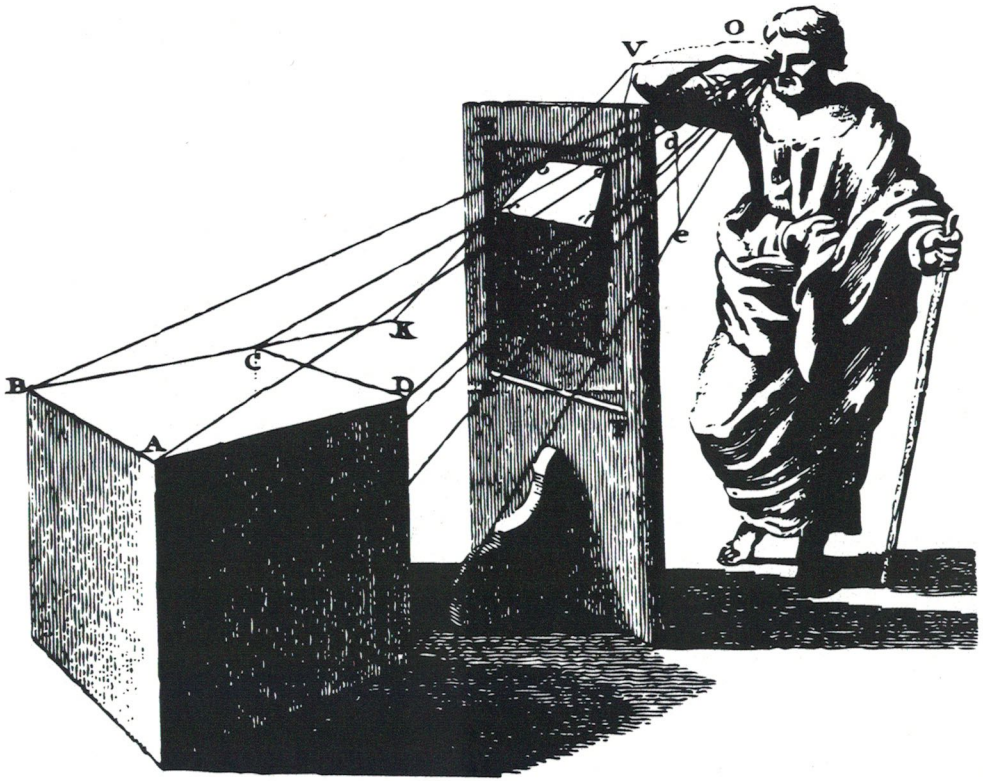
Perception of the Future and the Future of Perception [1]

Heinz von Foerster

"The definition of a problem and the action taken to solve it largely depend on the view which the individuals or groups that discovered the problem have of the system to which it refers. A problem may thus find itself defined as a badly interpreted output, or as a faulty output of a faulty output device, or as a faulty output due to a malfunction in an otherwise faultless system, or as a correct but undesired output from a faultless and thus undesirable system. All definitions but the last suggest corrective action; only the last definition suggests change, and so presents an unsolvable problem to anyone opposed to change."

— Herbert Brün, 1971.[2]



Truisms have the disadvantage that by dulling the senses they obscure the truth. Almost nobody will become alarmed when told that in times of continuity the future equals the past. Only a few will become aware that from this follows that in times of socio-cultural change the future will *not* be like the past. Moreover, with a future not clearly perceived, we do not know how to act with only one certainty left: if we don't act ourselves, we shall be acted upon. Thus, if we wish to be subjects, rather than objects, what we see now, that is, our perception, must be foresight rather than hindsight.

[1] This article is an adaptation of an address given on March 29, 1971, at the opening of the Twenty-fourth Annual Conference on World Affairs at the University of Colorado, Boulder, Colorado, U.S.A. reprinted from Von Foerster, Heinz. "Perception of the future and the future of perception." *Instructional Science* 1, no. 1 (1972): 31-43.
[2] Brün, H. 'Technology and the Composer,' in Von Foerster, H., ed., *Interpersonal Relational Networks.* (Cuernavaca: Centro Intercultural de Documentacion, 1971) 1–10.

My colleagues and I are, at present, researching the mysteries of cognition and perception. When, from time to time, we look through the windows of our laboratory into the affairs of this world, we become more and more distressed by what we now observe. The world appears to be in the grip of a fast-spreading disease which, by now, has assumed almost global dimensions. In the individual the symptoms of the disorder manifest themselves by a progressive corruption of his faculty to perceive, with corrupted language being the pathogene, that is, the agent that makes the disease so highly contagious. Worse, in progressive stages of this disorder, the afflicted become numb, they become less and less aware of their affliction.

This state of affairs makes it clear why I am concerned about perception when contemplating the future, for:

if we can't perceive,

we can't perceive of the future

and thus, we don't know how to act now.

I venture to say that one may agree with the conclusion. If one looks around, the world appears like an anthill where its inhabitants have lost all sense of direction. They run aimlessly about, chop each other to pieces, foul their nest, attack their young, spend tremendous energies in building artifices that are either abandoned when completed, or when maintained, cause more disruption than was visible before, and so on. Thus, the conclusions seem to match the facts. Are the premises acceptable? Where does perception come in?

Before we proceed, let me first remove some semantic traps, for—as I said before—corrupt language is the pathogene of the disease. Some simple perversions may come at once to mind, as when "incursion" is used for "invasion," "protective reaction" for "aggression," "food denial" for "poisoning men, beasts, and plants," and others. Fortunately, we have developed some immunity against such insults, having been nourished with syntactic monstrosities as "X is better" without ever saying "than what." There are, however, many more profound semantic confusions, and it is these to which I want to draw your attention now.

There are three pairs of concepts in which one member of these pairs is generally substituted for the other so as to reduce the richness of our conceptions. It has become a matter of fact to confuse process with substance, relations with predicates, and quality with quantity. Let me illustrate this with a few examples out of a potentially very large catalogue, and let me at the same time show you the paralytic behavior that is caused by this conceptual dysfunction.

