# Understanding Understanding: Essays on Cybernetics and Cognition

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# 6
# Responsibilities of Competence*

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At our last Annual Symposium I submitted to you a theorem to which Stafford Beer referred on another occasion as "Heinz Von Foerster's Theorem Number One". As some of you may remember, it went as follows:

"The more profound the problem that is ignored, the greater are the chances for fame and success."

Building on a tradition of a single instance, I shall again submit a theorem which, in all modesty, I shall call "Heinz Von Foerster's Theorem Number Two". It goes as follows:

"The hard sciences are successful because they deal with the soft problems; the soft sciences are struggling because they deal with the hard problems."

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Should you care to look closer, you may discover that Theorem 2 could serve as a corollary to Theorem 1. This will become obvious when we contemplate for a moment the method of inquiry employed by the hard sciences. If a system is too complex to be understood it is broken up into smaller pieces. If they, in turn, are still too complex, they are broken up into even smaller pieces, and so on, until the pieces are so small that at least one piece can be understood. The delightful feature of this process, the method of reduction, "reductionism", is that it inevitably leads to success.

Unfortunately, the soft sciences are not blessed with such favorable conditions. Consider, for instance, the sociologist, psychologist, anthropologist, linguist, etc. If they would reduce the complexity of the system of their interest, i.e., society, psyche, culture, language, etc., by breaking it up into smaller parts for further inspection they would soon no longer be able to claim that they are dealing with the original system of their choice. This is so, because these scientists are dealing with essentially non-linear systems whose salient features are represented by the *interactions* between whatever one may call their "parts" whose properties in isolation add little, if anything, to the understanding of the workings of these systems when each is taken as a whole. Consequently, if he wishes to remain in the field of his choice, the scientist who works in the soft sciences is faced with a formidable problem: he cannot afford to loose sight of the full complexity of his system, on the other hand it becomes more and more urgent that his problems be solved. This is not just to please him. By now it has become quite clear that his problems concern us all. "Corruption of our society", "psychological disturbances", "cultural erosion", the "breakdown of communication", and all the other of these "crises" of today are our problems as well as his. How can we contribute to their solution?

My suggestion is that we apply the *competences* gained in the hard sciences—and not the method of reduction—to the solution of the hard problems in the soft sciences. I hasten to add that this suggestion is not new at all. In fact, I submit that it is precisely *Cybernetics* that interfaces hard competence with the hard problems of the soft sciences. Those of us who witnessed the early development of cybernetics may well remember that before Norbert Wiener created that name for our science it was referred to as the study of "Circular-Causal and Feedback Mechanisms in Biological and Social Systems", a description it carried even years after he wrote his famous book. Of course, in his definition of Cybernetics as the science of "communication and control in the animal and the machine" Norbert Wiener went one step further in the generalization of these concepts, and today "Cybernetics" has ultimately come to stand for the science of *regulation* in the most general sense.

Since our science embraces indeed this general and all-pervasive notion, why then, unlike most of our sister sciences, do we not have a patron saint or a diety to bestow favors on us in our search for new insights, and who protects our society from evils from without as well as from within? Astronomers and physicists are looked after by Urania; Demeter patronizes agriculture; and various Muses help the various arts and sciences. But who helps Cybernetics?

One night when I was pondering this cosmic question I suddenly had an apparition. Alas, it was not one of the charming goddesses who bless the other arts and sciences. Clearly, that funny little creature sitting on my desk must be a demon. After a while he started to talk. I was right. "I am Maxwell's Demon", he said. And then he disappeared.

When I regained my composure it was immediately clear to me that nobody else but this respectable demon could be our patron, for Maxwell's Demon is *the paradigm for regulation*.

As you remember, Maxwell's Demon regulates the flow of molecules between two containers in a most *unnatural* way, namely, so that heat flows from the cold container to the hotter, as opposed to the natural course of events where without the demon's interference heat always flows from the hot container to the colder.

I am sure you also remember how he proceeds: He guards a small aperture between the two containers which he opens to let a molecule pass whenever a fast one comes from the cool side or a slow one comes from the hot side. Otherwise he keeps the aperture closed. Obviously, by this maneuver he gets the cool container becoming cooler, and the hot container getting hotter, thus apparently upsetting the Second Law of Thermodynamics. Of course, we know by now that while he succeeds in obtaining this perverse flow of heat, the Second Law remains untouched. This is because of his need for a flashlight to determine the velocity of the upcoming molecules. Were he at thermal equilibrium with one of the containers he couldn't see a thing: he is part of a black body. Since he can do his antics only as long as the battery of his flashlight lasts, we must include into the system with an active demon not only the energy of the two containers, but also that of the battery. The entropy gained by the battery's decay is not completely compensated by the negentropy gained from the increased disparity of the two containers.

The moral of this story is simply that while our demon cannot beat the Second Law, he can, by his regulatory activity, retard the degradation of the available energy, i.e., the growth of entropy, to an arbitrary slow rate.

This is indeed a very significant observation because it demonstrates the paramount importance of regulatory mechanisms in living organisms. In this context they can be seen as manifestations of Maxwell's Demon, retarding continuously the degradation of the flow of energy, that is, retarding the increase of entropy. In other words, as regulators living organisms are "entropy retarders".

Moreover, as I will show in a moment, Maxwell's Demon is not only an entropy retarder and a paradigm for regulation, but he is also a functional isomorph of a Universal Turing Machine. Thus, the three concepts of regulation, entropy retardation, and computation constitute an interlaced conceptual network which, for me, is indeed the essence of Cybernetics.



I shall now briefly justify my claim that Maxwell's Demon is not only the paradigm for regulation but also for computation.

When I use the term "computation" I am not restricting my self to specific operations as, for instance, addition, multiplication, etc. I wish to interpret "computation" in the most general sense as a mechanism, or "algorithm", for *ordering*. The ideal, or should I say the most general, representation of such mechanism is, of course, a Turing Machine, and I shall use this machine to illuminate some of the points I wish to make.

There are two levels on which we can think of "ordering". The one is when we wish to make a description of a given arrangement of things. The other one when we wish to re-arrange things according to certain descriptions. It will be obvious at once that these two operations constitute indeed the foundations for all that which we call "computation".

Let A be a particular arrangement. Then this arrangement can be computed by a universal Turing machine with a suitable initial tape expression which we whall call a "description" of A: D(A). The length L(A) of this description will depend on the alphabet (language) used. Hence, we may say that a language $\alpha_1$ reveals more order in the arrangement A than another language $\alpha_2$, if and only if the length $L_1(A)$ of the suitable initial tape description for computing A is shorter than $L_2(A)$, *or mutatis mutandis*.

This covers the first level of above, and leads us immediately to the second level.

Among all suitable initial tape descriptions for an arrangement $A_1$ there is a shortest one: $L^*(A_1)$. If $A_1$ is re-arranged to give $A_2$, call $A_2$ to be of a higher order than $A_1$ if and only if the shortest initial tape description $L^*(A_2)$ is shorter than $L^*(A_1)$, or *mutatis mutandis*.

This covers the second level of above, and leads us to a final statement of perfect ordering (computation).

Among all arrangements $A_i$ there is one, $A^*$, for which the suitable initial tape description is the shortest $L^*(A^*)$.

I hope that with these examples it has become clear that living organisms (replacing now the Turing machine) interacting with their environment (arrangements) have several options at their disposal: (i) they may develop "languages" (sensors, neural codes, motor organs, etc.) which "fit" their given environment better (reveal more order); (ii) they may change their surroundings until it "fits" their constitution; and (iii), they may do both. However, it should be noted that whatever option they take, it will be done by computation. That these computations are indeed functional isomorphs of our demon's activity is now for me to show.

The essential function of a Turing machine can be specified by five operations:

(i) *Read* the input symbol x.
(ii) *Compare* x with z, the intenal state of the machine.
(iii) *Write* the appropriate output symbol y.
(iv) *Change* the internal state z to the new state z′.
(v) *Repeat* the above sequence with a new input state x′.

Similarly, the essential function of Maxwell's Demon can be specified by five operations equivalent to those above:

(i) *Read* the velocity v of the upcoming molecule M.
(ii) *Compare* ($mv^2/2$) with the mean energy $\langle mv^2/2 \rangle$ (temperature T) of, say, the cooler container (internal state T).
(iii) *Open* the aperture if ($mv^2/2$) is greater than $\langle mv^2/2 \rangle$; otherwise keep it closed.
(iv) *Change* the internal state T to the new (cooler) state T′.
(v) *Repeat* the above sequence with a new uncoming molecule M′.

Since the translation of the terms occurring in the correspondingly labeled points is obvious, with the presentation of these two lists I have completed my proof.

How can we make use of our insight that Cybernetics is the science of regulation, computation, ordering, and entropy retardation? We may, of course, apply our insight to the system that is generally understood to be the *cause célèbre* for regulation, computation, ordering, and entropy retardation, namely, the human brain.

Rather than following the physicists who order their problems according to the number of *objects* involved ("The one-body problem", "The two-body problem", "The three-body problem", etc.), I shall order our problems according to the number of *brains* involved by discussing now "The one-brain problem", "The two-brain problem", "The many-brain problem", and "The all-brain problem".

## 1. The Single-Brain Problem: The Brain Sciences

It is clear that if the brain sciences do not want to degenerate into a physics or chemistry of living—or having once lived—tissue they must develop a theory of the brain: T(B). But, of course, this theory must be written by a brain: B(T). This means that this theory must be constructed so as to write itself T(B(T)).

Such a theory will be distinct in a fundamental sense from, say, physics which addresses itself to a (not quite) successful description of a "subjectless world" in which even the observer is not supposed to have a place. This leads me now to pronounce my Theorem Number Three:

"The Laws of Nature are written by man. The laws of biology must write themselves."



In order to refute this theorem it is tempting to invoke Gödel's Proof of the limits of the Entscheidungsproblem in systems that attempt to speak of themselves. But Lars Löfgren and Gotthard Günther have shown that self-explanation and self-reference are concepts that are untouched by Gödel's arguments. In other words, a science of the brain in the above sense is, I claim, indeed a legitimate science with a legitimate problem.

## 2. The Two-Brain Problem: Education

It is clear that the majority of our established educational efforts is directed toward the trivialization of our children. I use the term "trivialization" exactly as used in automata theory, where a trivial machine is characterized by its fixed input-output relation, while in a non-trivial machine (Turing machine) the output is determined by the input *and* its internal state. Since our educational system is geared to generate predictable citizens, its aim is to amputate the bothersome internal states which generate unpredictability and novelty. This is most clearly demonstrated by our method of examination in which only questions are asked for which the answers are known (or defined), and are to be memorized by the student. I shall call these questions "illegitimate questions".

Would it not be fascinating to think of an educational system that detrivializes its students by teaching them to ask "legitimate questions", that is, questions for which the answers are unknown?

## 3. The Many-Brain Problem: Society

It is clear that our entire society suffers from a severe dysfunction. On the level of the individual this is painfully felt by apathy, distrust, violence, disconnectedness, powerlessness, alienation, and so on. I call this the "participatory crisis", for it excludes the individual from participating in the social process. The society becomes the "system", the "establishment" or what have you, a depersonalized Kafkanesque ogre of its own ill will.

It is not difficult to see that the essential cause for this dysfunction is the absence of an adequate input for the individual to interact with society. The so-called "communication channels", the "mass media" are only one-way: they talk, but nobody can talk back. The feedback loop is missing and, hence, the system is out of control. What cybernetics could supply is, of course, a universally accessible social input device.

## 4. The All-Brain Problem: Humanity

It is clear that the single most distressing characteristic of the global system "mankind" is its demonstrated instability, and a fast approaching singularity. As long as humanity treats itself as an open system by ignoring the signals of its sensors that report about its own state of affairs, we shall approach this singularity with no breaks whatsoever. (Lately I began to wonder whether the information of its own state can reach all elements in time to act should they decide to listen rather than fight.)

The goal is clear: we have to close the system to reach a stable population, a stable economy, and stable resources. While the problem of constructing a "population servo" and an "economic servo" can be solved with the mental resources on this planet, for the stability of our material resources we are forced by the Second Law of Thermodynamics to turn to extra-planetary sources. About $2 \cdot 10^{14}$ kilowatts solar radiation are at our disposal. Wisely used, this could leave our earthy, highly structured, invaluable organic resources, fossilized or living, intact for the use and enjoyment of uncounted generations to come.

