piercing eyes, restless with the strain of the double duty which a deaf man puts upon them, was utterly insignificant. His favorite sports, in so far as he had any, seem to have been walking and bicycling. He seems to have been utterly self-contained, and though he had friends, admitted none to intimacy.

In his later years, after his Camden Town days, he settled in a little house in Torquay, in the West of England. I have heard, though I am not sure of the facts, that for a time he kept a second-hand bookshop there. It was to Torquay that the President of the Institution of Electrical Engineers, and on another occasion, B. A. Behrend, Vice President of the American Institute of Electrical Engineers, made pilgrimage, to persuade Heaviside to receive the highest honors of these two societies, which they only did with the utmost difficulty. In both cases they had to appeal to his personal friendship for them and to his unwillingness to hurt them to make Heaviside accept honors which had been tarnished for him by coming too late.

In his later years, weakened by poverty and the deprivations of the last war, Heaviside became almost helpless. A neighboring policeman, who regarded him with a good-natured contempt, brought him his daily milk and groceries. In this state, in 1925, Heaviside died as the result of injuries sustained some weeks before in a fall from a ladder.

Heaviside's works and letters abound in apothegms as biting as Swift's. On one occasion, after some particularly bitter attack on the narrowness of the Cambridge mathematicians of his day—and the Cambridge mathematicians of his day were on the whole a weak lot—he makes the statement that "Even Cambridge Mathematicians deserve justice." This may not seem particularly biting, but I have not H's works at hand here, and I can not give more striking examples.

Besides Heaviside, the other protagonist of our story is:

MICHAEL PUPIN. Born a Serbian peasant. For details of his life, see the apologia, From Immigrant Boy to Inventor, which is particularly nauseating panegyric of American as the Hope of Opportunity and of himself as the Self-made Hero. It should be placed beside Bok's egregious effort and the autobiography of Mary Antin.

Next in importance come:

THE FOUNDERS OF THE ATandT. These gentlemen are personally unknown to me, and I have no very clear idea of their dominating traits, singly and severally, but I take them to have been fine examples of the feral age of modern business: perhaps intelligent, certainly shrewd, quite possibly good fathers, husbands, and church members, not deliberately dishonest, but most certainly convinced that an idea, a dollar, and the public were all the rightful prey of the first entrepreneur with the enterprise to take them in.

As minor characters appear:

SIR WILLIAM HENRY PREECE, Chief Engineer of the British Post Office. Bland, charming, official, and not without a certain strictly limited intelligence. (He had a great deal to do with the Post Office's interest in Marconi.) Nevertheless a fool.

As Greek chorus I suggest:

B. A. BEHREND. Chief Electrical Engineer for Allis Chalmers. Born in Switzerland. Cultured, witty, charming, cynical, contemptuous of the skulduggery of business competition, but not unwilling to play poker if poker was the game on the table. He was one of those who made the pilgrimage to do honor to Heaviside at Torquay.

We must not forget:

Mr. C------ (Still alive and well.) The real inventor of the wave filter and originator of the details of modern loading-coil technique, as all his colleagues in the profession recognize. Not known outside the profession.

You will observe that there is no woman in the cast. Unless there was (or is) a Mrs. Pupin, there were no women in the cast. I can imagine a woman egging on Pupin's colossal vanity, but without any documents at hand, I have no right to assume that there was one.

Now for the story. In the late 'eighties, the telephone wasn't out of diapers yet, and while it was useful for short distance communication, its range was very short. There was however a speculative interest in what should be done to increase its range. Preece, led probably by the sound of the word "capacity," suggested increasing the electrostatic capacity of the line. Heaviside as a telegrapher well knew that the difficulty of the transoceanic cable was the excessive amount of this very same capacity, which makes any sudden change in a message dissipate itself over the entire ocean instead of appearing in the instrument at the other end. Preece held Heaviside's career in the hollow of his hand; but like the bourgeois Cyrano that he was, Heaviside did not hesitate to damn Preece's folly with a very careful naming of chapter and verse, and a very worldly-unwise choice of the most cutting epithet and most damaging example.

Heaviside was not content to state what was wrong. He set it right. He developed the theory of the distortionless line. If the four running constants of a line are properly proportioned--resistance, leakage, capacity, and electromagnetic inductance, the line will transmit a sound to the far end, weakened indeed, but not changed in character and rendered unintelligible. In the ordinary line, the inductance is not enough to realize this balance. Heaviside pointed out the proper balance, and the means to obtain it. He suggested that at distances of the order of one mile, the line be interrupted by coils of copper wire with cores of powdered iron, of an inductance specified by him.

