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EDITORIAL

Crisis in Cybernetics and General Systems Theory?

An increasing number of signs indicates that Cybernetics and its sister science, General Systems Theory (GST), are experiencing a serious crisis. The crisis is manifested by a decreasing interest in both Cybernetics and GST as shown particularly by a very small scope of offerings of these sciences in our colleges and universities. One of the founders of the Society for GST, Kenneth Boulding, expressed the fear that after present teachers of the general systems theory are gone, their courses will be discontinued altogether. A survey conducted by the ASC Cybernetics Forum has also shown a very disappointing state of cybernetics teaching in our country.

The crisis is probably caused by the inability of these sciences to fulfill the anticipation they aroused. An integration of sciences promised by cybernetics and by GST was not achieved. The expected practical impact of them on the development of psychological and social sciences also did not materialize to any significant degree. For example, some recent books on artificial intelligence—the field of knowledge which, in the opinion of some cyberneticists, is the major domain of cybernetics—hardly mentioned cybernetics at all. Recent publications highly critical of both sciences (see, for example, the books by D. Berlinski, On Systems Analysis, and R. Lilienfeld, The Rise of Systems Theory) and the lack of serious responses to them from cyberneticists and general systems theorists is another symptom of the crisis.

In order to overcome the crisis, both cyberneticists and general systems theorists should re-examine their basic premises and analyze the reasons for a lack of significant progress both in integrating the knowledge and in applications to mental and social processes.
The Cybernetics Forum will devote a special issue to this topic early in 1980. I invite you to address yourself to the problems raised in this editorial, and assure you that your manuscripts will receive most favorable consideration. The manuscript deadline for this special issue of the Cybernetics Forum, “Crisis in Cybernetics and General Systems Theory,” is December 1, 1979.

V. G. Drozin, Editor
What Is Involved in the Demand for Empirical Theories in System Science*

Laurence B. Hellpeln
University of Maryland
College Park, Maryland 20742

Abstract

Empiricism is briefly surveyed, and applied to system science by means of a model developed by H. Margenau in 1950. This model incorporated the operational definition of P. W. Bridgman, with a crude model of the cognitive system. The model divides the scientist's brain into a part on the level of his sense perception, closest to physical reality, the "P-plane;" and a more abstract region of mental constructs, or "C-field." Constructs in the C-field are connected by epistemic (or instrumental or operational) bonds (one end in the P-plane), or by constitutive bonds (neither end in the P-plane), or in some cases, by no bonds. The model shows how constructs become verifiable, and hypotheses become theories, by a circuit from the P-plane into the C-field and back to the P-plane at other than the point of entry. The model suggests that sciences which demand connection with reality have greater difficulty in doing so longer this circuit or the farther their C-field constructs are removed from the P-plane (i.e., the more abstract they are). System science, which tends to be abstract, has poorer prospects for empirically based theories than have experimental sciences. The demand that theories be empirically greatly restricts the number of possible theories and would, if observed in system science, greatly reduce the present range of the science.

A few remarks show how the imaginatively correct and simple model of Margenau is being elaborated in many sciences concerned with cognition.

The background of our topic is one of the oldest in recorded thought. Over two thousand years ago philosophers asked what seemed the most penetrating questions man can ask: What is real? Today the search continues, divided into two main aspects. Science is the search for reality, philosophy for the nature of reality. Since most of us here are scientists familiar with a particular region of reality, I infer that what actually draws us together is the second aspect, how to insure that, as far as possible, our system theories are realistic.

Evolution of Empiricism

Human consciousness is classically divided into three: cognition, affection, and conation. The conative and affective, however, dealing respectively with will and with emotions and feelings, describe what might be called "internal" reality, and no specific organs seem to be involved. The cognitive deals with awareness of environment, external and internal, obtained through special organs of sense. Cognition is meant when we refer to empiricism, for, with all its many dictionary shades of meaning, empiricism refers to knowledge based primarily on sensory experience.

Perhaps the first and greatest advances in the development of systematic thought were Plato's observations that the act of realization—of discerning reality—was connected with thought; and that (aside from emotion and will) there are two very different kinds of thought. There are fixed ideas, such as blue, hard, free men, behavior. And there are transient sense impressions, the moving, changing sights, sounds, odors, tastes and feelings of touch, heat, pressure and pain which we call direct sense impressions (DSI's). Plato perceived the difference and, not illogically, decided that the more permanent fixed ideas were the part of our thought through which reality is apprehended by the mind. The DSI's he did not dismiss, but considered less important because of their eternal dance of change. So great was Plato's influence that his identification of permanence with reality was accepted for two millennia. It led the rationalists to a methodology for obtaining knowledge using only thought and intuition, believed a kind of innate thought. On the assumption that only our stable, abstract ideas show us reality it was simply not necessary to observe the ephemeral sense perceptions in order to arrive at this reality. Of course the subject was more complicated than I have put it, but in essence it led to armchair search for truth and disregard of DSI's as criteria of reality.