If we are after fame and success we may ignore the profundity of these problems in computation, ordering, regulation, and entropy retardation. However, since we as cyberneticians supposedly have the competence to attack them, we may set our goal above fame and success by quietly going about their solution. If we wish to maintain our scientific credibility, the first step to take is to apply our competence to ourselves by forming a global society which is not so much *for* Cybernetics as it *functions* cybernetically. This is how I understand Dennis Gabor's exhortation in an earlier issue: "Cyberneticians of the world, unite!" Without communication there is no regulation; without regulation there is no goal; and without a goal the concept of "society" or "system" becomes void.

Competence implies responsibilities. A doctor must act at the scene of the accident. We can no longer afford to be the knowing spectators at a global disaster. We must share what competence we have through communication and cooperation in working together through the problems of our time. This is the only way in which we can fulfill our social and individual responsibilities as cyberneticians who should practice what they preach.

# 13
# Cybernetics of Cybernetics*

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Ladies and gentlemen—As you may remember, I opened my remarks at earlier conferences of our Society with theorems which, owing to the generosity of Stafford Beer, have been called "Heinz von Foerster's Theorems Number One and Number Two". This all is now history.[1,10] However, building on a tradition of two instances, you may rightly expect me to open my remarks today again with a theorem. Indeed I shall do so but it will not bear my name. It can be traced back to Humberto Maturana,[7] the Chilean neurophysiologist, who a few years ago, fascinated us with his presentation on "autopoiesis", the organization of living things.

Here is Maturana's proposition, which I shall now baptize "Humberto Maturana's Theorem Number One":

"*Anything said is said* by *an observer*."

Should you at first glance be unable to sense the profundity that hides behind the simplicity of this proposition let me remind you of West Churchman's admonition of this afternoon: "You will be surprised how much can be said by a tautology". This, of course, he said in utter defiance of the logician's claim that a tautology says nothing.

I would like to add to Maturana's Theorem a corollary which, in all modesty, I shall call "Heinz von Foerster's Corollary Number One":

"*Anything said is said* to *an observer*."

With these two propositions a nontrivial connection between three concepts has been established. First, that of an *observer* who is characterized by being able to make descriptions. This is because of Theorem 1. Of course, what an observer says is a description. The second concept is that of *language*. Theorem 1 and Corollary 1 connect two observers through language. But, in turn, by this connection we have established the third concept I wish to consider this evening, namely that of *society*: the two observers constitute

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the elementary nucleus for a society. Let me repeat the three concepts that are in a triadic fashion connected to each other. They are: first, the observers; second, the language they use; and third, the society they form by the use of their language. This interrelationship can be compared, perhaps, with the interrelationship between the chicken, and the egg, and the rooster. You cannot say who was first and you cannot say who was last. You need all three in order to have all three. In order to appreciate what I am going to say it might be advantageous to keep this closed triadic relation in mind.

I have no doubts that you share with me the conviction that the central problems of today are societal. On the other hand, the gigantic problem-solving conceptual apparatus that evolved in our Western culture is counterproductive not only for solving but essentially for perceiving social problems. One root for our cognitive blind spot that disables us to perceive social problems is the tradition\al explanatory paradigm which rests on two operation: One is *causation*, the other one *deduction*. It is interesting to note that something that cannot be explained—that is, for which we cannot show a cause or for which we do not have a reason—we do not wish to see. In other words, something that cannot be explained cannot be seen. This is driven home again and again by Don Juan, a Yaqui Indian, Carlos Casteneda's mentor.[2–5]

It is quite clear that in his teaching efforts Don Juan wants to make a cognitive blind spot in Castaneda's vision to be filled with new perceptions; he wants to make him "see". This is doubly difficult, because of Castaneda's dismissal of experiences as "illusions" for which he has no explanations on the one hand, and because of a peculiar property of the logical structure of the phenomenon "blind spot" on the other hand; and this is that we do not perceive our blind spot by, for instance, seeing a black spot close to the center of our visual field: we do not see that we have a blind spot. In other words, we do not see that we do not see. This I will call a second order deficiency, and the only way to overcome such deficiencies is with therapies of second order.

The popularity of Carlos Castaneda's books suggest to me that his points are being understood: new paradigms emerge. I'm using the term "paradigm" in the sense of Thomas Kuhn[6] who wants to indicate with this term a culture specific, or language specific, stereotype or model for linking descriptions semantically. As you may remember, Thomas Kuhn argues that there is a major change in paradigms when the one in vogue begins to fail, shows inconsistencies or contradictions. I however argue that I can name at least two instances in which not the emergent defectiveness of the dominant paradigm but its very flawlessness is the cause for its rejection. One of these instances was Copernicus' novel vision of a heliocentric planetary system which he perceived at a time when the Ptolemaeic geocentric system was at its height as to accuracy of its predictions. The other instance, I submit, is being brought about today by some of us who cannot—by their life—pursue any longer the flawless, but sterile path that explores the properties seen to reside within objects, and turn around to explore their very



properties seen now to reside within the observer of these objects. Consider, for instance, "obscenity". There is at aperiodic intervals a ritual performed by the supreme judges of this land in which they attempt to establish once and for all a list of all the properties that define an obscene object or act. Since obscenity is not a property residing within things (for if we show Mr X a painting and he calls it obscene, we know a lot about Mr X but very little about the painting), when our lawmakers will finally come up with their imaginary list we shall know a lot about them but their laws will be dangerous nonsense.

With this I come now to the other root for our cognitive blind spot and this is a peculiar delusion within our Western tradition, namely, "objectivity":

"The properties of the observer shall not enter the description of his observations."

But I ask, how would it be possible to make a description in the first place if not the observer were to have properties that allows for a description to be made? Hence, I submit in all modesty, the claim for objectivity is nonsense! One might be tempted to negate "objectivity" and stipulate now "subjectivity". But, ladies and gentlemen, please remember that if a nonsensical proposition is negated, the result is again a nonsensical proposition. However, the nonsensicality of these propositions either in the affirmative or in their negation cannot be seen in the conceptual framework in which these propositions have been uttered. If this is the state of affairs, what can be done? We have to ask a new question:

"What are the properties of an observer?"

Let me at once draw your attention to the peculiar logic underlying this question. For whatever properties we may come up with it is we, you and I, who have to make this observation, that is, we have to observe our own observing, and ultimately account for our own accounting. Is this not opening the door for the logical mischief of propositions that refer to themselves ("I am a liar") that have been so successfully excluded by Russell's Theory of Types not to bother us ever again? Yes and No!

It is most gratifying for me to report to you that the essential conceptual pillars for a theory of the observer have been worked out. The one is a calculus of infinite recursions;[11] the other one is a calculus of self-reference.[9] With these calculi we are now able to enter rigorously a conceptual framework which deals with *observing* and not only with the observed.

Earlier I proposed that a therapy of the second order has to be invented in order to deal with dysfunctions of the second order. I submit that the cybernetics of observed systems we may consider to be first-order cybernetics; while second-order cybernetics is the cybernetics of observing systems. This is in agreement with another formulation that has been given by Gordon Pask.[8] He, too, distinguishes two orders of analysis. The one in which the observer enters the system by stipulating the *system's* purpose. We may call this a "first-order stipulation". In a "second-order stipulation" the observer enters the system by stipulating *his own* purpose.

From this it appears to be clear that social cybernetics must be a second-order cybernetics—a *cybernetics of cybernetics*—in order that the observer who enters the system shall be allowed to stipulate his own purpose: he is autonomous. If we fail to do so somebody else will determine a purpose for us. Moreover, if we fail to do so, we shall provide the excuses for those who want to transfer the responsibility for their own actions to somebody else: "I am not responsible for my actions; I just obey orders." Finally, if we fail to recognize autonomy of each, we may turn into a society that attempts to honor commitments and forgets about its responsibilities.

I am most grateful to the organizers and the speakers of this conference who permitted me to see cybernetics in the context of social responsibility. I move to give them a strong hand. Thank you very much.

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# 14 Ethics and Second-Order Cybernetics*

Heinz von Foerster

Ladies and Gentlemen:

I am touched by the generosity of the organizers of this conference who not only invited me to come to your glorious city of Paris, but also gave me the honor of opening the Plenary sessions with my presentation. And I am impressed by the ingenuity of the organizers who suggested to me the title of my presentation. They wanted me to address myself to "Ethics and Second-Order Cybernetics." To be honest, I would have never dared to propose such an outrageous title, but I must say that I am delighted that this title was chosen for me.

Before I left California for Paris, others asked me full of envy, what am I going to do in Paris, what will I talk about? When I answered "I shall talk about Ethics and Second-Order Cybernetics" almost all of them looked at me in bewilderment and asked, "What is second-order cybernetics?" as if there were no questions about ethics. I am relieved when people ask me about second-order cybernetics and not about ethics, because it is much easier to talk about second-order cybernetics than it is to talk about ethics. In fact it is impossible to talk about ethics. But let me explain that later, and let me now say a few words about cybernetics, and of course, the cybernetics of cybernetics, or second-order cybernetics.

As you all know, cybernetics arises when effectors (say, a motor, an engine, our muscles, etc.) are connected to a sensory organ which in turn acts with its signals upon the effectors. It is this circular organization which sets cybernetic systems apart from others that are not so organized. Here is Norbert Wiener, who re-introduced the term "Cybernetics" into scientific discourse. He observed, "The behavior of such systems may be interpreted as directed toward the attainment of a goal." That is, it looks as if these systems pursued a purpose!

That sounds very bizarre indeed! But let me give you other paraphrases of what cybernetics is all about by invoking the spirit of women and men who

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rightly could be considered the mamas and papas of cybernetic thought and action. First there is Margaret Mead, whose name I am sure is familiar to all of you. In an address to the American Society of Cybernetics she remarked:

> As an anthropologist, I have been interested in the effects that the theories of Cybernetics have within our society. I am not referring to computers or to the electronic revolution as a whole, or to the end of dependence on script for knowledge, or to the way that dress has succeeded the mimeographing machine as a form of communication among the dissenting young. Let me repeat that, I am *not* referring to the way that *dress* has succeeded the mimeographing machine as a form of communication among the dissenting young.

And she then continues:

> I specifically want to consider the significance of the set of cross-disciplinary ideas which we first called "feed-back" and then called "teleological mechanisms" and then called it "cybernetics," a form of cross-disciplinary thought which made it possible for members of many disciplines to communicate with each other easily in a language which all could understand.

And here is the voice of her third husband, the epistemologist, anthropologist, cybernetician, and as some say, the papa of family therapy, Gregory Bateson, "Cybernetics is a branch of mathematics dealing with problems of control, recursiveness and information."

And here is the organizational philosopher and managerial wizard Stafford Beer, "Cybernetics is the science of effective organization."

And finally, here the poetic reflection of "Mister Cybernetics," as we fondly call him, the Cybernetician's cybernetician; Gordon Pask, "Cybernetics is the science of defensible metaphors."

It seems that cybernetics is many different things to many different people. But this is because of the richness of its conceptual base; and I believe that this is very good, otherwise cybernetics would become a somewhat boring exercise. However, all of those perspectives arise from one central theme; that of circularity. When, perhaps a half century ago, the fecundity of this concept was seen, it was sheer euphoria to philosophize, epistemologize, and theorize about its unifying power and its consequences and ramification on various fields. While this was going on, something strange evolved among the philosophers, the epistemologists and the theoreticians. They began to see themselves more and more as being included in a larger circularity; maybe within the circularity of their family; or that of their society and culture; or even being included in a circularity of cosmic proportions!

What appears to us today as being most natural to see and think, was then not only difficult to see, but wasn't even allowed to be thought. Why? Because it would violate the basic principle of scientific discourse which demands the separation of the observer from the observed. It is the principle of objectivity. The properties of the observer shall not enter the description of his observations.



I present this principle here, in its most brutal form, to demonstrate its non-sensicality. If the properties of the observer (namely to observe and describe) are eliminated, there is nothing left; no observation, no description. However, there was a justification for adhering to this principle, and this justification was fear; fear that paradoxes would arise when the observers were allowed to enter the universe of their observations. And you know the threat of paradoxes. To steal their way into a theory is like having the cloven-hoofed foot of the devil stuck in the door of orthodoxy.

Clearly when cyberneticians were thinking of partnership in the circularity of observing and communicating, they were entering into a forbidden land. In the general case of circular closure, A implies B; B implies C; and (Oh, horror!) C implies A! Or in the reflexive case, A implies B, and (Oh, shock!) B implies A! And now the devil's cloven-hoof in its purest form, the form of self-reference; A implies A (Outrage!)

I would like to invite you now to join me in a land where it is not forbidden; rather, where one is encouraged to speak about oneself. What else can one do anyway? This turn from looking at things "out there" to looking at "looking itself," arose I think, from significant advances in neurophysiology and neuropsychiatry. It appeared that one could now dare to ask the question of how the brain works. One could dare to write a theory of the brain.