Process/Substance

The primordial and most proprietary processes in any man and, in fact, in any organism, namely "information" and "knowledge," are now persistently taken as commodities, that is as substance. Information is, of course, the process by which knowledge is acquired, and knowledge is the processes that integrate past and present experiences to form new activities, either as nervous activity internally perceived as thought and will, or externally perceivable as speech and movement.[3] [4] [5] [6]

Neither of these processes can be "passed on" as we are told in phrases like, "Universities are depositories of Knowledge which are passed on from generation to generation," etc., for *your* nervous activity is just *your* nervous activity and, alas, not *mine*.

No wonder that an educational system that confuses the process of creating new processes with the dispensing of goods called "knowledge" may cause some disappointment in the hypothetical receivers, for the goods are just not coming: there are no goods.

Historically, I believe, the confusion by which knowledge is taken as substance comes from a witty broadsheet printed in Nuremberg in the Sixteenth Century. It shows a seated student with a hole on top of his head into which a funnel is inserted. Next to him stands the teacher who pours into this funnel a bucket full of "knowledge," that is, letters of the alphabet, numbers and simple equations. It seems to me that what the wheel did for mankind, the Nuremberg Funnel did for education: we can now roll faster down the hill.

Is there a remedy? Of course, there is one! We only have to perceive lectures, books, slides and films, etc., not as *information* but

[3] Maturana, H. R. 'Biology of Cognition' *BCL Report No. 9.0,* Biological Laboratory, Department of Electrical Engineering, University of Illinois, Urbana (1970) 93.
[4] Maturana, H. R. 'Neurophysiology of Cognition,' in Garvin, P., ed., *Cognition, A Multiple View* (New York: Spartan Books, 1971) 3–23.
[5] Von Foerster, H. "What is Memory that It May Have Hindsight and Foresight as well?", in Bogoch, S., ed., *The Future of the Brain Sciences,* (New York: Plenum Press, 1969) 19–64.
[6] Von Foerster, H. (1971). "Thoughts and Notes on Cognition," in Garvin, P., ed., *Cognition, A Multiple View,* (New York: Spartan Books, 1971) 25–48.

as *vehicles* for potential information. Then we shall see that in giving lectures, writing books, showing slides and films, etc., we have not solved a problem, we just created one, namely, to find out in which context can these things be seen so that they create in their perceivers new insights, thoughts, and actions.

Relation/Predicate

Confusing relations with predicates has become a political pastime. In the proposition "spinach is green," "green" is a predicate; in "spinach is good," "good" is a relation between the chemistry of spinach and the observer who tastes it. He may refer to his relation with spinach as "good." Our mothers, who are the first politicians we encounter, make use of the semantic ambiguity of the syntactic operator "is" by telling us "spinach *is* good"' as if they were to say "spinach is *green*."

When we grow older we are flooded with this kind of semantic distortion that could be hilarious if it were not so far reaching. Aristophanes could have written a comedy in which the wisest men of a land set out to accomplish a job that, in principle, cannot be done. They wish to establish, once and for all, all the properties that define an obscene object or act. Of course, "obscenity" is not a property residing within things, but a subject-object relationship, 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. Thus, 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.

"Order" is another concept that we are commanded to see in things rather than in our perception of things. Of the two sequences A and B,

A: 1,2,3,4,5,6,7,8,9

B: 8,5,4,9,1,7,6,3,2

Sequence A is seen to be ordered while B appears to be in a mess, until we are told that B has the same beautiful order as A, for B is in alphabetical order (eight, five, four, . . .). "Everything has order once it is understood" says one of my friends, a neurophysiologist, who can see order in what appears to me at first the most impossible scramble of

cells. My insistence here to recognize "order" as a subject-object relation and not to confuse it with a property of things may seem too pedantic. However, when it comes to the issue "law and order" this confusion may have lethal consequences. "Law and order" is no issue, it is a desire common to all; the issue is "which laws and what order," or, in other words, the issue is "justice and freedom."

Castration

One may dismiss these confusions as something that can easily be corrected. One may argue that what I just did was doing that. However, I fear this is not so; the roots are deeper than we think. We seem to be brought up in a world seen through descriptions by others rather than through our own perceptions. This has the consequence that instead of using language as a tool with which to express thoughts and experience, we accept language as a tool that determines our thoughts and experience.

It is, of course, very difficult to prove this point, for nothing less is required than to go inside the head and to exhibit the semantic structure that reflects our mode of perception and thinking. However, there are now new and fascinating experiments from which these semantic structures can be inferred. Let me describe one that demonstrates my point most dramatically.

The method proposed by George Miller[7] consists of asking independently several subjects to classify on the basis of similarity of meaning a number of words printed on cards (Figure 1). The subject can form as many classes as he wants, and any number of items can be placed in each class. The data so collected can be represented by a "tree" such that the branchpoints further away from the "root"' indicate stronger agreement among the subjects and hence suggest a measure of similarity in the meaning of the words for this particular group of subjects.

[7] Miller, G. A. "Psycholinguistic Approaches to the Study of Communication," in Arm, D. L., ed., *Journeys in Science*, (Albuquerque University: New Mexico, 1967) 22–73.

AGAIN	AIR	APPLE	BRING	CHEESE	COLD
COME	DARK	DOCTOR	EAT	FIND	FOOT
HARD	HOUSE	INVITE	JUMP	LIVE	MILK
NEEDLE	NOW	QUICKLY	SADLY	SAND	SEND
SLEEP	SLOWLY	SOFT	SUFFER	SUGAR	SWEET
TABLE	TAKE	VERY	WATER	WEEP	WHITE

Figure 1. Example of 36 words printed on cards to be classified according to similarity in meaning.

Fig. 2 shows the result of such a "cluster analysis" of the 36 words of Figure 1 by 20 adult subjects ("root" on the left). Clearly, adults classify according to syntactic categories, putting nouns in one class (bottom tree), adjectives in another (next to bottom tree), then verbs, and finally those little words one does not know how to deal with.

The difference is impressive when the adults' results are compared with the richness of perception and imagery of children in the third and fourth grade when given the same task (Figure 3). Miller reflects upon these delightful results:

> "Children tend to put together words that might be used in talking about the same thing—which cuts right across the tidy syntactic boundaries so important to adults. Thus all twenty of the children agree in putting the verb 'eat' with the noun 'apple'; for many of them 'air' is 'cold'; the 'foot' is used to 'jump'—You 'live' in a 'house'; 'sugar' is 'sweet', and the cluster of 'doctor,' 'needle,' 'suffer,' 'weep' and 'sadly' is a small vignette in itself."