At this time, one of Heaviside's brothers was connected with the Post Office in a practical engineering function. Heaviside actually tried his device out on one of the longer English telephone lines. I suspect from Heaviside's writings that the experiment was furtive and unauthorized. Partly because the line was too short to make a decisive experiment, and partly because the trial was of too brief duration, the results were ambiguous. Heaviside never applied for a patent. Even if he had, by the time long lines came in in the early 1900's, his patent would not have had many years to run, and would not yet have brought him in one penny. As it was, it was "dedicated to the public," in legal phraseology, and neither was, nor was capable of becoming, the property of anyone.

In the early days of the telephone industry, the service of a city was analogous to its gas or electric light service: a local monopoly, capable of being joined in holding companies joining many cities, but also capable of being developed without any reference to other cities. Indeed, in many places it was not even a monoploy, but several companies strove with one another to acquire the local traffic. Even where the conditions were better, there was no compelling reason to organize the industry as a whole.

The ATandT was formed in 1900 to centralize the industry in the United States. This could be done on only one basis, that of long lines. Long lines were only possible then, and for many years later, until the invention of amplifiers, on the perfectly sound basis of Heaviside's loading coils. However, this method, though the invention of Heaviside was the legal property of no one; and no company could dare to make the heavy speculative investment needed for the installation of long lines without the protection from random competition, or in other words, without a monopoly.

Since the only true basis for such a monopoly was then a patent on loading coils, and since Heaviside had no legal papers to show his fatherhood of his intellectual child, it was necessary to find another daddy for the baby. Even though the original idea could no longer be patented, some subsidiary idea might be. This would serve two ends: the legitimate one of giving the ATandT rights in the new improvement, and the more questionable one of securing a basis of litigation which might scare competitors off the entire long line field, because of legal expense, the engineering ignorance and generally unpredictable behavior of judges and juries, and the prestige which ATandT would have by having actually the first patent in the field.

As to the details, there were two possible courses. One was to have the new developments made by an ATandT engineer, and the other was to buy an outside invention, if possible. The first would have been much cheaper in cash over the counter. On the other hand, in a lawsuit, some judge or jury might have been persuaded to look askance at a patent made inside the company. Moreover, an invention brought from an outsider for a good round sum in hard cash would look a lot more convincing than an invention bought as per contract of employment for the sum of one dollar from an employee hired by the year to invent for a fixed salary.

There was one point which Heaviside had not stated with full explicitness in his published work, although the evidence is pretty clear that he knew the answer. This was the spacing of the loading coils. Heaviside gives a mile as the distance, which is a practical working one. He does not, however, give the principle determining this spacing. Actually, this distance is only critical one way: it can not be too big, or it will suppress the higher tones of the voice. It was here that the ATandT people secured their patent. They attacked this problem from two directions.

Mr. C——, who was then a young man in their employ, developed the desired spacing theory. Furthermore, and this is his real claim to greatness, he saw how the very imperfections of the line with too wide a spacing could be used as the basis of a new invention—the wave filter. In both cases, C——'s work is the real parent of all later investigations. On the other hand, Pupin put in a claim for both these inventions at the patent office. How he came to work on these problems I do not know, nor whether it was entirely independent of stimulation from the ATandT. At any rate, the matter came into interference proceedings in the U.S. Patent Office:-proceedings to which Heaviside was naturally not a party. Pupin won these, and the ATandT paid for his rights a sum which I have seen variously stated as one half a million dollars and a million dollars.

Observe now the position of the characters in our little drama. The company had a valid patent, established as valid by proceedings which had gone triumphantly against them, and the presumption that they would not spend half a million dollars for nothing, and certainly covering the spacing of the loading coils. Until this patent had been fought all the way to the Supreme Court, no man could say that it did not legally cover the loading coil in each and every aspect. Anyone who should have bucked the ATandT on the mere chance of a favorable decision in this matter would have been a damned fool. Mr. C------ had a steady job with the company, a great reputation and a great deal of sympathy in strictly professional circles within and without the company, for it was known that his was the sounder work. Pupin had a fortune, and the job of convincing himself that he had really deserved it. Heaviside had nothing but a clear conscience, and the freedom to say exactly what he thought.

He most certainly said it. He made fun of Pupin's work—and it certainly had plenty of weaknesses—and of Pupin's character—and that had plenty of weaknesses too. From the secure citadel of utter poverty, and a minimum of wants, he said things that stung even the great American Telephone and Telegraph Company—because they happened to be true. The Company tried to pay him for his early work. Undoubtedly there were human men in the Company, and I prefer to think that it was this humanity, coupled with a guilty conscience and a knowledge of his profound poverty, that prompted the offer. We can not forget, however, that a hostile Heaviside might have proved profoundly embarassing to the ATandT, just in case some strong competitor might arise somewhere to stick a knife in their ribs.