It may be argued that over the centuries since Aristotle, physicians and philosophers again and again developed theories of the brain. So, what's new of today's cyberneticians? What is new is the profound insight that a brain is required to write a theory of a brain. From this follows that a theory of the brain, that has any aspirations for completeness, has to account for the writing of this theory. And even more fascinating, the writer of this theory has to account for her or himself. Translated into the domain of cybernetics; the cybernetician, by entering his own domain, has to account for his or her own activity. Cybernetics then becomes cybernetics of cybernetics, or *second-order cybernetics*.

Ladies and Gentlemen, this perception represents a fundamental change, not only in the way we conduct science, but also how we perceive teaching, learning, the therapeutic process, organizational management, and so on and so forth; and I would say, of how we perceive relationships in our daily life. One may see this fundamental epistemological change if one first considers oneself to be an independent observer who watches the world go by; as opposed to a person who considers oneself to be a participant actor in the drama of mutual interaction of the give and take in the circularity of human relations.

In the case of the first example, as a result of my independence, I can tell others how to think and act, "Thou shalt . . ." "Thou shalt not . . ." This is the origin of moral codes. In the case of the second example, because of my interdependence, I can only tell myself how to think and act, "I shall . . ." "I shall not . . ." This is the origin of ethics.

This was the easy part of my presentation. Now comes the difficult part. I am supposed to talk about ethics. How to go about this? Where to begin?

In my search for a beginning I came across the lovely poem by Yveline Rey and Bernard Prieur that embellishes the first page of our program. Let me read to you the first few lines:

"Vous avez dit Ethique?"
Déjà le murmur s'amplifie en rumeur.
Soudain les roses ne montrent plus des épines.
Sans doute le sujet est-il brûlant.
Il est aussi d'actualité.

Let me begin with epines – with the thorns – and I hope, a rose will emerge. The thorns I begin with are Ludwig Wittgenstein's reflections upon ethics in his Tractatus Logico-Philosophicus. If I were to provide a title for this tractatus, I would call it Tractatus Ethico-Philosophicus. However, I am not going to defend this choice, I rather tell you what prompts me to refer to Wittgenstein's reflections in order to present my own.

I'm referring to point Number 6 in his Tractatus where he discusses the general form of propositions. Near the end of this discussion he turns to the problem of values in the world and their expression in propositions. In his famous point Number 6.421 he comes to a conclusion which I will read to you in the original German, "Es ist Klar, dass sich Ethik nicht aussprechen laesst." I wish I knew a French translation. I only know two English translations which are both incorrect. Therefore, I will present *my* translation into English, with my conviction that the simultaneous translators will do a superb job of presenting Wittgenstein's point in French. Here is my English version of 6.421, "It is clear that ethics cannot be articulated."

Now you understand why earlier I said, "My beginning will be thorns." Here is an International Congress on Ethics, and the first speaker says something to the effect that it is impossible to speak about ethics! But please be patient for a moment. I quoted Wittgenstein's thesis in isolation. Therefore it is not yet clear what he wanted to say.

Fortunately, the next point 6.422, which I will read in a moment, provides a larger context for 6.421. To prepare for what you are about to hear, you should remember that Wittgenstein was a Viennese. So am I. Therefore there is a kind of underground understanding which I sense you Parisians will share with us Viennese. Let me try to explain. Here now is point 6.422 in the English translation by Pears and McGuinness; "When an ethical law of the form "Thou shalt . . ." is laid down, one's first thought is, 'And what if I do not do it?' " When I first read this, my thought was that not everybody will share Wittgenstein's view. I think that this reflects his cultural background.

Let me continue with Wittgenstein, "It is clear however, that ethics has nothing to do with punishment and reward in the usual sense of the terms. Nevertheless, there must indeed be some kind of ethical reward and punishment, but they must reside in the action itself."



They must reside in the action itself! You may remember, we came across such self-referential notions earlier with the example, "A implies A" and its recursive relatives of second-order cybernetics. Can we take a hint from these comments for how to go about reflecting about ethics, and at the same time adhere to Wittgenstein's criterion? I think we can. I myself try to adhere to the following rule; to master the use of my language so that ethics is implicit in any discourse I may have. (e.g., in science, philosophy, epistemology, therapy, etc.)

What do I mean by that? By that I mean to let language and action ride on an underground river of ethics, and to make sure that one is not thrown off. This insures that ethics does not become explicit and that language does not degenerate into moralizations. How can one accomplish this? How can one hide ethics from all eyes and still let her determine language and action? Fortunately, ethics has two sisters who allow her to remain unseen. They create for us a visible framework; a tangible tissue within which and upon which we may weave the goblins of our life. And who are these two sisters? One is Metaphysics, the other is Dialogics.

My job now is to talk about these two ladies, and how they manage to allow ethics to become manifest without becoming explicit.

## Metaphysics

Let me first talk about Metaphysics. In order to let you see at once the delightful ambiguity that surrounds her, let me quote from a superb article, "The Nature of Metaphysics" by the British scholar W.H. Walsh. He begins his article with the following sentence, "Almost everything in metaphysics is controversial, and it is therefore not surprising that there is little agreement among those who call themselves metaphysicians about what precisely it is they are attempting."

Today, when I invoke Metaphysics, I do not seek agreement with anybody else about her nature. This is because I want to say precisely what it is when we become metaphysicians, whether or not we call ourselves metaphysicians. I say that we become a metaphysician any time we decide upon in principle undecidable questions. For instance, here is a decidable question, "Is the number 3,396,714 divisible by 2?" It will take you less than two seconds to decide that indeed this number is divisible by two. The interesting thing here is that it will take you exactly the same short time to decide if the number has not 7, but 7000 or 7 million digits. I could of course invent questions that are slightly more difficult; for instance, "Is 3,396,714 divisible by three?", or even more difficult ones. But there are also problems that are extraordinarily difficult to decide, some of them having been posed more than 200 years ago and remain unanswered.

Think of Fermat's "Last Theorem" to which the most brilliant heads have put their brilliant minds and have not yet come up with an answer. Or think of Goldbach's "Conjecture" which sounds so simple that it seems a proof cannot be too far away, "All even numbers can be composed as the sum of two primes." For example, 12 is the sum of the two prime numbers 5 and 7; or 20 = 17 + 3; or 24 = 13 + 11, and so on and so forth. So far, no counterexample to Goldbach's conjecture has been found. And even if all further tests would not refute Goldbach, it still would remain a conjecture until a sequence of mathematical steps is found that decides in favor of his good sense of numbers. There is a justification for not giving up and for continuing the search for finding a sequence of steps that would prove Goldbach. It is that the problem is posed in a framework of logico-mathematical relations which guarantees that one can climb from any node of this complex crystal of connections to any other node.

One of the most remarkable examples of such a crystal of thought is Bertrand Russell's and Alfred North Whithead's monumental *Principia Mathematica* which they wrote over a 10 year period between 1900 and 1910. This 3 volume *magnum opus* of more than 1500 pages was to establish once and for all a conceptual machinery for flawless deductions. A conceptual machinery that would contain no ambiguities, no contradictions and no undecidables.

Nevertheless, in 1931, Kurt Gödel, then 25 years of age, published an article whose significance goes far beyond the circle of logicians and mathematicians. The title of this article I will give you now in English, "On formally undecidable propositions in the *Principia Mathematica* and related systems." What Gödel does in his paper is to demonstrate that logical systems, even those so carefully constructed by Russell and Whitehead, are not immune to undecidables sneaking in.

However, we do not need to go to Russell and Whitehead, Gödel, or any other giants to learn about in principle undecidable questions. We can easily find them all around. For instance, the question about the origin of the universe is one of those in principle undecidable questions. Nobody was there to watch it. Moreover, this is apparent by the many different answers that are given to this question. Some say it was a single act of creation some 4 or 5,000 years ago. Others say there was never a beginning and that there will never be an end; because the universe is a system in perpetual equilibrium. Then there are those who claim that approximately 10 or 20 billion years ago the universe came into being with a "Big Bang" whose remnants one is able to hear over large radio antennas. But I am most inclined to trust Chuang Tse's report, because he is the oldest and was therefore the closest to the event. He says:

> Heaven does nothing, this nothing-doing is dignity;
> Earth does nothing, this nothing-doing is rest;
> From the union of these two nothing-doings arise all action
> And all things are brought forth.

I could go on and on with other examples, because I have not yet told you what the Burmese, the Australians, the Eskimos, the Bushmen, the



Ibos, etc., would tell you about their origins. In other words, tell me how the universe came about, and I will tell you who you are.

I hope that I have made the distinction between decidable and, in principle, undecidable questions sufficiently clear so that I may present the following proposition which I call the "metaphysical postulate:"

> Only those questions that are in principle undecidable, *we* can decide.

Why? Simply because the decidable questions are already decided by the choice of the framework in which they are asked, and by the choice of the rules used to connect what we label "the question" with what we take for an "answer." In some cases it may go fast, in others it may take a long, long time. But ultimately we arrive after a long sequence of compelling logical steps at an irrefutable answer; a definite "yes," or a definite "no."

But we are under no compulsion, not even under that of logic, when we decide on in principle undecidable questions. There is no external necessity that forces us to answer such questions one way or another. We are free! The compliment to necessity is not chance, it is choice! *We can choose who we wish to become when we have decided on an in principle undecidable question*.

That is the good news, as American journalists would say, now comes the bad news. With this freedom of choice we are now responsible for the choice we make. For some, this freedom of choice is a gift from heaven. For others such responsibility is an unbearable burden. How can one escape it? How can one avoid it? How can one pass it on to somebody else?

With much ingenuity and imagination, mechanisms have been contrived by which one could bypass this awesome burden. Through hierarchies, entire institutions have been built where it is impossible to localize responsibility. Everyone in such a system can say, "I was told to do 'X.'" On the political stage, we hear more and more the phrase of Pontius Pilate, "I have no choice but 'X.'" In other words, "Don't hold me responsible for 'X.' Blame someone else." This phrase apparently replaces, "Among the many choices I had, I decided on 'X.'"

I mentioned objectivity before, and I mention it here again as a popular device for avoiding responsibility. As you may remember, objectivity requires that the properties of the observer be left out of any descriptions of his observations. With the essence of observing (namely the processes of cognition) having been removed, the observer is reduced to a copying machine with the notion of responsibility successfully juggled away.

Objectivity, Pontius Pilate, hierarchies, and other devices are all derivations of a choice between a pair of in principle undecidable questions which are, "Am I *apart from* the universe?" Meaning whenever I *look*, I'm looking as if through a peephole upon an unfolding universe; or, "Am I *part of* the universe?" Meaning whenever I *act*, I'm changing myself and the universe as well.

Whenever I reflect on these two alternatives, I'm surprised by the depth of the abyss that separates the two fundamentally different worlds that can be created by such a choice. That is to see myself as a citizen of an independent universe, whose regulations, rules and customs I may eventually discover; or to see myself as a participant in a conspiracy, whose customs, rules, and regulations we are now inventing.

Whenever I speak to those who have made their decision to be either discovers or inventors, I'm impressed by the fact that neither of them realizes that they have ever made that decision. Moreover, when challenged to justify their position, a conceptual framework is constructed which itself turns out to be the result of a decision upon an in principle undecidable question.

It seems as though I'm telling you a detective story while keeping quiet about who is the good guy and who is the bad guy; or who is sane and who is insane; or who is right and who is wrong. Since these are in principle undecidable questions, it is for each of us to decide, and then take responsibility for. There is a murderer. I submit that it is unknowable whether he is or was insane. The only thing we *know* is what I say, what you say, or what the expert says he is. And what I say, what you say, and what the expert says about his sanity or insanity is my, is your, and is the expert's responsibility. Again, the point here is not the question "Who's right and who's wrong?" This is an in principle undecidable question. The point here is freedom; freedom of choice. It is José Ortega y Gasset's point:

> Man does not have a nature, but a history. Man is nothing but a drama. His life is something that has to be chosen, made up as he goes along. And a human consists in that choice and invention. Each human being is the novelist of himself, and though he may choose between being an original writer and a plagiarist, he cannot escape choosing. He is condemned to be free.

You may have become suspicious of me qualifying all questions as being in principle undecidable questions. This is by no means the case. I was once asked how the inhabitants of such different worlds as I sketched before, (the inhabitants of the world they discover, and the inhabitants of a world they invent) can ever live together. Answering that is not a problem. The discovers will most likely become astronomers, physicists and engineers; the inventors family therapists, poets, and biologists. And living together won't be a problem either, as long as the discoverers discover inventors, and the inventors invent discoverers. Should difficulties develop, fortunately we have this full house of family therapists who may help to bring sanity to the human family.