What is wrong with our education that castrates our power over language? Of the many factors that may be responsible I shall name only one that has a profound influence on our way of thinking, namely, the misapplication of the "scientific method."

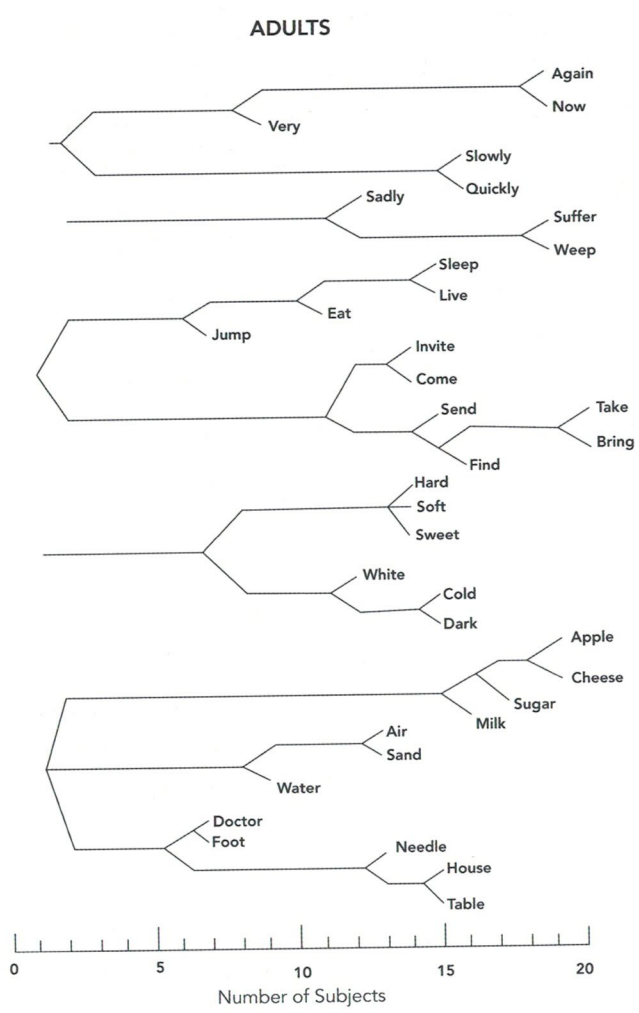


Figure 2. Cluster analysis of the 36 words of Fig. 1 classified by 20 adult subjects. Note that syntactic categories are faithfully respected, while semantic relations are almost completely ignored.

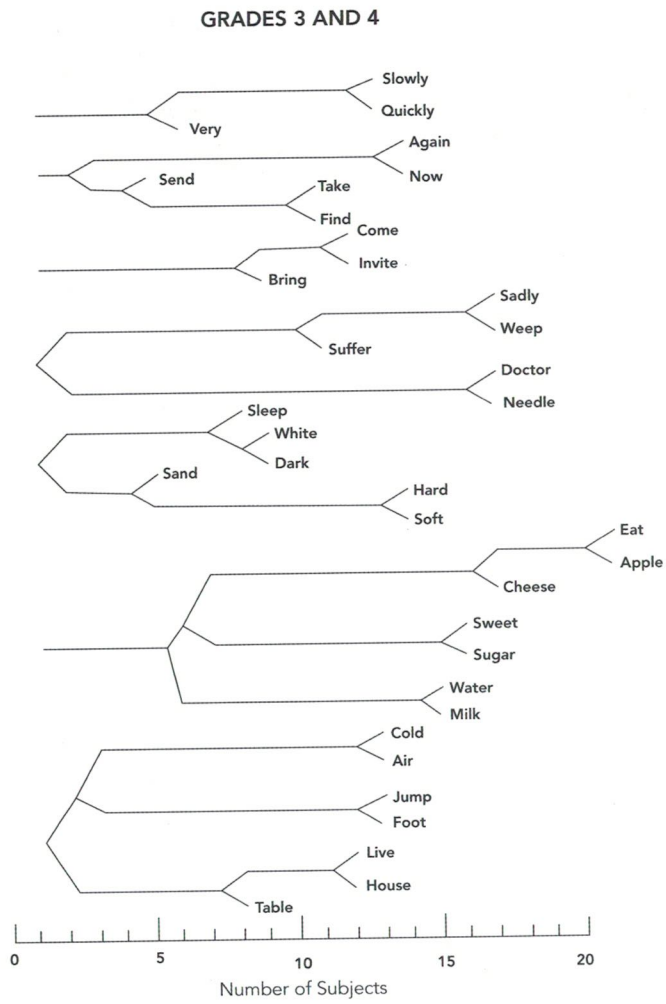


Figure 3. The sample 36 words of Figs. 1 and 2 classified by children in the third and fourth grade. Note the emergence of meaningful cognitive units, while syntactic categories are almost completely ignored.

Scientific Method

The scientific method rests on two fundamental pillars:

(i) Rules observed in the past shall apply to the future. This is usually referred to as the principle of conservation of rules, and I have no doubt that you are all familiar with it. The other pillar, however, stands in the shadow of the first and thus is not so clearly visible:

(ii) Almost everything in the universe shall be irrelevant. This is usually referred to as the principle of the necessary and sufficient cause, and what it demands is at once apparent when one realizes that "relevance" is a triadic relation that relates a set of propositions (*P1*, *P2*, ...) to another set of propositions (*Q1*, *Q2*, ...) in the mind (*M*) of one who wishes to establish this relation. If *P* are the causes that are to explain the perceived effects *Q*, then the principle of necessary and sufficient cause forces us to reduce our perception of effects further and further until we have hit upon the necessary and sufficient cause that produces the desired effect: everything else in the universe shall be irrelevant.

It is easy to show that resting one's cognitive functions upon these two pillars is counter-productive in contemplating any evolutionary process, be it the growing up of an individual, or a society in transition. In fact, this was already known by Aristotle who distinguished two kinds of cause, one the "efficient cause," the other the "final cause," which provide us with two distinct explanatory frameworks for either inanimate matter, or else living organisms, the distinction being that the efficient cause *precedes* its effect while the final cause *succeeds* its effect. When striking with a match the treated surface of a matchbook, the striking is the (efficient) cause for tile match to ignite. However, the cause for my striking the match is my wish to have it ignited (final cause).