Heaviside, however, far from being flattered or intimidated by what was to become the greatest corporation in the world, refused to accept one penny except as a payment for his invention, upon the acknowledgment by the Company that he, and not Pupin, was the true inventor of the loading coil. This, however, the Company could do under no condition. It would with one stroke of the pen destroy all its monopolistic rights, and render valueless its chief stock in trade. Thus, we have the spectacle of a single poor, deaf man negotiating with equal strength with a company greater than many nations, and successfully defying it.

In this battle between the great company and a great man, Pupin received the blows of both sides. Heaviside despised him as a fraud, and the company despised him as a stooge. Outwardly, he was their wonder inventor, and no doubt of his ability was to be tolerated either in others or in himself; within, his fellow-engineers knew that between Heaviside and C------, Pupin's credit was pretty thin. Again and again Pupin tried to prove himself by new attempts at invention and research, but the power was not in him. Unable to advance, and the retreat to modesty cut off by that accursed half-million, despised by the man whose reputation he had wronged, despised within by those who surrounded him with all outward signs of respect—who can doubt that his life was a Hell within? With no new triumphs to justify the old, and nothing but the reality of the old one to prevent him from standing before himself a convicted fraud, is it any wonder that he began to justify himself before his own soul, to push further and further back into his childhood the roots of his great discovery? Or that he tried with every means in his power to exorcise that mocking, contemptuous, impregnable spirit of a Heaviside? If you doubt that this was his inner course, you have but to read his own apologia.

Thus you have these two men, who never met, yet who for better or for worse modelled the course of each other's life. On the one hand you have Heaviside, deaf, poor, contentious, but master of his soul, soured and embittered, but gratified in his failing years, perhaps not so much by official awards and honors, as by the universal admission of his genius and power. On the other, you have poor Pupin, for whom riches and the extraneous honors of academies, the glory of a popular hero and the authorship of a book of national reputation, have not been able to replace or conceal an incurable, irremediable insecurity. In Columbia University there is a great physical laboratory called by his name, dedicated by His Excellency Nicolas Murray Butler, President of the university, but Pupin's real monument is in the hearts of his colleagues, and it is built of contempt. In every true way, he died a lonely man.

My sources for this judgment, besides my own reading of Pupin's book and the published and unpublished works of Heaviside, are to be found in an extensive conversation with electrical engineers of the present and the past generations, within and without the Bell Telephone System, and in particular in the many meetings I had with the late B. A. Behrend, former vice-president of the AIEE, who as you remember made pilgrimage to Heaviside at Torquay to confer upon him an honorary membership, which Heaviside was only with great difficulty persuaded to accept.

Whether there is dramatic material in the events I relate, you can judge far better than I can. To me, however, it seems that the two careers of Pupin and Heaviside, separated in space but joined by fate, offer much that is dramatic. The tale should consist of episodes: an Electrical Society meeting in London, in some lecture-room of gas-light and stale varnish, musty, fusty, and commonplace, with the bland, impenetrable Preece baited by the crank Heaviside; the furtive attempt at testing the loading-coils, and its failure: a directors' meeting in New York; the bookstore in Torquay contrasted with an Academy meeting in Washington or an academic procession with Pupin present and so on. A man like Behrend might perhaps be used as narrator and spectator.

If you have managed to read up to this point, and feel that I have been wasting your time, I am sorry. I have written this letter because I think that there is material, in a very raw form, which you might put to use. I have neither the ability nor the time to push this material further. To alter events, names, personalities, companies, inventions, yet preserve the verisimilitude of the situation and its spiritual meaning, and to express these through the medium and within the limitations of a given art, are things that belong to an expert like yourself. If you find nothing of interest in the bit of history I relate, don't even bother to answer this letter. If however it seems usable grist to your mill, I have no claims on it, and you are welcome to use it as you see fit. The only thing is that I should of course wish to be protected from the embarassment of a too literal and recognizable rendering of names, companies, and situations; but this, of course, you would do anyway.

I have heard that authors and producers are sometimes worried by people who volunteer material to them, and then later make it a basis for claims and vexations plagiarism suits. To clear up any annoyance in this regard which the receipt of this letter may cause, I here state that I freely hand this material to you, to be used or not to be used as it may please you, with or without your communicating with me, and that I waive any claims on this whole of it or on any part.

Very truly yours,

Norbert Wiener

Norbert Wiener.

P.S. If you wish to verify either my own bona fides or the authenticity of the incidents here related, I suggest that you turn to Professor Eric Temple Bell, of the California Institute of Technology in Pasadena.