I have a dear friend who grew up in Marakesh. The house of his family stood on the street that divides the Jewish and the Arabic quarters. As a boy, he played with all the others, listened to what they thought and said, and learned of their fundamentally different views. When I asked him once who was right he said, "They are both right."



"But this cannot be," I argued from an Aristotelian platform, "Only one of them can have the truth!"

"The problem is not truth," he answered, "The problem is trust."

I understood. The problem is understanding. The problem is understanding understanding! The problem is making decisions upon in principle undecidable questions.

At that point Metaphysics appeared and asked her younger sister Ethics, "What would you recommend I bring back to my proteges, the metaphysicians, regardless of whether or not they refer to themselves as such?" Ethics answered, "Tell them they should always try to act so as to increase the number of choices. Yes, increase the number of choices!"

## Dialogics

Now I would like to turn to Ethics' sister, Dialogics. What are the means at her disposal to insure that Ethics can manifest herself without becoming explicit? You may already have guessed that it is, of course, language. I am not referring here in the sense of the noises produced by pushing air past our vocal cords; or language in the sense of grammar, syntax, semantics, semiotics; nor the machinery of phrases, verb phrases, noun phrases, deep structure, etc. When I refer here to language, I refer to language the "dance." Similar to when we say "It takes two to Tango," I am saying, "It takes two to language."

When it comes to the dance of language, you the family therapists are of course the masters, while I can only speak as an amateur. Since "amateur" comes from "amour," you'll know at once that I love to dance this dance. In fact, what little I know of this dance I learned from you. My first lesson came when I was invited to sit in an observation room and observe through the one way mirror a therapeutic session in progress with a family of four. For a moment my colleagues had to leave, and I was by myself. I was curious as to what I would see when I couldn't hear what was said, so I turned off the sound.

I recommend that you perform this experiment yourself. Perhaps you will be as fascinated as I was. What I saw then, the silent pantomime, the parting and closing of lips, the body movements, the boy who only once stopped biting his nails . . . what I saw then were the dance steps of language, the dance steps alone, without the disturbing effects of the music. Later I heard from the therapist that this session was very successful indeed. I thought, what magic must sit in the noises these people produced by pushing air past their vocal cords and by parting and closing their lips. Therapy! What magic indeed! And to think that the only medicine at your disposal are the dance steps of language and its accompanying music. Language! What magic indeed!

It is left to the naive to believe that magic can be explained. Magic cannot be explained. Magic can only be practiced, as you all well know. Reflecting on the magic of language is similar to reflecting upon a theory of the brain. As much as one needs a brain to reflect upon a theory of the brain, one needs the magic of language to reflect upon the magic of language. It is the magic of those notions that they need themselves to come into being. *They are of second-order.* It is also the way language protects itself against explanation by always speaking about itself.

There is a word for language, namely "language." There is a word for word, namely "word." If you don't know what word means, you can look it up in a dictionary. I did that. I found it to be an "utterance." I asked myself, "What is an utterance?" I looked it up in the dictionary. The dictionary said that it means "to express through words." So here we are back where we started. Circularity; A implies A.

But this is not the only way language protects itself against explanation. In order to confuse her explorer she always runs on two different tracks. If you chase language up one track, she jumps to the other. If you follow her there, she is back on the first. What are these two tracks? One track is the track of appearance. It runs through a land that appears stretched out before us; the land we are looking at as though through a peephole. The other track is the track of function. It runs through the land that is as much a part of us as we are a part of it; the land that functions like an extension of our body.

When language is on the track of appearance it is a monologue. There are noises produced by pushing air past vocal cords. There are the words, the grammar, the syntax, the well formed sentences. Along with these noises goes the denotative pointing. Point to a table, make the noise "table"; point to a chair, make the noise "chair."

Sometimes it does not work. Margaret Mead quickly learned the colloquial language of many tribes by pointing to things and waiting for the appropriate noises. She told me that once she came to a particular tribe, pointed to different things, but always got the same noises, "chumulu." A primitive language she thought, only one word! Later she learned that "chu mulu" means "pointing with finger."

When language switches to the track of function it is dialogic. There are, of course, these noises; some of them may sound like "table," others like "chair." But there need not be any tables or chairs because nobody is pointing at tables or chairs. These noises are invitations to the other to make some dance steps together. The noises "table" and "chair" bring to resonance those strings in the mind of the other which, when brought to vibration, would produce noises like "table" and "chair." Language in its function is connotative.

In its appearance, language is descriptive. When you tell your story, you tell it as it was; the magnificent ship, the ocean, the big sky, and the flirt you had that made the whole trip a delight. But for whom do you tell it? That's the wrong question. The right question is; with whom are you going to dance your story, so that your partner will float with you over the decks of your ship, will smell the salt of the ocean, will let the soul expand over the sky? And there will be a flash of jealousy when you come to the point of your flirt.



In its function, language is constructive because nobody knows the source of your story. Nobody knows, nor ever will know how it was, because "as it was" is gone forever.

You remember René Descartes as he was sitting in his study, not only doubting that the was sitting in his study, but also doubting his existence. He asked himself, "Am I, or am I not?" "Am I, or am I not?" He answered this rhetorical question with the solipsistic monologue, "Je pense, donc je suis" or in the famous Latin version, "Cogito ergo sum." As Descartes knew very well, this is language in its appearance, otherwise he would not have quickly published his insight for the benefit of others in his "Discourse de la méthode." Since he understood the function of language as well, in all fairness he should have exclaimed, "Je pense, donc nous sommes", "Cogito ergo sumus" or, "I think, therefore *we* are."

In its appearance, the language I speak is *my* language. It makes me aware of myself. This is the root of *consciousness*. In its function, my language reaches out for the other. This is the root of *conscience*. And this is where Ethics invisibly manifests itself through dialogue. Permit me to read to you what Martin Buber says in the last few lines of his book *Das Problem des Menschen*:

> Contemplate the human with the human, and you will see the dynamic duality, the essence together. Here is the giving and the receiving, here is the aggressive and the defensive power, here the quality of searching and of responding, always both in one, mutually complementing in alternating action, demonstrating together what it is; human. Now you can turn to the single one and you can recognize him as human for his potential of relating. We may come closer to answering the question, "What is human?" when we come to understand him as the being in whose dialogic, in his mutually present two-getherness, the encounter of the one with the other is realized and recognized at all times.

Since I cannot add anything to Buber's words, this is all I can say about ethics, and about second-order cybernetics.

Thank you very much.

# 8
# On Constructing a Reality*

Heinz von Foerster

Draw a distinction!
G. Spencer Brown[1]

## The Postulate

I am sure you remember the plain citizen Jourdain in Molière's *Le Bourgeois Gentilhomme* who, nouveau riche, travels in the sophisticated circles of the French aristocracy and who is eager to learn. On one occasion his new friends speak about poetry and prose, and Jourdain discovers to his amazement and great delight that whenever he speaks, he speaks prose. He is overwhelmed by this discovery: "I am speaking Prose! I have always spoken Prose! I have spoken Prose throughout my whole life!"

A similar discovery has been made not so long ago, but it was neither of poetry nor of prose—it was the environment that was discovered. I remember when, perhaps ten or fifteen years ago, some of my American friends came running to me with the delight and amazement of having just made a great discovery: "I am living in an Environment! I have always lived in an Environment! I have lived in an Environment throughout my whole life!"

However, neither M. Jourdain nor my friends have as yet made another discovery, and that is when M. Jourdain speaks, may it be prose or poetry, it is he who invents it, and, likewise, when we perceive our environment, it is we who invent it.

Every discovery has a painful and a joyful side: painful, while struggling with a new insight; joyful, when this insight is gained. I see the sole purpose of my presentation to minimize the pain and maximize the joy for those who have not yet made this discovery; and for those who have made it, to

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let them know they are not alone. Again, the discovery we all have to make for ourselves is the following postulate.

### *The Environment as We Perceive It Is Our Invention*

The burden is now upon me to support this outrageous claim. I shall proceed by first inviting you to participate in an experiment; then I shall report a clinical case and the results of two other experiments. After this I will give an interpretation, and thereafter a highly compressed version of the neurophysiological basis of these experiments and my postulate of before. Finally, I shall attempt to suggest the significance of all that to aesthetical and ethical considerations.

## Experiments

### *The Blind Spot*

Hold book with right hand, close left eye, and fixate star of Figure 1 with right eye. Move book slowly back and forth along line of vision until at an appropriate distance (from about 12 to 14 inches) round black spot disappears. With star well focused, spot should remain invisible even if book is slowly moved parallel to itself in any direction.

This localized blindness is a direct consequence of the absence of photo receptors (rods or cones) at that point of the retina, the "disk," where all fibers leading from the eye's light-sensitive surface converge to form the optic nerve. Clearly, when the black spot is projected onto the disk, it cannot be seen. Note that this localized blindness is not perceived as a dark blotch in our visual field (seeing a dark blotch would imply "seeing"), but this blindness is not perceived at all, that is, neither as something present, nor as something absent: Whatever is perceived is perceived "blotchless."

### *Scotoma*

Well-localized occipital lesions in the brain (e.g., injuries from high-velocity projectiles) heal relatively fast without the patient's awareness of any perceptible loss in his vision. However, after several weeks motor dysfunction in the patient becomes apparent, for example, loss of control of arm or leg movements of one side or the other. Clinical tests, however, show that there is nothing wrong with the motor system, but that in some cases

Figure 1.

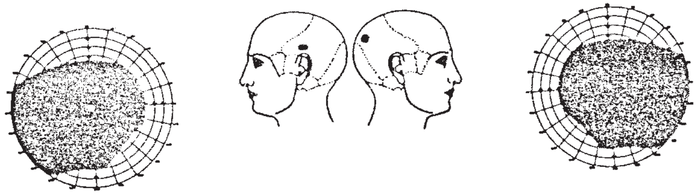


Figure 2.

there is substantial loss (Fig. 2) of a large portion of the visual field (*scotoma*).[9] A successful therapy consists of blind-folding the patient over a period of one to two months until he regains control over his motor system by shifting his "attention" from (nonexistent) visual clues regarding his posture to (fully operative) channels that give direct postural clues from (proprioceptive) sensors embedded in muscles and joints. Note again absence of perception of "absence of perception," and also the emergence of perception through sensorimotor interaction. This prompts two metaphors: Perceiving is doing, and If I don't see I am blind, I am blind; but if I see I am blind, I see.

## *Alternates*

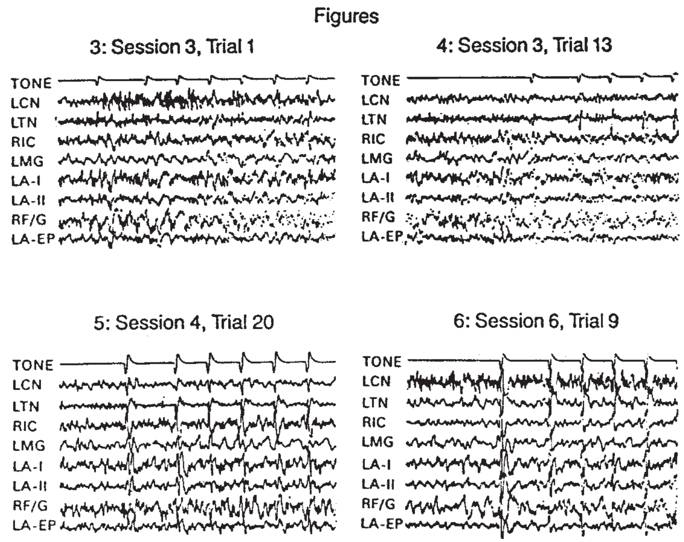
A single word is spoken once into a tape recorder and the tape smoothly spliced (without click) into a loop. The word is repetitively played back with high rather than low volume. After one or two minutes of listening (from 50 to 150 repetitions), the word clearly perceived so far abruptly changes into another meaningful and clearly perceived word: an "alternate." After ten to thirty repetitions of this first alternate, a sudden switch to a second alternate is perceived, and so on.[6] The following is a small selection of the 758 alternates reported from a population of about 200 subjects who were exposed to a repetitive playback of the single word *cogitate: agitate, annotate, arbitrate, artistry, back and forth, brevity, ça d'était, candidate, can't you see, can't you stay, Cape Cod you say, card estate, cardiotape, car district, catch a tape, cavitate, cha cha che, cogitate, computate; conjugate, conscious state, counter tape, count to ten, count to three, count yer tape, cut the steak, entity, fantasy, God to take, God you say, got a data, got your pay, got your tape, gratitude, gravity, guard the tit, gurgitate, had to take, kinds of tape, majesty, marmalade.*

## *Comprehension**

Into the various stations of the auditory pathways in a cat's brain microelectrodes are implanted that allow a recording (electroencephalogram)

* Literally, *con* = together; *prehendere* = to seize, grasp.