Perhaps, with this distinction, my introductory remarks may appear much clearer. Of course, I had in mind the final cause when I said that if we can perceive of the future (the match being ignited), we know how to act now (strike!). This leads me immediately to draw a conclusion, namely: at any moment we are free to act toward the future we desire. In other words, the future will be as we wish and perceive it to be. This may come as a

shock only to those who let their thinking be governed by the principle that demands that only the rules observed in the past shall apply to the future. For those the concept of "change" is inconceivable, for change is the process that obliterates the rules of the past.

Quality/Quantity

In order to protect society from the dangerous consequences of change, not only a whole branch of business has emerged, but also the Government has established several offices that busy themselves in predicting the future by applying the rules of the past. These are the Futurists. Their job is to confuse quality with quantity, and their products are "'future scenarios" in which the qualities remain the same, only the quantities change: more cars, wider highways, faster planes, bigger bombs, etc. While these "future scenarios" are meaningless in a changing world, they have become a lucrative business for entrepreneurs who sell them to corporations that profit from designing for obsolescence.

With the diagnosis of the deficiency to perceive qualitative change, that is, a change of our subject-object and subject-subject relationships, we are very close to the root of the epidemic that I mentioned in my opening remarks. An example in neurophysiology may help to comprehend the deficiency that now occurs on the cognitive level.

Dysgnosis

The visual receptors in the retina, the cones and the rods, operate optimally only under certain conditions of illumination. Beyond or below this condition we suffer a loss in acuity or in color discrimination. However, in the vertebrate eye the retina almost always operates under these optimal conditions, because of the iris that contracts or dilates so as to admit under changing conditions of brightness the same amount of light to the receptors. Hence, the scenario "seen" by the optic nerve has always the same illumination independent of whether we are in bright sunshine or in a shaded room. How, then, do we know whether it is bright or shady?

The information about this datum resides in the regulator that compares the activity in the optic nerve with the desired standard and causes the iris to contract when the activity is too high, and to dilate when it is too small. Thus, the information of brightness does not come from inspecting the scenario—it appears always to be of similar brightness—it comes from an inspection of the regulator that suppresses the perception of change.

There are subjects who have difficulties in assessing the state of their regulator, and thus they are weak in discriminating different levels of brightness. They are called "dysphotic." They are the opposite of photographers, who may be called "photic," for they have a keen sense of brightness discrimination. There are subjects who have difficulties in assessing the regulators that maintain their identity in a changing world. I shall call individuals suffering from this disorder "dysgnostic," for they have no way of knowing themselves. Since this disorder has assumed extraordinary dimensions, it has indeed been recognized at the highest national level.

As you all know, it has been observed that the majority of the American people cannot speak. This is interpreted by saying that they are "silent"; I say they are *mute*. However, as you all know very well, there is nothing, wrong with the vocal tract of those who are mute: the cause of their muteness is deafness. Hence, the so-called "silent majority" is *de facto* a "deaf majority."

However, the most distressing thing in this observation is that there is again nothing wrong with their auditory system; they could hear if they wanted to: but they don't want to. Their deafness is voluntary, and in others it is their blindness.

At this point proof will be required for these outrageous propositions. *TIME Magazine* (1970)[8] provides it for me in its study of Middle America.

[8] TIME Magazine. *"The Middle Americans"*, (January 5, 1970).

There is the wife of a Glencoe, Illinois lawyer, who worries about the America in which her four children are growing up: "I want my children to live and grow up in an America as I knew it," [note the principle of conservation of rule where the future equals the past] "where we were proud to be citizens of this country. I'm damned sick and tired of listening to all this nonsense about how awful America is." [Note voluntary deafness.]

Another example is a newspaper librarian in Pittsfield, Massachusetts, who is angered by student unrest: "Every time I see protestors, I say, 'Look at those creeps.'" [Note reduction of visual acuity.] "But then my 12-year old son says, 'They're not creeps. They have a perfect right to do what they want'" [Note the un-adult-erated perceptual faculty in the young.]

The tragedy in these examples is that the victims of "dysgnosis" not only do not know that they don't see, hear, or feel, they also do not want to.

How can we rectify this situation?

Trivialization

I have listed so far several instances of perceptual disorders that block our vision of the future. These symptoms collectively constitute the syndrome of our epidemic disease. It would be the sign of a poor physician if he were to go about relieving the patient of these symptoms one by one, for the elimination of one may aggravate another. Is there a single common denominator that would identify the root of the entire syndrome?

To this end, let me introduce two concepts, they are the concepts of the "trivial" and the "non-trivial" machine. The term "machine" in this context refers to well-defined functional properties of an abstract entity rather than to an assembly of cogwheels, buttons and levers, although such assemblies may represent embodiments of these abstract functional entities.

A trivial machine is characterized by a one-to-one relationship between its "input" (stimulus, cause) and its "output" (response, effect). This invariable relationship is "the machine." Since this relationship is determined once and for all, this is a deterministic system; and since an output once observed for a given input will be the same for the same input given later, this is also a predictable system.

Non-trivial machines, however, are quite different creatures. Their input-output relationship is not invariant, but is determined by the machine's previous output; its previous steps determine its present reactions. While these machines are again deterministic systems, for all practical reasons they are unpredictable: an output once observed for a given input will most likely be not the same for the same input given later.

In order to grasp the profound difference between these two kinds of machines it may be helpful to envision "internal states" in these machines. While in the trivial machine only one internal state participates always in its internal operation, in the non-trivial machine it is the shift from one internal state to another that makes it so elusive.

One may interpret this distinction as the Twentieth Century version of Aristotle's distinction of explanatory frameworks for inanimate matter and living organisms.

All machines we construct and buy are, hopefully, trivial machines. A toaster should toast, a washing machine wash, a motorcar should predictably respond to its driver's operations. In fact, all our efforts go into one direction, to create trivial machines or, if we encounter non-trivial machines, to convert them into trivial machines. The discovery of agriculture is the discovery that some aspects of Nature can be trivialized: If I till today, I shall have bread tomorrow.