Renaissance thinkers like Galileo realized that ideas are not innate, that fixed ideas can be incorrect, made invalid by evidence of the senses. The many sense organs with which the body is provided were now seen as "gates" through

Descriptors: empiricism, physical reality, sense perception, cognition, operational definition, hypothesis verification, theory construction, information science, system science, objective state, algorithm.

which enter, not our notions of the outside world, but much or all of the material out of which the notions arise. A great illumination flooded the old evolutions of concrete and abstract ideas. Downgrading the previously dominant abstractions, Locke and his followers now declared that "Nothing is in the mind that was not first in the senses." This corrected the old misinterpretation of the relative importance of abstract and concrete ideas, but again introduced serious error. It was an over-shoot, because the so-called strict empiricists denied all evidence except that of the senses. They mistrusted rationalization (a connotation that still lingers). Even while using abstract reasoning to make hypotheses, they thought of knowledge as largely based on direct experience. To them, reality was sensory, all else suspicious.

Nevertheless, realization of the importance of sense data was a second great advance in the theory of knowledge. It provided a method to advance knowledge, with far-reaching effects. If sense impressions were criteria for reality, then the real could be discovered by planned experiments the outcomes of which would be decided by sense data. With experimentation began the age of modern science.

**Operationism and Physical Reality**

The relations with reality of the two kinds of mental content took much longer to resolve. The problem was brought to a head in the twentieth century not, as you might suppose, in philosophy or psychology, but in physics. The physicists made elaborate theories about the structure of matter and the universe. Many were mathematical and, of course, abstract. The theories had to embody numerous constraints ("Every law of nature is a constraint." W. Ross Ashby, *An Introduction to Cybernetics*, University Paperbacks, 1956, reprinted 1971, p. 130). One of the most severe constraints was the apparently dual nature of matter: it includes both the organic material of which we are composed, and the inorganic material of the universe in which we are embedded. Another, with which the physicists were more immediately concerned, was that their theories had to be consistent with reality as observed by sensors or instruments on the ordinary, human scale, and also with the micro-properties of atomic and nuclear structure and the macro-properties of the cosmos. As is well known, these demands for conceptual validity over an enormous range in physical scale led to a new epistemology. There have been many contributors, and the epistemological revolution is by no means over. Its early effects are summarized in such works as those of Bridgman and Margenau. A compact exposition of how the physicist of the 1950's and the modern scientist in physics and many other fields view the problem is contained in Margenau's book, *The Nature of Physical Reality—A Philosophy of Modern Physics* (McGraw Hill, 1950). Much of what follows is my brief personal version of parts of this work. It starts, as does Margenau's account, with Bridgman's concepts on operational definitions in science.

Bridgman (*The Logic of Modern Physics*, Macmillan, 1927; *The Nature of Physical Theory*, Princeton University Press, 1937) was concerned with the possibility of defining physical concepts in such a way that they would always be consistent with nature. Two apparently sound physical definitions had persisted since Newton. These were "absolute time" (time is the same everywhere) and "distant simultaneity" (an aspect of the same concept). Einstein's study of the operations involved in measuring time with clocks and light signals showed, as we can easily see now, that there is no way to observe an event in remote space which occurs at the same time as on the earth; we always observe the past—since light from the event takes time to travel to us.

In order to avoid unrealizable concepts Bridgman assumed that nature is self-consistent. Roughly, this means that, if the same operations are performed under the same conditions, nature will give the same experimental answer. The concept "length of this room" is based on placing a measure rod at one wall, marking where it ends, repeating until, at the other wall, a part of the stick only is needed; counting the parts, and adding all the least parts. The "paper and pencil" operations of taking an average of trial lengths, and calculating the error, are included. The more carefully these operations are followed, the more faithfully the same value is obtained. Bridgman demanded that every physical concept be defined by means of performable operations; either actually performed, or potentially performable, in reducing the concept to sense perception. If this was not possible, the definition was to be discarded as operationally "meaningless"—unperformable. His formula, "the concept is synonymous with the set of operations" was recognized and accepted by the observational sciences. It is a great advance in two ways: it asserts that consistency in nature is to be sought at the DSI level; and it focuses attention on the operations of the observer. The observer enters the experiment in a way theory had not previously required.