Figures 3–6

from the nerve cells first to receive auditory stimuli (cochlea nucleus, CN) up to the auditory cortex.[10] The cat so prepared is admitted into a cage that contains a food box whose lid can be opened by pressing a lever. However, the lever–lid connection is operative only when a short single tone (here $C_6$, which is about 1000 hertz) is repetitively presented. The cat has to learn that $C_6$ "means" food. Figures 3–6 show the pattern of nervous activity at eight ascending auditory stations and at four consecutive stages of this learning process.[10] The cat's behavior associated with the recorded neural activity is for "random search" in Figure 3, "inspection of lever" in Figure 4, "lever pressed at once" in Figure 5, and "walking straight toward lever (full comprehension)" in Figure 6. Note that no tone is perceived as long as this tone is uninterpretable (Figs. 3,4; pure noise), but the whole system swings into action with the appearance of the first "beep" (Figs. 5,6; noise becomes signal), when sensation becomes comprehensible, when *our* perception of "beep, beep; beep" is in the *cat's* perception "food, food, food."

## Interpretation

In these experiments I have cited instances in which we see or hear what is not "there," or in which we do not see or hear what is "there" unless coordination of sensation and movement allows us to "grasp" what appears to be there. Let me strengthen this observation by citing now the "principle of undifferentiated encoding":

The response of a nerve cell does *not* encode the physical nature of the agents that caused its response. Encoded is only "how much" at this point on my body, but not "what."

Take, for instance, a light-sensitive receptor cell in the retina, a "rod" that absorbs the electromagnetic radiation originating from a distant source. This absorption causes a change in the electrochemical potential in the rod, which will ultimately give rise to a periodic electric discharge of some cells higher up in the postretinal networks (see below, Fig. 15), with a period that is commensurate with the intensity of the radiation absorbed, but without a clue that it was electromagnetic radiation that caused the rod to discharge. The same is true for any other sensory receptor, may it be the taste buds, the touch receptors, and all the other receptors that are associated with the sensations of smell, heat and cold, sound, and so on: They are all "blind" as to the quality of their stimulation, responsive only as to their quantity.

Although surprising, this should not come as a surprise, for indeed "out there" there is no light and no color, there are only electromagnetic waves; "out there" there is no sound and no music, there are only periodic variations of the air pressure; "out there" there is no heat and no cold, there are only moving molecules with more or less mean kinetic energy, and so on. Finally, for sure, "out there" there is no pain.

Since the physical nature of the stimulus—its *quality*—is not encoded into nervous activity, the fundamental question arises as to how does our brain conjure up the tremendous variety of this colorful world as we experience it any moment while awake, and sometimes in dreams while asleep. This is the "problem of cognition," the search for an understanding of the cognitive processes.

The way in which a question is asked determines the way in which an answer may be found. Thus it is upon me to paraphrase the "problem of cognition" in such a way that the conceptual tools that are today at our disposal may become fully effective. To this end let me paraphrase (→) "cognition" in the following way:

$$\text{cognition} \rightarrow \text{computing a reality}$$

With this I anticipate a storm of objections. First, I appear to replace one unknown term *cognition*, with three other terms, two of which, *computing* and *reality*, are even more opaque than the definiendum, and with the only definite word used here being the indefinite article *a.* Moreover, the use of the indefinite article implies the ridiculous notion of other realities besides "the" only and one reality, our cherished Environment; and finally I seem to suggest by "computing" that everything, from my wristwatch to the galaxies; is merely computed, and is not "there." Outrageous!

Let me take up these objections one by one. First, let me remove the semantic sting that the term *computing* may cause in a group of women and men who are more inclined toward the humanities than to the sciences.



Harmlessly enough, computing (from *com-putare*) literally means to reflect, to contemplate (*putare*) things in concert (*com*), without any explicit reference to numerical quantities. Indeed, I shall use this term in this most general sense to indicate any operation (not necessarily numerical) that transforms, modifies, rearranges, orders, and so on, observed physical entities ("objects") or their representations ("symbols"). For instance, the simple permutation of the three letters *A*,*B*,*C*, in which the last letter now goes first—*C*,*A*,*B*—I shall call a computation; similarly the operation that obliterates the commas between the letters—*CAB*—and likewise the semantic transformation that changes *CAB* into *taxi*, and so on.

I shall now turn to the defense of my use of the indefinite article in the noun phrase *a reality*. I could, of course, shield myself behind the logical argument that solving for the general case, implied by the *a*, I would also have solved any specific case denoted by the use of *the*. However, my motivation lies much deeper. In fact, there is a deep hiatus that separates the *the* school of thought from the *a* school of thought in which, respectively, the distinct concepts of "confirmation" and "correlation" are taken as explanatory paradigms for perceptions. The *the* school: My sensation of touch is *confirmation* for my visual sensation that here is a table. The *a* school: My sensation of touch in *correlation* with my visual sensation generate an experience that I may describe by "here is a table."

I am rejecting the *the* position on epistemological grounds, for in this way the whole problem of cognition is safely put away in one's own cognitive blind spot: Even its absence can no longer be seen.

Finally one may rightly argue that cognitive processes do not compute wristwatches or galaxies, but compute at best *descriptions* of such entities. Thus I am yielding to this objection and replace my former paraphrase by

$$\text{cognition} \rightarrow \text{computing descriptions of a reality}$$

Neurophysiologists, however, will tell us[4] that a description computed on one level of neural activity, say, a projected image on the retina, will be operated on again on higher levels, and so on, whereby some motor activity may be taken by an observer as a "terminal description," for instance, the utterance, "Here is a table." Consequently, I have to modify this paraphrase again to read

$$\text{cognition} \rightarrow \text{computing descriptions of}$$

where the arrow turning back suggests this infinite recursion of descriptions of descriptions, etc. This formulation has the advantage that one unknown, namely, "reality," is successfully eliminated. Reality appears only implicit as the operation of recursive descriptions. Moreover, we may take advantage of the notion that computing descriptions is nothing else but computations.

Hence

$$\text{cognition} \rightarrow \text{computations of}$$

In summary, I propose to interpret cognitive processes as never-ending recursive processes of computation, and I hope that in the following *tour de force* of neurophysiology I can make this interpretation transparent.

## Neurophysiology

### *Evolution*

In order that the principle of recursive computation be fully appreciated as being the underlying principle of all cognitive processes—even of life itself, as one of the most advanced thinkers in biology assures me[5]—it may be instructive to go back for a moment to the most elementary—or as evolutionists would say, to very "early"—manifestations of this principle. These are the "independent effectors," or independent sensorimotor units, found in protozoa and metazoa distributed over the surface of these animals (Fig. 7). The triangular portion of this unit, protruding with its tip from the surface, is the sensory part; the onion-shaped portion, the contractile motor part. A change in the chemical concentration of an agent in the immediate vicinity of the sensing tip, and "perceptible" by it, causes an instantaneous contraction of this unit. The resulting displacement of this or any other unit by change of shape of the animal or its location may, in turn, produce perceptible changes in the agent's concentration in the vicinity of these units, which, in turn, will cause their instantaneous contraction, and so on. Thus we have the recursion

$$\rightarrow \text{change of sensation} \rightarrow \text{change of shape}$$

Separation of the sites of sensation and action appears to have been the next evolutionary step (Fig. 8). The sensory and motor organs are now connected by thin filaments, the "axons" (in essence degenerated muscle fibers having lost their contractility), which transmit the sensor's perturbations to its effector, thus giving rise to the concept of a "signal": See something here, act accordingly there.

The crucial step, however, in the evolution of the complex organization of the mammalian central nervous system (CNS) appears to be the appear-



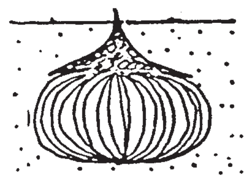


Figure 7.

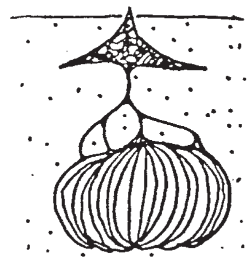


Figure 8.

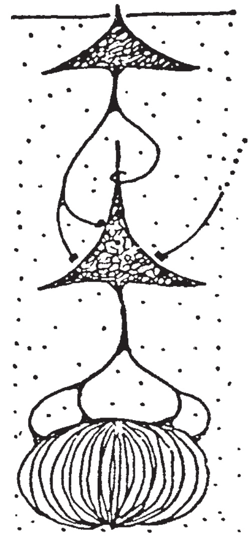


Figure 9.

ance of an "internuncial neuron," a cell sandwiched between the sensory and the motor unit (Fig. 9). It is, in essence, a sensory cell, but specialized so as to respond only to a universal "agent," namely, the electrical activity of the afferent axons terminating in its vicinity. Since its present activity may affect its subsequent responsivity, it introduces the element of computation in the animal kingdom and gives these organisms the astounding latitude of nontrivial behaviors. Having once developed the genetic code for assembling an internuncial neuron, to add the genetic command *repeat* is a small burden indeed. Hence, I believe, it is now easy to comprehend the rapid proliferation of these neurons along additional vertical layers with growing horizontal connections to form those complex interconnected structures we call "brains."

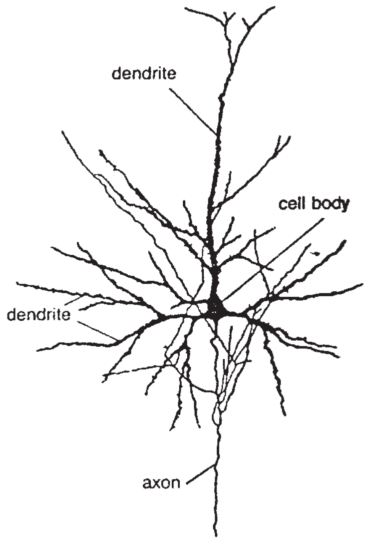



Figure 10.

## *The Neuron*

The neuron, of which we have more than 10 billion in our brain, is a highly specialized single cell with three anatomically distinct features (Fig. 10): (1) the branch-like ramifications stretching up and to the side, the "dendrites"; (2) the bulb in the center housing the cell's nucleus, the "cell body"; and (3), the "axon," the smooth fiber stretching downward. Its various bifurcations terminate on dendrites of another (but sometimes—recursively—on the same) neuron. The same membrane that envelops the cell body forms also the tubular sheath for dendrites and axon, and causes the inside of the cell to be electrically charged against the outside with about $^1/_{10}$ of a volt. If in the dendritic region this charge is sufficiently perturbed, the neuron "fires" and sends this perturbation along its axon to its termination, the synapses.

## *Transmission*

Since these perturbations are electrical, they can be picked up by "microprobes," amplified and recorded. Figure 11 shows three examples of periodic discharges from a touch receptor under continuous stimulation, the low frequency corresponding to a weak stimulus, the high frequency to a strong stimulus. The magnitude of the discharge is clearly everywhere the same, the pulse frequency representing the stimulus intensity, but the intensity only.



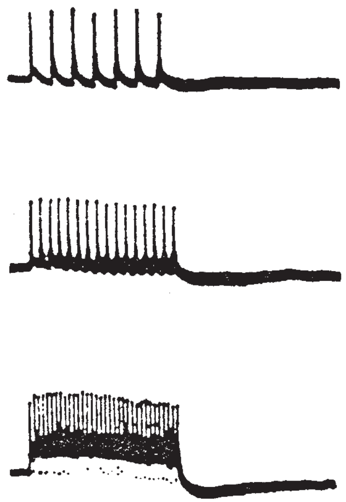


Figure 11.

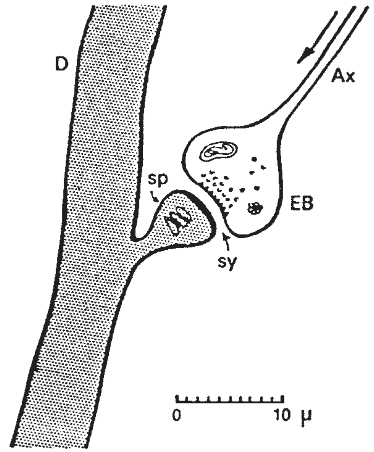



Figure 12.