Granted, that in some instances we may be not completely successful in producing ideally trivial machines. For example, one morning turning the starter key to our car, the beast does not start. Apparently it changed its internal state, obscure to us, as a consequence of previous outputs (it may have exhausted its gasoline supply) and revealed for a moment its true nature of being a nontrivial machine. But this is, of course, outrageous and this state of affairs should be remedied at once.

While our pre-occupation with the trivialization of our environment may be in one domain useful and constructive, in another domain it is useless and destructive. Trivialization is a dangerous panacea when man applies it to himself.

Consider, for instance, the way our system of education is set up. The student enters school as an unpredictable "non-trivial machine." We don't know what answer he will give to a question. However, should he succeed in this system the answers he gives to our questions must be known. They are the "right" answers:

Q: "When was Napoleon born?"

A: "1769"

Right!

Student = Student

but

Q: "When was Napoleon born?"

A: "Seven years before the Declaration of Independence."

Wrong!

Student = Non-student

Tests are devices to establish a measure of trivialization. A perfect score in a test is indicative of perfect trivialization: the student is completely predictable and thus can be admitted into society. He will cause neither any surprises nor any trouble.

Future

I shall call a question to which the answer is known an "illegitimate question." Wouldn't it be fascinating to contemplate an educational system that would ask of its students to answer "legitimate questions" that is questions to which the answers are unknown (H. Brün in a personal communication). Would it not be even more fascinating to conceive of a society that would establish such an educational system? The necessary condition for such an utopia is that its members perceive one another as autonomous, non-trivial beings. Such a society shall make, I predict, some of the most astounding discoveries. Just for the record, I shall list the following three:

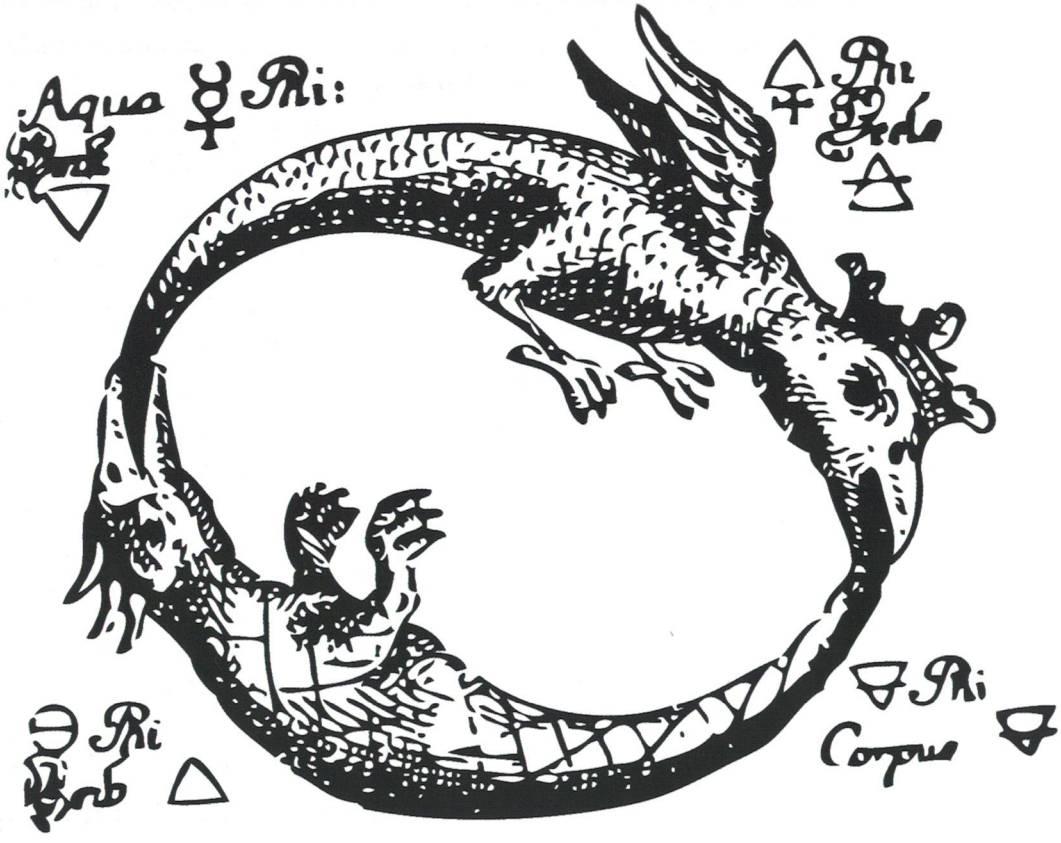
1. Education is neither a right nor a privilege: it is a necessity.
2. Education is learning to ask legitimate questions.

A society who has made these two discoveries will ultimately be able to discover the third and most utopian one:

3. "A is better off when B is better off."

From where we stand now, anyone who seriously makes just one of those three propositions is bound to get into trouble. Maybe you remember the story Ivan Karamazov makes up in order to intellectually needle his younger brother Alyosha. The story is that of the Great Inquisitor. As you recall, the Great Inquisitor walks on a very pleasant afternoon through his town, I believe it is Salamanca; he is in good spirits. In the morning he has burned at the stakes about a hundred and twenty heretics, he has done a good job, everything is fine. Suddenly there is a crowd of people in front of him, he moves closer to see what's going on, and he sees a stranger who is putting his hand onto a lame person, and that lame one can walk. Then a blind girl is brought before him, the stranger is putting his hand on her eyes, and she can see. The Great Inquisitor knows immediately who He is, and he says to his henchmen: "Arrest this man." They jump and arrest this man and put Him into jail. In the night the Great Inquisitor visits the stranger in his cell and he says: "Look, I know who You are, troublemaker. It took us one thousand and five hundred years to straighten out the troubles you have sown. You know very well that people can't make decisions by themselves. You know very well people can't be free. We have to make their decisions. We tell them who they are to be. You know that very well. Therefore, I shall burn You at the stakes tomorrow." The stranger stands up, embraces the Great Inquisitor and kisses him. The Great Inquisitor walks out, but, as he leaves the cell, he does not close the door, and the stranger disappears in the darkness of the night.

Let us remember this story when we meet those troublemakers, and let us keep the door open for them. We shall recognize them by an act of creation:



"Let there be vision: and there was light."