Margenau incorporated this idea into his views, but saw that more was needed. The method is not completely foolproof. It does force us to think about what we are actually doing. If what we are doing is at the machine or sensory level it is very difficult to be consistent. For example, computer programs force us to think out exact sequences of operations. If we are not consistent with the reality of the computer it will indicate our inconsistencies by not responding, or not responding in the expected way. Using metaphor, a computer always performs an operational definition. It tests the concept we define by means of the set of operations we make it perform. The same is true of a physical instrument. It defines a concept by the set of operations performed in it or with it. If these are purely physical, and not interpretive, the data and derived concept will very probably be consistent with nature. An operational definition is better, the closer the operations to the level of sensor or machine. Of course any concept is somewhat removed from sense perception, to a partly abstract region of the mind. And some mistakenly straightforward concepts, like "simultaneity," which was discovered inoperable when the distances became great compared to those on the earth, cannot be wholly avoided. The protection of rei operations diminishes rapidly if the set of defining operations are mainly mental. The abstract mind is immensely adaptable, pliable, and not at all a rigid machine or computer that forces us to notice inconsistent connections.
Margenau’s scheme is shown in Figure 1. The vertical heavy line labelled Nature is the “plane” of the stimuli for our sense data, DSI’s.* Everything to the left is cognitive material, more or less abstract. The nodes are constructs of some subject, let us say, physics. The nodes labelled 1, 2, 3 which have double lines connecting them with the sensory plane are special mental constructs. Although not observed in Nature, they connect with Nature in the sense that they arise out of measurement or observation. Examples of physical constructs are length, mass, electric charge, density, viscosity.

Margenau called the connections of constructs derived from the P-plane of Nature (shown by double lines) epistemic (or operational, or instrumental) connections. These constructs are based on DSI’s. The expression “direct sense impression” is of course a slight misnomer. There is no immediate experience of the environment. Our most “direct” sense impressions are actually indirect, or mediated. Perhaps they should be labelled MDSI’s, for “most direct,” or “mediated direct sense impressions.” For example, visual DSI’s pass through the eye, optic nerve, brain connections and biological filters, and a final transformation of electrochemical-neural pulses into vivid images. We do not know how this occurs, but we do know that the DSI’s are our most vivid and detailed representations of Nature. They are the most persuasive. “Seeing is believing.” The special role of the epistemic-connected constructs is to relate the plane of Nature with the more abstract, less vivid constructs not connected with Nature. These latter may be mentally connected but not by epistemic connections. Constructs so connected are connected by formal or constitutive connections. Examples are acceleration (related to distance and time measurements); and electric charge density (related to electric meter readings). Margenau points out that some of the epistemic-connected constructs could be constitutive, and some constitutive-connected constructs could be made epistemic. So he rejects an absolute ranking of “more epistemic” or “more constitutive.” And possibly none of the constructs in a field of science are one or the other. Always there is a mix, and the reality revealed by natural science depends on both. Reliability is increased by multiple connections. In Figure 1 constructs 1-6 are multiply-connected, constitutively and epitomically, while construct 7 is singly-connected. Because its one connection is constitutive, construct 7 is insular, and there is no way to test its reality independent of that of construct 5. Construct 8 is insular. There is no empiric path to it in the construct—or C-field. The constellation of constructs which include 9 and 10 is internally connected constitutively—the constructs mutually support each other in the abstract C-field. If there is no logical inconsistency between them (they do not assert ideas which cannot all be logically true at the same time) a strong appearance of reality develops. However, what is strengthened is not a case for reality, but for internal consistency of the constructs qua constructs. This is the situation in mathematics, when a set of axioms is assumed, and they together determine a system that is consistent, and perhaps highly useful, but not necessarily real. It is also customary in applied mathematical sciences such as operations research, cybernetics or system science to first set up conceptual universes of all possible solutions, before narrowing them to a subset of feasible solutions. It often develops that a system of mathematical constructs eventually does find an outlet to the P-plane through an epistemic connection. Of the non-Euclidean geometries, each internally consistent, none necessarily describe Nature until an operational test of their implications decides. As a general rule, neither insular nor insular constructs should be used in constructing an empiric theory, if the theory is to have value. And now, what is the value of a scientific theory?