## *Synapse*

Figure 12 sketches a synaptic junction. The afferent axon (Ax), along which the pulses travel, terminates in an end bulb (EB), which is separated from the spine (sp) of a dendrite (D) of the target neuron by a minute gap (sy), the "synaptic gap." (Note the many spines that cause the rugged appearance of the dendrites in Fig. 10). The chemical composition of the "transmitter substances" filling the synaptic gap is crucial in determining the effect an arriving pulse may have on the ultimate response of the neuron: Under certain circumstances it may produce an "inhibitory effect" (cancellation

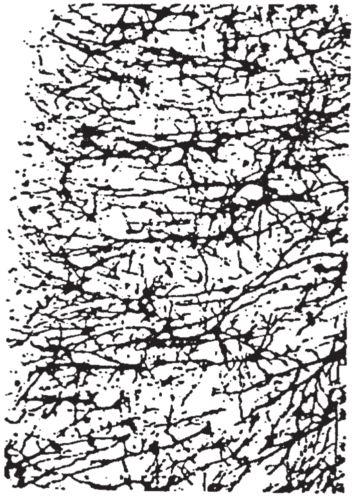


FIGURE 13.

another simultaneously arriving pulse), in others a "facilitory effect" (augmenting another pulse to fire the neuron). Consequently, the synaptic gap can be seen as the "microenvironment" of a sensitive tip, the spine, and with this interpretation in mind we may compare the sensitivity of the CNS to changes of the *internal* environment (the sum total of all microenvironments) to those of the *external* environment (all sensory receptors). Since there are only 100 million sensory receptors, and about 10,000 billion synapses in our nervous system, we are 100 thousand times more receptive to changes in our internal than in our external environment.

## The Cortex

In order that one may get at least some perspective on the organization of the entire machinery that computes all perceptual, intellectual, and emotional experiences, I have attached Figure 13,[7] which shows a magnified section of about 2 square millimeters of a cat's cortex by a staining method that stains only cell body and dendrites, and of those only 1% of all neurons present. Although you have to imagine the many connections among these neurons provided by the (invisible) axons, and a density of packing that is 100 times that shown, the computational power of even this very small part of a brain may be sensed.

## Descartes

This perspective is a far cry from that held, say, 300 years ago:[2]

If the fire A is near the foot B [Fig. 14], the particles of this fire, which as you know move with great rapidity, have the power to move the area of the skin of this foot


FIGURE 14.

that they touch; and in this way drawing the little thread, c, that you see to be attached at base of toes and on the nerve, at the same instant they open the entrance of the pore, d,e, at which this little thread terminates, just as by pulling one end of a cord, at the same time one causes the bell to sound that hangs at the other end. Now the entrance of the pore or little conduit, d,e, being thus opened, the animal spirits of the cavity F, enter within and are carried by it, partly into the muscles that serve to withdraw this foot from the fire, partly into those that serve to turn the eyes and the head to look at it, and partly into those that serve to advance the hands and to bend the whole body to protect it.

Note, however, that some behaviorists of today still cling to the same view,[8] with one difference only, namely, that in the meantime Descartes' "animal spirit" has gone into oblivion.

## Computation

The retina of vertebrates, with its associated nervous tissue, is a typical case of neural computation. Figure 15 is a schematic representation of a mammalian retina and its postretinal network. The layer labeled 1 represents the array of rods and cones, and layer 2 the bodies and nuclei of these cells. Layer 3 identifies the general region where the axons of the receptors synapse with the dendritic ramifications of the "bipolar cells" (4) which, in turn, synapse in layer 5 with the dendrites of the ganglion cells" (6), whose

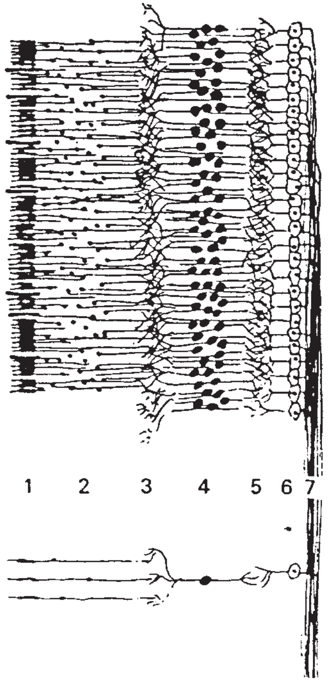



Figure 15.

activity is transmitted to deeper regions of the brain via their axons, which are bundled together to form the optic nerve (7). Computation takes place within the two layers labeled 3 and 5, that is, where the synapses are located. As Maturana has shown[3] it is there where the sensation of color and some clues as to form are computed.

Form computation: Take the two-layered periodic network of Figure 16, the upper layer representing receptor cells sensitive to, say, "light." Each of these receptors is connected to three neurons in the lower (computing) layer, with two excitatory synapses on the neuron directly below (symbolized by buttons attached to the body) and with one inhibitory synapse (symbolized by a loop around the tip) attached to each of the two neurons, one to the left and one to the right. It is clear that the computing layer will not respond to uniform light projected on the receptive layer, for the two excitatory stimuli on a computer neuron will be exactly compensated by the inhibitory signals coming from the two lateral receptors. This zero response will prevail under strongest and weakest stimulations as well as for slow or rapid changes of the illumination. The legitimate question may now arise: "Why this complex apparatus that doesn't do a thing?"

Consider now Figure 17, in which an obstruction is placed in the light path illuminating the layer of receptors. Again all neurons of the lower layer will remain silent, except the one at the edge of the obstruction, for it



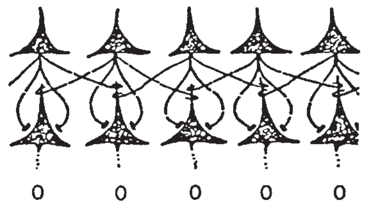



Figure 16.

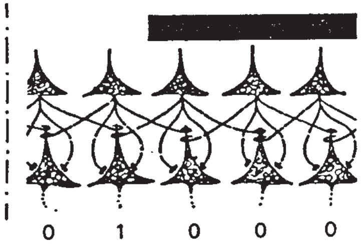



Figure 17.

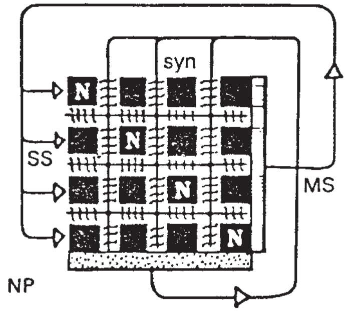



Figure 18.

receives two excitatory signals from the receptor above, but only one inhibitory signal from the sensor to the left. We now understand the important function of this net, for it computes any spatial *variation* in the visual field of this "eye," independent of the intensity of the ambient light and its temporal variations, and independent of place and extension of the obstruction.

Although all operations involved in this computation are elementary, the organization of these operations allows us to appreciate a principle of considerable depth, namely, that of the computation of abstracts, here the notion of "edge."

I hope that this simple example is sufficient to suggest to you the possibility of generalizing this principle in the sense that "computation" can be seen on at least two levels, namely, (1) the operations actually performed and (2) the organization of these operations represented here by the structure of the nerve net. In computer language (1) would again be associated with "operations," but (2) with the "program." As we shall see later, in "biological computers" the programs themselves may be computed on. This leads to the concepts of "metaprograms," "meta-metaprograms," and so on. This, of course, is the consequence of the inherent recursive organization of those systems.

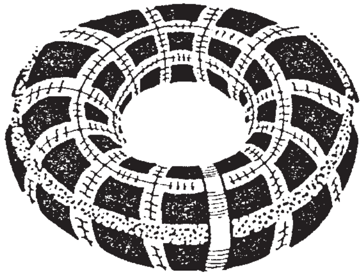


FIGURE 19.

## *Closure*

By attending to all the neurophysiological pieces, we may have lost the perspective that sees an organism as a functioning whole. In Figure 18 I have put these pieces together in their functional context. The black squares labeled *N* represent bundles of neurons that synapse with neurons of other bundles over the (synaptic) gaps indicated by the spaces between squares. The sensory surface (SS) of the organism is to the left, its motor surface (MS) to the right, and the neuropituitary (NP), the strongly innervated master gland that regulates the entire endocrinal system, is the stippled lower boundary of the array of squares. Nerve impulses traveling horizontally (from left to right) ultimately act on the motor surface (MS) whose changes (movements) are immediately sensed by the sensory surface (SS), as suggested by the "external" pathway following the arrows. Impulses traveling vertically (from top to bottom) stimulate the neuropituitary (NP), whose activity release steroids into the synaptic gasp, as suggested by the wiggly terminations of the lines following the arrow, and thus modify the *modus operandi* of all synaptic junctures, hence the *modus operandi* of the system as a whole. Note the double closure of the system that now recursively operates not only on what it "sees," but on its operators as well. In order to make this twofold closure even more apparent I propose to wrap the diagram of Figure 18 around its two axes of circular symmetry until the artificial boundaries disappear and the torus (doughnut) in Figure 19 is obtained. Here the "synaptic gap" between the motor and sensory surfaces is the striated meridian in the front center, the neuropituitary the stippled equator. This, I submit, is the functional organization of a living organism in a (dough) nut shell.

The computations within this torus are subject to a nontrivial constraint, and this is expressed in the postulate of cognitive homeostais:

> The nervous system is organized (or organizes itself) so that it computes a stable reality.

This postulate stipulates "autonomy," that is, "self-regulation," for every living organism. Since the semantic structure of nouns with the prefix *self-* becomes more transparent when this prefix is replaced by the noun,



*autonomy* becomes synonymous with *regulation of regulation*. This is precisely what the doubly closed, recursively computing torus does: It regulates its own regulation.

## Significance

It may be strange in times like these to stipulate autonomy, for autonomy implies responsibility: If I am the only one who decides how I act, then I am responsible for my action. Since the rule of the most popular game played today is to make someone else responsible for *my* acts—the name of the game is "heteronomy"—my arguments make, I understand, a most unpopular claim. One way of sweeping it under the rug is to dismiss it as just another attempt to rescue "solipsism," the view that this world is only in my imagination and the only reality is the imagining "I." Indeed, that was precisely what I was saying before, but I was talking only about a single organism. The situation is quite different when there are two, as I shall demonstrate with the aid of the gentleman with the bowler hat (Fig. 20).

He insists that he is the sole reality, while everything else appears only in his imagination. However, he cannot deny that his imaginary universe is populated with apparitions that are not unlike himself. Hence he has to

FIGURE 20.

concede that they themselves may insists that they are the sole reality and everything else is only a concoction of their imagination. In that case their imaginary universe will be populated with apparitions, one of which may be *he*, the gentleman with the bowler hat.

According to the principle of relativity, which rejects a hypothesis when it does not hold for two instances together, although it holds for each instance separately (Earthlings and Venusians may be consistent in claiming to be in the center of the universe, but their claims fall to pieces if they should ever get together), the solipsistic claim falls to pieces when besides me I invent another autonomous organism. However, it should be noted that since the principle of relativity is not a logical necessity—nor is it a proposition that can be proven to be either true or false—the crucial point to be recognized here is that I am free to choose either to adopt this principle or to reject. If I reject it, I am the center of the universe, my reality is my dreams and my nightmares, my language is monologue, and my logic monologic. If I adopt it, neither I nor the other can be the center of the universe. As in the heliocentric system, there must be a third that is the central reference. It is the relation between Thou and I, and this relation is *identity*:

$$\text{reality} = \text{community}$$

What are the consequences of all this in ethics and aesthetics?

*The ethical imperative*: Act always so as to increase the number of choices.

*The aesthetical imperative*: If you desire to see, learn how to act.

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# zeros + ones

DIGITAL WOMEN + THE NEW TECHNOCULTURE

"Feedbacks of this general type are certainly found in human and animal reflexes," wrote Norbert Wiener. "When we go duck shooting, the error which we try to minimize is not that between the position of the gun and the actual position of the target but that between the position of the gun and the anticipated position of the target. Any system of anti-aircraft fire control must meet the same problem." The anticipated moment of impact is taken into account, fed back into the calculations which lead to the desired outcome. The end result is engineered in reverse.



## cybernetics

Norbert Wiener

When Wiener published his *Cybernetics: Communication and Control in Animal and Machine* in 1948, he announced the dawn of a new era of communication and control. The term cybernetics comes from the Greek word for steersman, the figure who guides the course of a ship. What it actually described in Wiener's terms was both the steersman and the ship, which together compose what became known as a cybernetic organism, or cyborg.

Cybernetic systems are machines which incorporate some device allowing them to govern or regulate themselves, and so run with a degree of autonomy. Cybernetic systems have little in common with "older machines, and in particular the older attempts to produce automata" such as Babbage's silver dancer. What sets "modern automatic machines such as the controlled missile, the proximity fuse, the automatic door opener, the control apparatus for a chemical factory, and the rest of the modern armoury of automatic machines which perform military or industrial functions" apart from clockwork machines is that they "possess sense organs; that is, receptors for messages coming from the outside." These are systems which receive, transmit, and measure sense data, and are "effectively coupled to the external world, not merely by their energy flow, their metabolism, but also by a flow of impressions, of incoming messages, and of the actions of outgoing messages."