On Constructing a Reality[1]

Heinz von Foerster

Abstract: "Draw a distinction!"[2]

The Postulate: I am sure you remember the plain citizen Jourdain in Moliere's *Bourgeois Gentilhomme* who, *nouveau riche*, travels in the sophisticated circles of the French aristocracy, and who is eager to learn. On one occasion with his new friends they 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 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 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.

I. *Blindspot*. Hold [Figure 1] next page with your right hand, close your left eye and fixate asterisk of Fig. 1 with your right eye. Move the book slowly back and forth along line of vision until at an appropriate distance, from about 12 to 14 inches, the round black spot disappears. Keeping the asterisk well focused, the spot should remain invisible even if the figure is slowly moved parallel to itself in any direction.

Figure 1

This localized blindness is a direct consequence of the absence of photo receptors (rods or cones) at that point of the retina, the "disc", where all fibers, leading from the eye's light sensitive surface, converge to

[1]This is an abbreviated version of a lecture given at the opening of the fourth International Conference on Environmental Design Research on April 15, 1973, at the Virginia Polytechnic Institute in Blacksburg, Virginia.

[2]Brown, G. S., *Laws of Form.* New York, Julian Press, page 3, 1972.

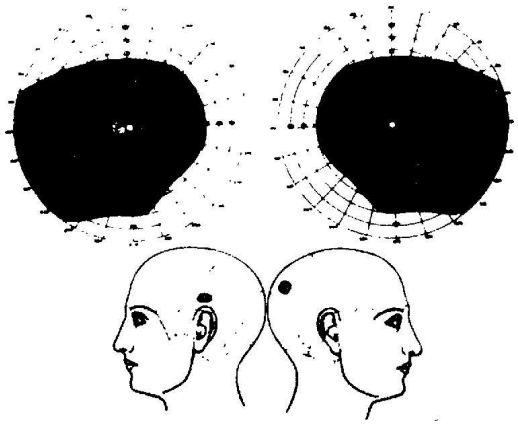


Figure 2

form the optic nerve. Clearly, when the black spot is projected onto the disc, 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 "blotch-less".

II. *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, e.g., loss of control of arm or leg movements of one side or the other, etc. Clinical tests, however, show that there is nothing wrong with the motor system, but that in some cases there is substantial loss of a large portion of the visual field (*scotoma*) (Fig. 2)[3]. A successful therapy consists of blindfolding the patient over a period of one to two months until he regains control over his motor system by shifting his "attention" from "non-existent" visual clues regarding his posture to "fully operative" channels that give direct postural clues from "Proprioceptive" sensors embedded in muscles and joints. Note again the absence of perception of "absence of perception", and also the emergence of perception through sensor-motor 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".

III. *Alternates*. A single word is spoken once into a tape recorder and the tape smoothly spliced, without a click, into a loop. The word is repetitively played back with a 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 10 to 30 repetitions of this first alternate, a sudden switch to a second alternate is perceived, and so on[4].

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; ca d'etait; candidate; can't you see; can't you stay; cape cod you say; card estate; cardio tape; 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 date; got your pay; got your tape; gratitude; gravity; guard the tit;*

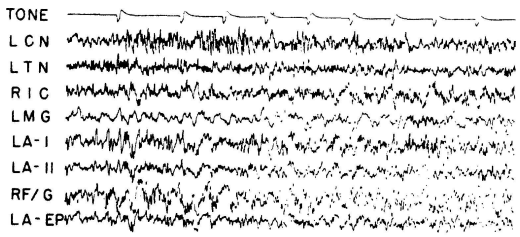


Figure 3: Trial 1 (no behavioral evidence of learning)

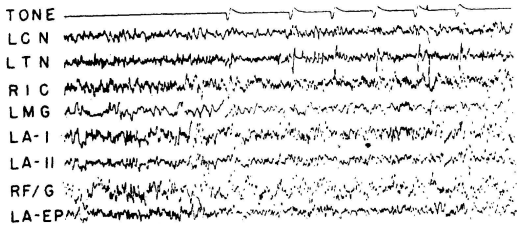


Figure 4: Trial 13 (begins to wait for tones)

Figure 5: Trial 4/20 (hypothesizes)

Figure 6: Trial 6/9 (understands)

gurgitate; had to take; kinds of tape; majesty; marmalade.

IV. *Comprehension*. Literally defined: *con* ⇒ together; *prehendere* ⇒ to seize, grasp. Into the various stations of the auditory pathways in a cat's brain, micro-electrodes are implanted which allow a recording, "Electroencephalogram", from the nerve cells first to receive auditory stimuli, Cochlea Nucleus: CN, up to the Auditory Cortex[5]. The so prepared cat 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 C6, that is about 1000 Hz) is repetitively presented[6]. The cat has to learn that C6 "means" food. Figures 3 to 6 show the pattern of nervous activity at eight ascending auditory stations, and at four consecutive stages of this learning process[7] The cat's behavior associated with the recorded neural activity is for Fig. 3: "Random search"; Fig. 4: "Inspection of lever"; Fig. 5: "Lever pressed at once"; and for Fig. 6: "Walking straight toward lever (full comprehension)". 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", which absorbs the electro-magnetic 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 post-retinal networks with a period that is commensurate with the intensity of the radiation absorbed, but without a clue that it was electro-magnetic 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, etc.: 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 electro-magnetic 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.

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[3]Teuber, H. L., "Neuere Betrachtungen uber Sehstrahlung und Sehrinde" in Jung, R., Kornhuber H. (Eds.) *Das Visuelle System*, Berlin, Springer, pages 256–274, 1961.

[4]Naeser, M. A., and Lilly, J. C., "The Repeating Word Effect: Phonetic Analysis of Reported Alternates", *Journal of Speech and Hearing Research*, 1971.

[5]Worden, F. G., "EEG Studies and.Conditional Reflexes in Man", in Brazier, Mary A. B., *The Central Nervous System and Behavior*, New York, Josiah Macy Jr. Foundation, pages 270–291, 1959.

[6]"Hz" means 1 cycle per second, is the unit for oscillations named after Heinrich Hertz who generated the first radio signals.

[7]*op cit.*

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 ($\rightarrow$) "cognition" in the following way:

COGNITION $\rightarrow$ 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, re-arranges, or orders 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.