III. Predictive Value of a Theory

“The value of a scientific theory lies in its ability to predict.” (Leon Brillouin: Relativity Reexamined, Academic Press, 1970, p. 1.) This concise answer is widely accepted, but not widely understood. Margenau (loc. cit., p. 105) warns, tongue in cheek:

> “The word prediction, as used in science, does not mean ‘forecast’ in a temporal sense. Pre- implies ‘prior to completed knowledge.’ It does not contrast with post- as does ante. The counterpart of prefix is not postfix but suffix. It is therefore unnecessary to coin a new word, post-diction, to denote that we should call prediction of the past. The use of this word, though it has been suggested, would seem a bit ‘preposterous.’”

The popular use of theory in forecasting is included in predicting, but the idea of prediction is broader. Scientific prediction is an application of logic. It affirms that if the conditions of the construct are fulfilled, then the relations involved in the construct will be true. The use of several connected constructs is a compound conditional statement, more nar-
row, precise and harder to fulfill than any single statement. Assuming the compound is still logically consistent (its premises can all be true together) then some observation \( P_i \) may lead through epistemic connection with one of the constructs to all the others in the field, and through an epistemic connection back to some point \( P_j \). This circuit from P-plane to P-plane is empirical prediction. Of course if \( P_j \) turns out to be \( P_i \), the prediction is a tautology and trivial. If \( P_j \) is not \( P_i \), and is some unexpected event, then the prediction is less trivial. This is the essence of modern empiricism—prediction of some non-trivial outcome which can be observed. It is what we mean when we say a theory must be testable by sense perception or instrumental registration which can be reduced to sense perception. *Strict empiricism* would perhaps not deny the existence of the internal path into and out of the C-field, but would place value only on path \( P_j \) in the P-plane. Since path \( P_j \) may not even exist, this violates our present views as greatly as Plato’s doctrine that observation is not valuable for attaining reality.

In Figure 2 the large circle suggests that once such a circuit is established, it tends to verify all the constructs connected into the logical chain. When a construct is verified it becomes what Margenau calls a *verifact*, if sufficiently verified (and what constitutes *sufficient verification* forms much of science, involving probability, measurement, and other subjects) a set of connected verifacts can be regarded as theory. Passage from hypothesis (assumption of the circuit before it has been verified) to theory is related to sufficient verification. Of course a hypothesis need not assume a complete circuit. It can assume a single construct, epistemically connected, if there is to be empirical value placed on it. But a single epistemic connection does not allow two-point prediction. The most valuable hypotheses contain one epistemic connection \( P_i \) to a constitutive circuit, and a hypothesized epistemic reentry to some different real effect \( P_j \). There is a hypothetical path from \( P_i \) to \( P_j \) other than in the real plane of Nature. Testing the connection to \( P_j \) is said to be a “crucial” experiment for a hypothesis. Progress in science is rapid if a large body of hypotheses, verified and non-trivial, is converted to theory. One remark should be made, however, about the idea that non-trivial prediction means “greater distance between \( P_i \) and \( P_j \).” Non-triviality also tends to mean a longer circuit in the C-field; and, since there is no way to measure the psychological “distance” between observations \( P_i \) and \( P_j \) either internally or externally, the concept is not yet precise. Perhaps it might be made more precise by borrowing Shannon’s definition of information as that which is unlikely relative to a given set of message possibilities.

Margenau also described a number of time-honored desirable qualities for constructs. See list under 5, Figure 3.

Scientific theories are intergenerationally collaborative artifacts. In their beginnings within the minds of one or a few persons they often contain unconscious biases. In mature sciences most such “traps” have been “stepped into” and sprung. Their C-fields appear internally consistent, epistemically connected constructs rigidly unambiguous. On the frontiers, however, this is less true. New sciences are especially vulnerable. They can contain too many facts in the P-plane, too few constructs; or too many constructs and too few observables. They can contain many constitutively-connected constructs, with insufficient epistemic connections. Empirically-based theory requires a robust epistemic layer. Otherwise arbitrary constructs go undetected. Insular constructs may use the same name for different ideas, or the same construct with different names. There is no substitute for discriminable P-plane predictions. Otherwise possibilities for error are innumerable. The mind does not seem capable of being aware of all its assumptions, particularly if they are “far out” in the C-field. The farther out, the greater the possibility of insular or, harder to detect, peninsular constructs. The only remedy seems to be slow, patient communication among workers, checking each other endlessly.