While Wiener was among the first to name such processes, cybernetics has no neat source, no single point of origin. Cybernetic circuits and feedback loops could retrospectively be identified in a variety of modern contexts and theories, including those of Immanuel Kant, Adam Smith, Karl Marx, Alfred Wallace, Friedrich Nietzsche, and Sigmund Freud. Wiener's work picked up on many elements of these earlier researches. Energetic feedback loops are certainly at work in James Watt's steam engine, which is regulated by a governor which "keeps the engine from running wild when its load is removed. If it starts to run wild, the bars of the governor fly upward from centrifugal action, and in their upward flight they move a lever which partly cuts off the admission of steam. Thus the tendency to speed up produces a partly compensatory tendency to slow down." There are suggestions that "the first homeostatic machine in human history" came long before the steam engine with twelfth-century compasses. Sometimes Ktesibios's "regular," a water clock dating to the third century B.C., is given the honor of being "the first nonliving object to self-regulate, self-govern, and self-control . . . the first *self* to be born outside of biology . . . a true *auto* thing—directed from within."



As Wiener's work made clear, however, the old distinctions between autonomous activity within and outside biology could no longer be applied. As his reference to animal and machine suggested, cybernetic systems were composed at all scales and of any combination of materials, and the same patterns, processes, and functions could now be observed in technical and organic systems alike. Input and output devices allow them to connect and communicate with whatever composes their outside world; feedback loops and governors give them some measure of self-control. Prioritizing the processes common to lively systems of all varieties, rather than the essential qualities which had more recently distinguished them, Wiener argued that organisms—animals, humans, all kinds of beings—and things—nonorganic systems and machines—"are precisely parallel in their analogous attempts to control entropy through feedback." No matter how extreme, the differences between these systems were simply matters of degree. Human beings were no exception to these basic ways of life.



Cybernetic systems, it now seemed, had always been organizing themselves. Wiener's work was merely the occasion for them to become perceptible to a world which still thought that everything needed to be organized by some outside force. As "the theory of the message among men, machines, and in society as a sequence of events in time," cybernetics was conceived as an attempt to "hold back nature's tendency toward disorder by adjusting its parts to various purposive ends." This tendency toward disorder is entropy, defined by the Second Law of Thermodynamics as the inexorable tendency of any organization to drift into a state of increasing disorder. Wiener describes a world in which all living organisms are "local and temporary islands of decreasing entropy in a world in which the entropy as a whole tends to increase." Cybernetic systems, like organic lives, were conceived as instances of a struggle for order in a continually degenerating world which is always sliding towards chaos. "Life is an island here and now in a dying world. The process by which we living beings resist the general stream of



corruption and decay is known as *homeostasis.*" Wiener's cybernetic systems, be they living or machinic, natural or artificial, are always conservative, driven by the basic effort to stay the same.

"It seems almost as if progress itself and our fight against the increase of entropy intrinsically must end in the downhill path from which we are trying to escape," wrote Wiener in the 1950s. "It is highly probable that the whole universe around us will die the heat death, in which the world shall be reduced to one vast temperature equilibrium in which nothing really new ever happens. There will be nothing left but a drab uniformity out of which we can expect only minor and insignificant local fluctuations." Nevertheless, Wiener assures his readers that it may well be "a long time yet before our civilization and our human race perish." We are "not yet spectators at the last stages of the world's death," and a multiplication of cybernetic loops could ensure that this point was continually warded off.



*The Sex Which Is Not One* is not impressed. "Consider this principle of constancy which is so dear to you: what 'does it mean'? The avoidance of excessive inflow/outflow-excitement? Coming from the other? The search, at any price, for homeostasis? For self-regulation? The reduction, then, in the machine, of the effects of movements from/toward its outside? Which implies reversible transformations *in a closed circuit,* while discounting the variable of time, except in the mode of *repetition of a state of equilibrium.*" She is dying to run away.

Hunting for the abstract principles of organization and an organized life, cybernetics was supposed to be introducing unprecedented opportunities to regulate, anticipate, and feed all unwelcome effects back into its loops. It also exposed the weaknesses of all attempts to predict and control. Cybernetic systems enjoy a dynamic, interactive relation with their environment which allows them to feed into and respond to it. Feedback "involves sensory members which are actuated by motor members and perform the function of *tell-tales* or *monitors*—that is, of elements which indicate a performance. It is the function of these mechanisms to control the mechanical tendency toward disorganization; in other words, to produce a temporary and local reversal of the normal direction of entropy." It is also the inevitable function of these mechanisms to engage and interact with the volatile environments in which they find themselves. "No system is closed. The outside always seeps in . . ." Systems cannot stop interacting with the world which lies outside of themselves, otherwise they would not be dynamic or alive. By the same token, it is precisely these engagements which ensure that homeostasis, perfect balance, or equilibrium, is only ever an ideal. Neither animals nor machines work according to such principles.

Long before Wiener gave them a name, it was clear that cybernetic systems could run into "several possible sorts of behaviour considered undesirable by those in search of equilibrium. Some machines went into runaway, exponentially maximizing their speed until they broke or slowing down until they stopped. Others oscillated and seemed unable to settle to any mean. Others—still worse—embarked on sequences of behaviour in which the amplitude of their oscillation would itself oscillate or would become greater and greater," turning themselves into systems with "positive gain, variously called *escalating* or *vicious* circles." Unlike the negative feedback loop which turns everything to the advantage of the security of the whole, these runaway, schismogenetic processes take off on their own to the detriment of the stability of the whole.

Undermining distinctions between human, animal, and machine, Wiener also challenged orthodox conceptions of life,





death, and the boundary between the two. Were self-governing machines alive? If not, why not? After all, they were certainly not dead matter, impassive and inert. And, since many lifeforms were less sophisticated than automatic machines, the status of being alive could not simply be a matter of complexity.

Only by reverting to some notion of essences was it possible to distinguish between the liveliness of an organism and that of a machine. In principle, neither was more or less dead or alive than the other. Life and death were no longer absolute conditions, but interactive tendencies and processes, both of which are at work in both automatic machines and organisms. Regardless of their scale, size, complexity, or material composition, things that work do so because they are both living and dying, organizing and disintegrating, growing and decaying, speeding up and slowing down. "Every intensity controls within its own life the experience of death, and envelops it." Either extreme can be fatal, and in this sense systems do die in a final and absolute and final sense. "Death, then, does actually happen." But it is not confined to the great event at the end of life. This is a death which is also "felt in every feeling," a death which "never ceases and never finishes happening in every becoming." All living systems are dying: this is the definition of life. Something that lives is something that will die, which is why "the hint of death is present in every biological circuit."

***"And I am just the person to drop off some fine day when nobody knows anything about the matter or expects it . . .***
***"Do not fancy me ill. I am apparently very well at present. But there are the seeds of destruction within me. This I know.***
***"Though it may only develop by hairs' breadths . . ."***

**Ada Lovelace, December 1842**

Whether a system comes to an end as a consequence of too much or too little activity, its particular elements will be redistributed and rearranged within some new system which emerges in its wake. In this sense, Wiener also undermined the extent to which any working system can consider itself to be an individuated entity with some organizing essence of its own. It is not only at its demise that a system's components connect with others and reconfigure: they are always doing this. Just as the steersman was both an autonomous, self-regulating system, and also the governing element in a new autonomous, self-regulating system which he composed together with the ship, so Wiener's systems had no absolute identity. Continually interacting with each other, constituting new systems, collecting and connecting themselves to form additional assemblages, these systems were only individuated in the most contingent and temporary of senses.



Economies, societies, individual organisms, cells: At these and every other scale of organization, the stability of any system depends on its ability to regulate the speeds at which it runs, ensuring that nothing stops too soon, goes too slow, runs too fast, goes too far. And there is always something hunting, trying to break the speed limits necessary to its organized form, tipping over a horizon at which point, even though another, long-term stability may emerge on the other side, it can no longer be said that the system survives. Nothing can guarantee a system's immunity to these runaway effects. Invulnerability would be homeostasis, an absolute and fatal stability. This is what it has to seek, but also something it attains only at the price of its own demise.

"If the open system is determined by anything, it is determined by the goal of STAYING THE SAME." Systems committed to the maintenance of equilibrium are always holding back, and always in danger of running away. "Only when the system enters positive feedback does this determination change." At which point it also becomes clear that running away is what they were always trying to do: "Feedback tends to oppose what the system is already doing." It is this prior exploratory tendency which negative feedback tries to resist: "All growth is positive feedback and must be inhibited." It is only after the emergence of regulatory checks and balances that systems can then find themselves out of control, fueled by too much efficiency, overflowing with their own productivity, seeking only to break down or break through their own organization. And "once this exponential process has taken off, it becomes a necessary process, until such a time as second-order negative feedback—just as necessarily—brings the runaway processes to a halt so that the system as a whole may survive by qualitative change (revolution)." Positive feedback has to run its inexorable course, and every attempt to confine it will merely encourage its tendencies toward either destruction or qualitative change. "When the ecosystem is subjected to disturbances that go beyond a certain THRESHOLD, the stability of the ecosystem can no longer be maintained within the context of the norms available to it. At this point the oscillations of the ecosystem can be controlled only by second-order negative feedback: the destruction of the system or its emergence as a metasystem." Running toward the limits of its functioning, it will either collapse or exceed this threshold and reorganize on its other side. "Any system-environment relationship that goes outside the 'homeostatic plateau' results in the destruction of the system—unless, that is, it can adapt by changing structure in order to survive." Which may well amount to the same thing.

***" 'The hour has come for you to live, Hadaly.'***

***" 'Ah, master, I do not wish to live,' murmured the soft voice through the hanging veil."***

**Villiers de l'Isle Adam, *L'eve future***

"I always feel in a manner as if I *had* died," wrote Ada, "as if I can conceive & know *something* of *what* the change is. That there is some remarkable tact & intuition about me on the subject I have not a doubt . . ." Hadaly, Ada, wrapped around each other . . . neither something nor nothing, dead nor alive. Missing in action. Absent without leave.



What gives a cyborg its autonomy and separates it off from its environment is not some ineffable quotient of soul or mind, or even fixed boundaries surrounding it. And while Wiener found it easy to consider each cybernetic system in relatively isolated terms, when cybernetics reemerged at the end of the twentieth century, it was not so easy to draw these lines. Blossoming into theories of chaos, complexity, connectionism, and emergent and self-organizing networks, Wiener's relatively simple and self-contained cybernetic systems could no longer be confined to circuits such as those connecting the pilot and the ship, but incorporated all and any of the elements which compose them, and those with which they come into contact: eyes, hands, skin, bones, decks, rails, wheels, rudders, maps, stars, currents, winds, and tides. It encompasses a literally endless list of components working together at an equally endless variety of interlocking and connecting scales. Systems such as these are not merely composed of one or two loops and a governor, but a myriad of interacting components too complex and numerous to name.

## sea change

"For a long time turbulence was identified with disorder or noise." Then, in a 1977 book called *Order Out of Chaos*, Ilya Prigogine and Isabelle Stengers demonstrated that "while turbulent motion appears as irregular or chaotic on the macroscopic scale, it is, on the contrary, highly organized on the microscopic scale. The multiple space and time scales involved in turbulence correspond to the coherent behaviour of millions and millions of molecules."



"How does a flow cross the boundary from smooth to turbulent?" Suddenly. It involves "a kind of macroscopic behaviour that seems hard to predict by looking at the microscopic details. When a solid is heated, its molecules vibrate with the added energy. They push outward against their bonds and force the substance to expand. The more heat, the more expansion. Yet at a certain temperature and pressure, the change becomes sudden and discontinuous.

"The particles of cigarette smoke rise as one, for a while," forming a smooth continuous strand. "Then confusion appears, a menagerie of mysterious wild motions. Sometimes these motions received names: the oscillatory, the skewed varicose, the cross-roll, the knot, the zig-zag rhythms with overlapping speeds." There are "fluctuations upon fluctuations, whorls upon whorls," paisley patterns and swirling sequences as elements of the substance in transition communicate with each other and effectively make a "decision" to change at the same time. Tobacco smoke is a perfect example of the way in which what appears to be a long smooth line is actually composed of molecules which only give themselves away in the moment they interrupt the flow. "A rope has been stretching; now it breaks. Crystalline form dissolves, and the molecules slide away from one another. They obey fluid laws that could not have been inferred from any aspect of the solid." It is characteristic of all such shifts that the "entities and variables that fill the stage at one level of discourse vanish into the background at the next-higher or lower level."