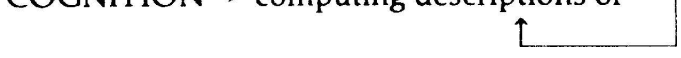
I shall now turn to the defense of my use of the indefinite article in the noun-phrase "a reality". I could, of course, shield myself behind the logical argument that solving for the general case, implied by the "a", I would also have solved any specific case denoted by the use of "the". However, my 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 which 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:

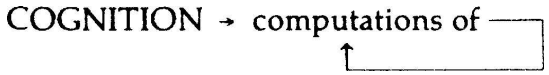
COGNITION $\rightarrow$ computing descriptions of a reality.

Neurophysiologists, however, will tell us that a description computed on one level of neural activi ty, 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"[8]. Consequently, I have to modify this paraphrase again to read:



[8]Maturana, H. R., "Neurophysiology of Cognition," in Garvin, P., *Cognition: A Multiple View*,. New York, Spartan Press, pages 3–23, 1970.

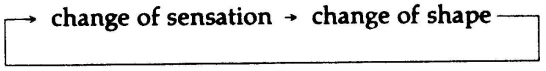
where the arrow turning back suggests this infinite recursion of descriptions of descriptions ... etc. This formulation has the advantage that one unknown, namely, "reality" is successfully eliminated. Reality appears only implicit as the operation of recursive descriptions. Moreover, we may take advantage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



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

I. *Evolution*. In order that the principle of recursive computation is 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—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(6). These are the "independent effectors", or independent sensory-motor 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,?etc. Thus, we have the recursion:



Separation of the sites of sensation and action appears to have been the next evolutionary step (Figure 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 appearance 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 non trivial 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".

II. *Neuron*. The neuron, of which we have more than ten billion in our brain, is a highly specialized single cell with three anatomically distinct features (Fig. 10): (a) the branch-like ramifications stretching up and to the side, the "dendrites"; (b) the bulb in the center housing the cell's nucleus, the "cell body";

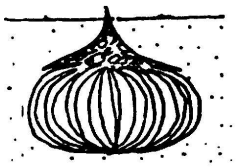


Figure 7

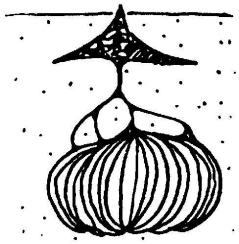


Figure 8

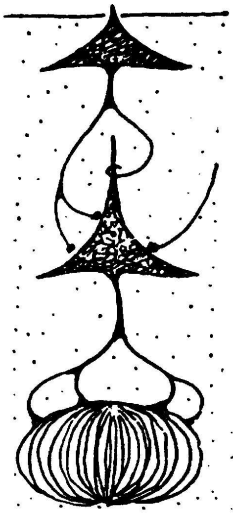


Figure 9

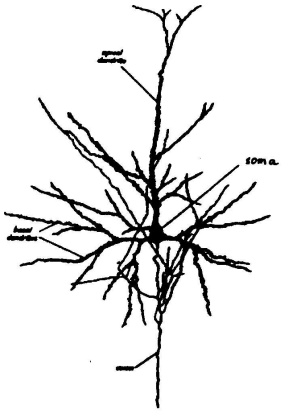


Figure 10

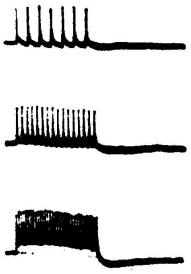


Figure 11

and (c), 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 which envelopes 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 one tenth of a volt. If in the dendritic region this charge is sufficiently perturbed, the neuron "fires" and sends this perturbation along its axons to their terminations, the synapses.

III. *Transmission*. Since these perturbations are electrical, they can be picked up by "microprobes", amplified and recorded. Fig. 11 shows three examples of periodic discharges from a touch receptor under continuous stimulation, the low frequency corresponding to a weak, 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.

IV. *Synapse*. Fig. 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

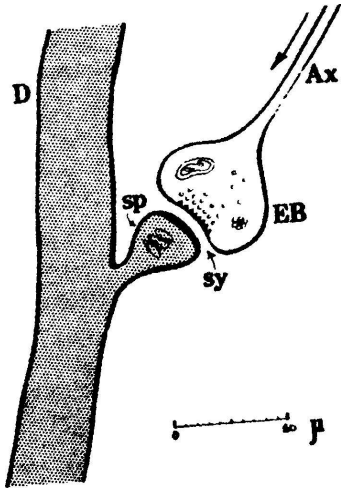


Figure 12

Figure 13

certain circumstances it may produce an "inhibitory effect" (cancellation of 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 "micro-environment" 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 micro-environments) to those of the *external* environment (all sensory receptors). Since there are only a hundred million sensory receptors, and about ten-thousand billion synapses in our nervous system, we are 100,000 times more receptive to changes in our internal than in our external environment.

V. *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 Fig. 13 which shows magnified a section of about 2 square millimeters of a cat's cortex by a staining method which stains only cell body and dendrites, and of those only 1% of all neurons present[9].

Although you have to imagine the many connections among these neurons provided by the (invisible) axons, and a density of packing that is a hundred times that shown, the computational power of even this very small part of a brain may be sensed.

VI. *Descartes*. This perspective is a far cry from that being held, say three hundred years ago: "If the

[9]Sholl, D. A., *The Organization of the Cerebral Cortex*, London, Methuen, 1956.

Figure 14

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 that they touch; and in this way drawing the little thread, c, that you see to be attached at the 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[10].

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 with one difference only, namely, that in the meantime Descartes' "animal spirit" has gone into oblivion[11].

VII. *Computation*. The retina of vertebrates with its associated nervous tissue is a typical case of neural computation. Fig. 15 is a schematic representation of a mammalian retina and its post-retinal 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 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, it is there where the sensation of color and some clues as to form are computed[12]

Form computation: take the two-layered periodic network of Fig. 16, the upper layer representing receptor

[10]Descartes, R., *L'Homme*, Paris, Angot, 1664. Reprinted in *Ouevres de Descartes*, XI, Paris, Adam and Tannery, pages 119-209, 1957.

[11]Skinner, B. F., *Beyond Freedom and Dignity*, New York, Knopf, 1971.