![Figure 2](image)

**Figure 2**

Model of Prediction (Margenau)

Empirical Observation \( P_i \) leads through C-field to Observation \( P_j \)

**Empiricism and System Science**

This brings us to the facts of our discussion, now empiricism enters theory in system science. If we accept the epistemological background sketched above, the answer is fairly straightforward. To the extent that system science regards itself, or wishes to be, empirically based, it must conduct itself like any experimental science. It must operationally test the connections of its constructs with the P-plane. It must examine their internal connections, so that its theories are based on hypothesized circuits from the P-plane, through the C-region, back to the P-plane.

Conforming with these requirements is harder, however, for system science than for the experimental sciences. Perhaps the outstanding characteristic of system science is generalization. System scientists try to be comprehensive, to subsume many or all alternatives to a problem. They use large conceptual classes, abstract constructs far in the C-field. Connections with Nature are *a priori* remote. In fact, the construct “system” is an abstraction from so many configurations of Nature that without further qualifications a system connotes little more than relations between parts of some whole. If that whole is finite, the system has an environment. This gives rise to distinctions between relations between the system and environment—at the core of cybernetics and system theory. To be a system, however,
does not require that the system or environment be in the plane of Nature rather than in abstract C-locations in the mind of the system conceive. The stipulation of epistemist connections for its constructs is a sharp constraint on the kinds of theories which system science can construct. The restriction enormously reduces their number, in the same way that adding boundary conditions to a differential equation cuts down the number of valid solutions; or assuming, in logic, that certain truth table cases will not occur. In brief, a demand for empirically based theories in system science is a demand to exclude all but a few. Those theories which survive must connect with experience. The theories are then hypotheses verified in the P-plane of Nature. This must be understood, for many system scientists may be unwilling to accept such a narrowing of the field.

In Figure 3, I have tried to summarize Margenau's concept of the process, with especial reference to empirical theories in system science.

1. No Concepts in P-region only
   (Strict Empiricism)
2. No Concepts in C-region only
   (Strict Rationalism)
3. All Concepts Multiply — Connecting C-field and P-region
4. All Concepts Incorporated Into Theories: Non-trivial Prediction
5. Other Desirable Traits (Margenau):
   Logical Fertility
   Permanence, Stability
   Extensibility
   Causality
   Simplicity, Elegance

Figure 3 Empirical System Science

Epilog: New Directions

The above survey of what empiricism would mean if strictly observed in system science is my projection onto views expressed over a quarter century ago, still essentially correct. They convey, however, no idea of the intense investigation of the interactions of man's body and mind with environment, which has taken place since. Biology has been transformed. Operations research, cybernetics, information science and system science have emerged. Therefore let me point out a few of the new directions.

1. The C-field is being explored and "mapped." Many sciences are involved. Among them are physiology, neurology, psychophysics and cognitive psychology, artificial intelligence, information science, semiotics, and others. Two of the threads running through their models are networks of different kinds of elements, and hierarchical organizations or "levels." Both of these relate to a function, or purpose, of an organism or a society. "Holism" stressed by system science is widely accepted.

2. The P-plane is being explored and "mapped." In Margenau's model the P-plane is undifferentiated. It is simply "the realm of the evanescent surges of sensory perception." By extension of Nature to nature, "it might include sudden pain, spontaneous feelings of elation, unreasoning desires, and so forth" (Margenau, p. 450), i.e., the affective and conative. Most of the new work, however, is still in the cognitive. The P-plane now has at least as many dimensions as the sensory modes of experience. Operational definitions have been adopted in many scientific fields. Above I have suggested an algorithm as a prescriptive set of operations on the machine level, which therefore contains a descriptive set suitable for an operational definition of a "machine construct." Many system scientific contributions expand this. See for instance Donald E. Knuth: Algorithms, Scientific American, April 1977, which also makes a point that computer "constructs" may not be human. They must, however, be translatable to human constructs in the P-region.

3. The psychological development (ontology) of the human has long been explored, e.g., by Jean Piaget and followers. According to this school the stages at which logical reasoning becomes available to the child follow a sequence. The possibility of empiric science should occur late in the sequence. The individual must have developed not only his (her) own personal constructs, but the constructs of the field in which the empiric science is to be conducted. He must also have discovered a mutual code—natural language—with which to compare the constructs in his C-field with those in the C-fields of others. A contribution to this has been to point out that what is commonly called the "objective" state is "manufactured" by science from the "subjective" state in which we live permanently. The various disciplines "achieve uniqueness of concept by a method of communication feedbacks and checks which insure compatibility, or call attention to differences. This state, in which a concept is maintained by a social subgroup through continual checks for variety is 'objective.' The objective state of any individual is simply a subgroup of his subjective states." (Heilprin, L.B.: "Impact of Cybernetics on Information Science and Vice Versa," in Systems, Cybernetics and Information Networks, K. Samuelson, ed. Stockholm University and Royal Institute of Technology, Stockholm, Sweden, 1972. Obviously, one aim of empiricism is to achieve and maintain the objective state of scientific theories.