## the peahen's tale

When Darwin defined natural selection as the "preservation of favourable variations and the rejection of injurious variations," he took his cue from the techniques of artificial selection employed by breeders of animals and plants. While breeders have their own purposes in mind, they are not in a position to make the variations themselves occur: They are simply accentuating or diminishing modifications which have already emerged in among the population they keep. And while breeders were making occasional judgments about what was favorable or injurious on the basis of outwardly obvious characteristics—the length of a tail, the color of a flower—Darwin's natural selection was a blind automatic process whose only external influences were provided by the environment with which the organism was continually maintaining, adjusting, and improving its ability to interact. "It may be said that natural selection is daily and hourly scrutinizing, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and invisibly working, whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life."

With his argument that organisms survived because they were fit enough to do so, and not because they were handpicked by God, Darwin certainly succeeded in removing theology from the evolutionary picture. Biological selection was not divine, but natural, and the organisms which proliferated were simply those which proliferated. Natural selection "is a game





with its own rules. All that count are the changes that affect the number of offspring. If they reduce that number, they are mistakes; if they increase it, they are exploits." In these terms, which are so broad as to be tautological, natural selection is widely accepted and relatively uncontroversial. Beyond these sweeping terms, natural selection is both extraordinarily complex and certainly not the only factor in the evolutionary game.

While Darwin's theory of natural selection emphasized the regulatory mechanisms at work in individuated organisms and well-defined species, Darwin was neither as conservative nor dogmatic as the work of many later Darwinians might suggest. And even he was aware that other processes were in play. Sexual difference was one of the most obvious anomalies. "When the males and females of any animal have the same general habits of life, but differ in structure, colour and ornament," he wrote, "such differences have been mainly caused by sexual selection: that is, individual males have had, in successive generations, some slight advantage over other males, in their weapons, means of defence, or charms; and have transmitted these advantages to their male offspring."

The question begged by these comments was where these advantages had come from, and although Darwin posed it in these male terms, it was clear that sexual selection was a matter of specifically female choice. Studies of the infamous fruit fly, *drosophilia subsobscura,* suggest that males and females dance around each other, apparently until the female decides to accept the male as a mate. It seems that "the female accepts a male who keeps up adequately during the dance, and rejects one who does not. The female is, therefore, extremely discriminating; in contrast, a male will dance with and attempt to mount a blob of wax on the end of a bristle." Early attempts to explain such procedures, which are by no means confined to the fruit fly, reduced the behavior of both females and males to the quest for fitness prioritized by natural selection. If only the fittest of the species survive, it is fitness that the females are putting to the test. Unfortunately for this theory, females do not necessarily choose males who are fit in Darwinian terms. Female guppies choose males whose bright colors leave them vulnerable to predators. Female nightingales choose males whose serenades also announce their presence to their enemies. Even more frequently quoted is the peacock whose beautiful but impractical tail is extremely attractive to discriminating peahens, but is nothing more than a liability in terms of his ability to survive.

The nightingale's song, the guppies' colors, the fruit fly's dances, and the peacock's tail are all emergent from "virility tests designed to get most males killed through exhaustion, disease and violence purely so that females can tell which males have the best genes." In effect, males function as "the female sex's health insurance policy," often at great cost to themselves. The high levels of testosterone induced by the demands of female sexual selection may give males their distinguishing features, but they also weaken the immune systems of males, and leave them so vulnerable to a kind of remote control by their female counterparts that it has even been described as "the supreme female 'invention,' " perhaps "an evolutionary plot on behalf of females."

The drab peahen and the unsung female nightingale figure among the vast ranks of inconspicuous females which use the males of their species as "genetic sieves, to sift out the good genes and discard the bad. They do this by equipping males with all sorts of encumbrances and then setting them to work in competition, either beating each other up or risking their lives against predators and parasites." The peacock has an extraordinary tail not because it improves his chances of survival: more







often than not, it gets in his way. Left to his own devices, he would no doubt be a far more functional shape. As Charlotte Perkins Gilman wrote, the male "is not profited personally by his mane or crest or tail-feathers: they do not help him get his dinner or kill his enemies," and can even "react unfavourably upon his personal gains, if, through too great development, they interfere with his activity or render him a conspicuous mark for enemies." But the peacock's tail is out of his control. It is the sexual preference of the peahens which determines the characteristics of his colors and his tail, so much so that their behavior "resembles artificial breeding in this respect, with the peahen in the role of breeder."

Natural and sexual selection function in conjunction with each other, ideally to the optimal advantage of them both. His chances of survival may be compromised, but the peacock gains the sex appeal that is likely to allow him to reproduce. The runaway development of his tail is simply an "advertising cost" designed to make him attractive to peahens. Sexual selection made it clear that female behavior was not merely a variation on the theme of natural selection. Females not only exert an enormous influence on the behaviors of males and, by implication, their species as a whole. Their selection procedures also constitute an inherently unstable and destabilizing feature of natural selection, always threatening to exceed its countervailing conservative demands.

Not that this female breeding program necessarily makes itself known. Sexual difference may be balanced, sustained, and reproduced for generations, until some subtle mutation in the male begins to appeal to what has hitherto been a minority female preference. Regardless of whether they are male or female, the offspring produced by females carrying, and exercising, these preferences will then carry both the gene for the longer tail and the gene for its preference. Male offspring develop the longer tail, and pass both this gene and the gene for female preference to their offspring, with whom the process continues. Female offspring exercise the gene for long-tail preference and carry the gene for longer tails, which expresses itself in any male progeny. The process begins to run away. The species starts to move too fast. The equilibrium which was supposed to be guaranteed by the balanced sexes and mutually reinforcing modes of selectivity hits skid row, goes out of control. Even though the peacock's tail has reached the optimum stage of its development; even after he has become as sexually desirable as the females would wish, "the further development of the plumage character will still proceed, by reason of the advantage gained in sexual selection, even after it has passed the point in development at which its advantage in Natural Selection has ceased."



After this the female gene "rides, like a surfer, on a wave of ever-increasing tail lengths sweeping through the population." In effect, it chooses itself. When it chooses males with long tails it is also choosing those which carry a "hidden" gene for the females' preference for them. "The two characteristics affected by such a process, namely plumage development in the male, and sexual preference for such developments in the female . . . advance together, and so long as the process is unchecked by severe counterselection, will advance with ever-increasing speed. In the total absence of such checks, it is easy to see that the speed of development will be proportional to the development already attained, which will therefore increase with time exponentially, or in geometric progression. There is thus in any bionomic situation in which sexual selection is capable of conferring a great reproductive advantage, as certainly occurs in some polymorphic birds, the potentiality of a runaway process, which, however small the beginnings from which it arose, must, unless unchecked, produce great effects, and in the later stages with great rapidity."

"Where one function is carried to unnatural excess, others are weakened, and the organism perishes." As Gilman writes, "All morbid conditions tend to extinction. One check has always existed to our inordinate sex-development, nature's ready relief, death." Positive feedback can always go too far. Any further and the peacock would die.

Darwin was well aware of the importance of sexual selection, the influence of female choice, and the peculiarity of the peacock's tail which, like all characteristics specific to males, seemed bound to be an evolutionary disadvantage. But he simply stated these syndromes as unexplained facts. The peacock's tail is simply beautiful because the peahens like it that way. "So it was female choice which caused the males' long tails. But what caused the female preference? Darwin simply took it for granted." In a sense, there was little else he could do. The female line seems to run in circles of its own. As R. A. Fisher was later to suggest, female preference was "caused, essentially, by *itself.*"



Although sexual selection had been discussed by generations of evolutionary biologists, it was not until the mid-1980s that it was widely acknowledged that "in many species, females had a large say in the matter of their mating partner." The fact that the majority of investigators have their own male interests at heart has undoubtedly contributed to the neglect of this evolutionary tale. But any suggestion that there has been some deliberate conspiracy of silence gives evolutionary biology far more credit than even its most dogmatic exponents would want to claim. Sexual selection is not a matter of linear transmission, but a self-reinforcing loop with which orthodox conceptions of evolution have simply been unable to cope. The self-stimulating circuits of female sexual selection are so utterly alien to a biological ethos of organizing points and straight lines that they have been both inexplicable and often imperceptible as well. The suppression of the runaway female circuitry runs far deeper than the discourses and laboratories of the modern sciences: It is crucial to the survival of the species itself.

## wetware

***"Life is not life, but rock rearranging itself under the sun."***

**Dorion Sagan**

The microbiotic continuum extends from the earliest forms of oceanic life. Irigaray's *Marine Lover* longs to "think of the sea from afar, to eye her from a distance, to use her to fashion his higher reveries, to weave his dreams of her, and spread his sails while remaining safe in port." But the oceans "have far more to them than the mere capacity to dazzle an observer in outer space." They cover two thirds of planet Earth—or sea—and support at least "half of the mass of living matter in the world." And whereas life "on the land is for the most part two-dimensional, held by gravity to the solid surface," submarine living is an immersive, multidimensional process. When they first crept onto the land, "terrestrial organisms had to build for themselves structures and components that could perform the environmental services that marine organisms can take for granted." On land, "direct physical connections become essential." Water is no longer ambient, the medium in which life is immersed, but instead an irrigation system which connects and passes through all land life. Now the "biota has had to find ways to carry the sea within it and, moreover, to construct watery conduits from 'node' to 'node.' " Land life is literally pleated and plied, complex. It has effectively "taken the sea beyond the sea and folded it back inside of itself," assembling itself as a network of molecular arteries and veins, a hydraulic system keeping life afloat.





"Acting over evolutionary time as a rising tide, the land biota literally carries the sea and its distinctive solutes over the surface of the land" forming a "terrestrial sea" of "countless and interconnected conduits" which "expands with every increase in the volume of tissues and sap and lymph of the creatures that constitute it."

The notion that blood is seawater has long faded into disuse. But suggestions that land-based life is the epiphenomenon of fluid transmissions within and between all organisms is a disturbing twist in a modern tale devoted to the dry solidities of land and its territorial claims. There are hints that "the appearance of complex life on land was a major event in which a kind of mutant sea invaded the land surface. It was as if the nimble offspring of the old sea had learned how to slosh and slop up onto land, with the tissues and vascular systems of land organisms acting as a complex, water-retaining sponge. Cuticle and skin took the functional place of the surface tension of water where sea meets air."

"The land biota represents not simply *life* from the sea, but a variation of the sea itself," and living, land-based fluids "are not a mere remnant or analog of the sea; they are actually a *new* type of sea or marine environment: Hypersea." This continuity of ocean and land is supported by the fuzzy zones between plants and less complex forms of life: bacteria, algae, fungi, lichens. "Trees are neither found nor needed in the sea," which continues to be "numerically dominated by tiny single-celled *protista,* including algae and protozoa." And "from the first appearance of marine bacteria in the fossil record, which apparently formed conspicuous scums or mats on the substrate," it seems that "the earliest terrestrial communities probably also formed microbial mats and crusts on moist surfaces." Consisting of "highly flattened fronds, sheets and circlets," these microbial mats are "composed of numerous slender segments quilted together," microscopic threads interwoven to form cooperative carpets of bacterial life.

## dryware

Modernity's new man was a landlubber. He charted the oceans but set up camp on "an island, enclosed by nature itself within unalterable limits. It is the land of truth—enchanting name!—surrounded by a wide and stormy ocean, the native home of illusion, where many a fog bank and many a swiftly melting iceberg give the deceptive appearance of further shores, deluding the adventurous seafarer." There is plenty beyond its shores: madness, fate, the ship of fools. But *nihil ulterius* is inscribed "on those Pillars of Hercules which nature herself has erected in order that the voyage of our reason may be extended no further than the continuous coastline of experience itself reaches."

He needs the illusions of the ocean, whose groundless appearances ground his truths. "If a man wants to delude himself, the sea will always lend him the sails to fit his fortune." But even the most single-minded of modernity's colonial adventures was destined to backfire. Navigation always "delivers man to the uncertainty of fate," and he never quite loses his fears of the ocean, its Siren sounds. "One thing at least is certain: water and madness have long been linked in the dreams of European man." He is always haunted by the fear that things might slip back into "the river with its thousand arms, the sea with its





thousand roads, to that great uncertainty external to everything."

"If only the sea did not exist. If they could just create her in dreams." All they really want to do is mop the oceans up, solidify the unfortunate fluidity with which they are confused. Which is why "they long for ice. To go further north than north. And to rest on ice. To float in the calm of mirrors. And sleep dry."