[12]Maturana, H. R., "A Biological Theory of Relativistic Colour Coding in the Primate Retina", Arch. Biologia y Medicina Exper., Suppl. No. 1, Soc. Biologia de Chile, Santiago, Universidad de Chile, 1968.

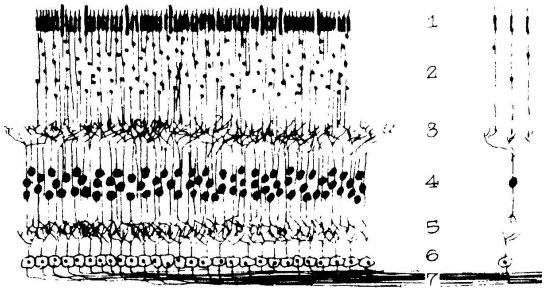
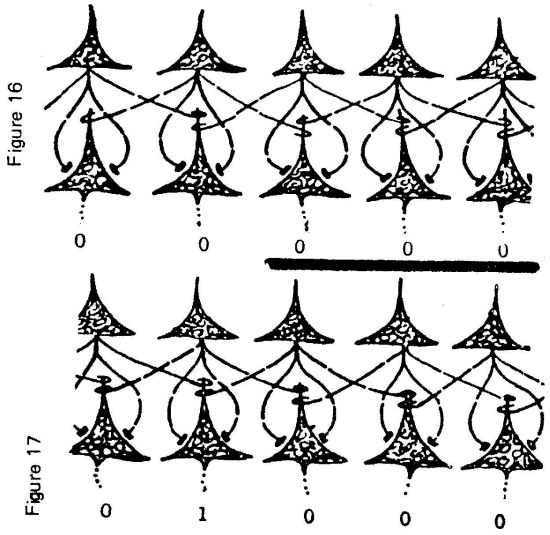


Figure 15



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 stimulation as well as to 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 Fig. 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 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 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, (a) the operations actually performed, and (b) the organization of these operations represented here by the structure of the nerve net.

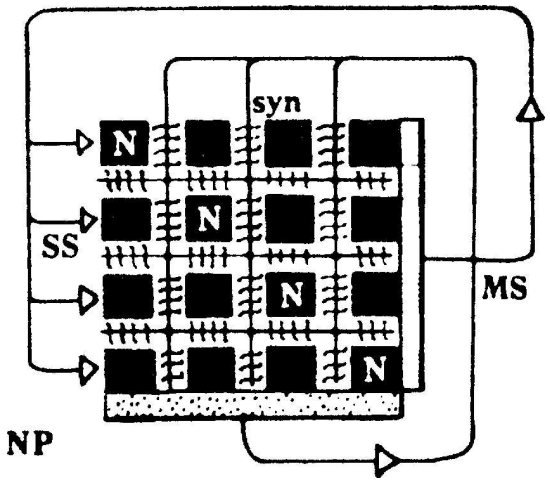


Figure 18

In computer language (a) would again be associated with "operations", but (b) with the "program". As we shall see later, in "biological computers" the programs themselves may be computed on. This leads to the concepts of "meta-programs", "meta-meta-programs", ... etc. This, of course, is the consequence of the inherent recursive organization of those systems.

VIII. *Closure*. By attending to all the neurophysiological pieces, we may have lost the perspective that sees an organism as a functioning whole. In Fig. 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 mastergland that regulated 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 releases steroids into the synaptic gaps, 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 which 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 Fig. 18 around its two axes of circular symmetry until the artificial boundaries disappear and the torus (doughnut) as in Fig. 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. (Fig. 19)

The computations within this torus are subject to a non-trivial constraint, and this is expressed in the Postulate of Cognitive Homeostasis:

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

This postulate stipulates "autonomy", i.e., "self regulation", for every living organism. Since the semantic structure of nouns with 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.

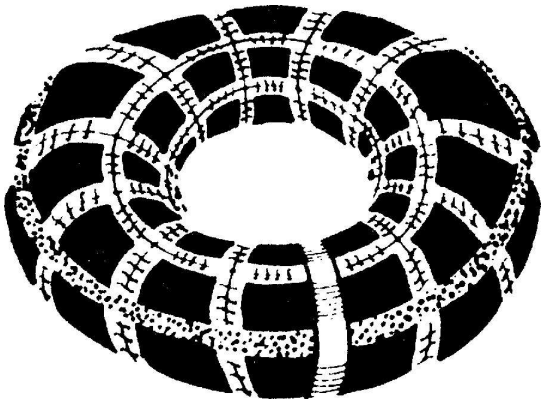


Figure 19

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).

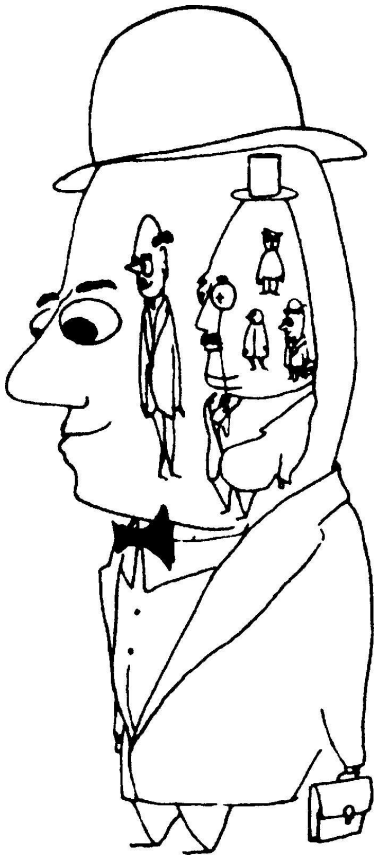


Figure 20

He insists that he is the sole reality, while everything else appears only in his imagination. How ever, he cannot deny that his imaginary universe is populated with apparitions that are not unlike himself. Hence, he has to concede that they themselves may insist 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 it. If I reject it, I am the center of the universe, my reality are my dreams and my nightmares, my language is monologue, and my logic mono-logic. If I adopt it, neither me 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:

Reality = 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.

Acknowledgement

I am indebted to Lebbeus Woods, Rodney Clough and Gordon Pask for offering their artistic talents to embellish this paper with Figs. (7, 8, 9, 16, 17), (18, 19), and (20) respectively.