*I thank Professor Margenau for use of Figures 1 and 2 from his book.
I. Introduction and General Approach

This work analyzes and interprets the behavior of the American economy in terms of systems concepts. Its purpose is to overcome some of the limitations of current econometric models that affect both their forecasting accuracy and conclusions about economic policy. It is believed that these limitations are inherent in certain of the substantive concepts underlying the models. If this belief is correct, then what is required is not simply more data or technical improvements but an alternative framework embodying a different point of view.

The approach here is only concerned with major changes in the economy and the fundamental relationships which seem to govern them, not questions of detail. As such, it makes use of aggregate data and deals with a restricted set of variables. The data cover the period 1948-1976, which gives a total of twenty-nine years or twenty-eight year-to-year changes. Initially, the analysis is non-parametric; that is, it is concerned with the direction of change in the variables rather than magnitude of change. At a later stage, considerations of magnitude are introduced. Relationships are not expressed in the form of mathematical equations. Instead, the directional movements of the variables over time are treated as an information stream which can be analyzed for significant combinations.

The work is divided into four main parts. In the first, the economy is formulated as though it were a self-regulating feedback system. Policy factors are suppressed and the concept of "control from within" is explored. In the second, the response of the economy to various combinations of fiscal and monetary policy is examined, while the internal determinants dealt with in the first formulation are ignored. This interprets economic behavior from the standpoint of "control from without." In the third section, these alternative concepts are compared, integrated with each other, and reconciled. Finally, in the fourth section, the implications of this interaction for understanding, prediction, and control are assessed. Attention is focused on the timing and phasing of monetary and fiscal policy, the manner in which they amplify or dampen swings in the economy, the longer terms effects on real growth, and their effectiveness in dealing with inflation.

II. "Control from Within": The Economy Viewed as a Self-Regulating Feedback System

The GNP implicit price deflator is used as a proxy for the rate of inflation and the yield on three-month treasury bills as proxy for interest rates. These are viewed as internal adjustment mechanisms which regulate the increases and decreases in the rate of growth of real GNP. When both of them accelerate, the rate of real growth will turn down in the following year. When either or both of them decelerate, the rate of real growth will turn up. This has been true in twenty-six of twenty-eight cases. The two exceptions are 1965 and 1973. In 1964, both prices and interest rates were up, indicating a downturn in the growth rate for the next year. Instead, the economy turned up in 1965. This may have been due to the fact that "Operation Twist," which sought to force up short-term rates while keeping long-term rates down, was still in force in 1964 and thus distorted the normal significance of the three-month treasury bill rate. The slight deceleration of the rate of growth of the economy which occurred in 1973 despite prices and interest rates in the preceding year pointing in the other direction seems almost certainly ascribable to the massive exogenous shock rendered to the economy by the oil crisis in the latter part of 1973.

The strength of this relationship between prices and interest rates in a given year and the subsequent direction of the economy indicates that the course of the economy essentially can be predicted without reference to monetary and fiscal policy. This is generally contrary to the concept implicit in econometric models, which require exogenous assumptions concerning policy in order to make forecasts. The suggestion here is that, once the economy is launched on a particular course, its momentum is sufficiently great that it cannot be deflected in the short run. To the extent that the character of monetary and fiscal policy is relevant at all to determining the direction of the economy, it is relevant for the following year, not the year in which it is applied. The failure to fully appreciate this time lag may be the reason the econometric models have frequently missed major turning points. In any event, conditioning forecasts
on correctly guessing what future policy may be would appear to rest on a misconception of some of the underlying dynamics at work.

In general, the economy needs to be viewed from the standpoint that the whole is more than the sum of the parts and the whole is more stable than the parts. This emerges from that fact that while increases and decreases in the rate of both gross private domestic investment and consumption also can be predicted on the basis of prices and interest rates, the reliability of prediction is slightly lower. The other two components of gross national product—government purchases of goods and services and net exports of goods and services—cannot be predicted in this manner at all, of course. Nevertheless, the whole is predictable not only because the private section outweighs the public sector but because changes in investment and consumption compensate for each other. In addition, as noted above, prices and interest rates can move in contrary directions without changing the course of the economy as a whole. Thus, in an operational sense, total GNP is more stable than either its components or its regulating mechanisms. Indeed, to a very real extent, it may be argued that it is this relatively greater instability in the behavior of the parts which permits the economy as a whole to achieve the degree of stability that it has. On this view, such commonly expressed concerns as fear that the economy may slow down “because investment spending is lagging” or, conversely, optimism that it will continue to move up “because consumer spending is strong” are beside the point if the fundamental adjustment mechanisms are pointing the opposite way.

Thus, it is possible to conceptualize the economy as being a self-regulating feedback system. The rise and fall of interest rates, the recurring acceleration and deceleration in prices and the rate of real growth are inherent in the character of the system and necessary to its functioning. The system has to fluctuate. If the growth rate were to move in an unbroken succession of increases, it would explode. If it were to display an unbroken pattern of decreases, it would grind to a halt. Instead, after it has moved a certain distance in either direction, prices and interest rates act to reverse the direction. When this feedback will take place is not predictable. But once it has taken place it is identifiable and the effect it will have on the rate of real growth is predictable.

The association between the direction of the rate of real growth and the direction of monetary policy in any given year appears to be random. The same is true for fiscal policy. When the direction of the rate of real growth in the following year is examined, there is no discernible improvement in the relationship. This suggests that neither monetary policy alone nor fiscal policy alone can be regarded as a reliable determinant of the course of the economy.

The action of monetary policy and fiscal policy in combination is then analyzed. There are four possible combinations: both policies are stimulative, both are restrictive, monetary policy is stimulative while fiscal policy is restrictive, and monetary policy is restrictive while fiscal policy is stimulative.

None of these combinations are determinate in the year in which they are applied. In the following year, the relationship is quite different. Concerted policies of stimulation are followed by an acceleration in the growth rate seven times out of nine. Concerted policies of restraint are followed by a deceleration seven times out of eight. Thus, in the seventeen cases in which fiscal and monetary policy are pointed in the same direction, the economy moved in that direction in fourteen of them.

In the remaining eleven cases, monetary policy and fiscal policy were pointed in opposing directions. In these circumstances, the response of the economy seemingly was random, accelerating four times and decelerating seven times. However, when one other policy variable was introduced, the direction the economy subsequently took could be accounted for in nine of the eleven cases. This variable was the effective tax rate. Two variants were used. One was the effective tax rate on corporate profits. The other was the effective tax rate on personal income. The quantitative results were the same in both instances, although the specific cases they failed to account for differed.

On balance, then, it appears possible to treat the economy as a “black box” and “to explain the behavior of the growth rate on the basis of the external control exercised in the form of monetary and fiscal policy. As with the explanation based on internal control, the behavior takes place after a time lag and this relationship permits predictability. However, when the two alternative modes of explanation and prediction are compared, it is evident that the formulation resting on the thesis of internal control has greater explanatory power. This fits the behavior of the economy in twenty-six out of twenty-eight cases while the external control formulation only succeeds in covering twenty-three of them.

III. “Control from Without”:
The Economy Viewed as a “Black Box”

The money supply is defined in terms of M1. Increases and decreases in the rate of growth of the money supply are employed as a proxy for monetary policy. Whether there is a surplus or deficit in the government sector of the national income accounts is used as a proxy for fiscal policy. In this section, the response of the economic system to these external forms of control is explored, without reference to the internal controls examined in the first section.

IV. Reconciliation of “Control from Within” with “Control from Without”

Neither the concept of control within or control from without is complete by itself, for the internal adjustment mechanisms always operate within a framework of some policy. Treating them separately serves to give some indication of their relative weight, but a more comprehensive explanation requires an analysis of their interaction.
There were sixteen cases in which the direction of both prices and interest rates was up, and in fifteen of these the economy turned down in the following year, as noted in Section II. These cases were distributed among all four of the possible combinations of monetary and fiscal policy. There was only one case in which joint policy was stimulative, but this was overborne by the action of prices and interest rates so that the economy turned down the following year. As against this, there were seven cases in which joint policy was restrictive, and the economy subsequently moved down in all these cases as well. Since in these cases policy and internal adjustment mechanisms both pointed in the same direction, the resultant behavior of the economy can be ascribed as much to one as the other. It is only when the remaining eight cases in which policy was neutral, with monetary policy being offset by fiscal policy, are examined that the control exercised by the internal adjustment mechanisms is thrown into sharp relief. Here the economy turned down seven out of eight times in the following year, so that what was indeterminate from the standpoint of policy became determinate from the standpoint of the internal adjustment mechanisms.

At the other end of the scale, when prices and interest rates pointed in the direction of an upturn, such an upturn in fact materialized eleven out of twelve times. This was broken down into eight cases in which policy was also stimulative, one in which it was restrictive, and three in which it was neutral. Nevertheless, the one failure case, in which the rate of economic growth decelerated, took place in the wake of both policy and the internal adjustment mechanisms pointing in the direction of stimulus. This was the 1972-1973 case which already has been interpreted in terms of the oil crisis.

One of the significant things about this interaction between policy and the internal adjustment mechanisms is the fact that most of the cases in which monetary and fiscal policy were jointly stimulative were associated with the price-interest rate combination being stimulative also; and, conversely, when they were restrictive, the latter was pointed towards restriction too. This raises the questions of whether it was the policy combination which caused the price interest rate combination. It is possible to make this interpretation. However, it has to be tempered by two considerations. The first is that concerted policies did not always produce the same price-interest rate combination. Concerted policies of stimulus were associated with prices and interest rates both being up in one case, prices being up and interest rates down in a second, and prices being down while interest rates were up in a third; in the other six cases prices and interest rates were both down. Similarly, while concerted policies of restraint were associated with both prices and interest rates being up in seven cases, there was one additional case in which the former were both down. The second consideration is that in the two instances in which the price-interest rate combination was opposed to the direction pointed to by policy, the price-interest rate combination prevailed, while in no instance did policy succeed in overriding the price-interest rate combination. Thus, the link between policy and the direction of prices and interest rates is weaker than the link between prices and interest rates and the direction of the economy. In these circumstances, it seems fair to say that policy is dependent upon the action of prices and interest rates to be effective but that the latter have at least a measure of independence from policy.

V. Implications

A. Systems Behavior and Policy Effectiveness

Inherently, the economy has to fluctuate, at times accelerating and at times decelerating. These movements and their reversals appear to be governed principally by the action of prices and interest rates. But, in turn, this action always takes place within the context of some combination of monetary and fiscal policy. When these policies offset each other so that their net thrust is neutral, the behavior of prices and interest rates can be looked at as being produced by the internal dynamics of the economic system. When the policies are concerted, their effect generally is to reinforce the action of these internal mechanisms, although it is also possible for them to contradict them.

Concerted policies imply an attempt at "management," at deliberate regulation of the pace of economic activity. However, this is not always strictly the case in fact. Monetary policy may be pointed at some other objective such as adjusting the balance of payments, while the surplus or deficit in the account of the government sector may be determined more by the aim of prosecuting a war or achieving various social goals. Accordingly, the operational character of various policy combination needs to be distinguished from the motives inspiring them; the two are not invariably the same.

Policy effectiveness can be tested by the criteria of the effect on real growth and the effect on prices. The average annual rate of growth over the period was 3.5%. Concerted policies of stimulus produced an average rate of 5.0%. The counterpart policies of restraint produced an average growth rate of 1.2. Thus, such policies were nominally successful. On the other hand, the neutral policies resulted in an average growth rate of 3.9%. This was 0.6% higher than the combined average of the stimulative and restrictive policies. To this extent, while the policies of stimulus may have achieved a higher rate of growth than would have otherwise prevailed in a particular year, the offsetting policies of restraint produced such low rates that the two taken together were inferior to simply neutral policies.

When the effects on the price level are looked at, the type of policy combination employed makes surprisingly little difference. The average rate of price increase for stimulative policies was 3.6% versus 3.4% for policies of restraint. As against this, the neutral policies averaged 3.3%. Thus, the suggestion is inescapable that the most concerted "management" policies can accomplish is to possibly shift the timing of an acceleration or deceleration from one year to another. They certainly cannot prevent such movements, and over a succession of years they produce a significantly lower rate of real growth without any compensating gain in reducing the rate of inflation.

This, it may be argued, is the most fundamental point of
all. The proponents of economic “management” are wont to believe that it is always necessary to push the economy in one direction or the other. They believe this for a variety of reasons. Some of them think that the economy needs to be stimulated to increase the level of employment, tund ambitious programs of social service, etc. They think every downturn, irrespective of conditions, will turn into another Great Depression unless they “do something.” Alternatively, there are those who think that every upturn needs to be braked in short order or else inflation will run rampant; and that when the economy is primed to turn down it needs a helping shove. What none of the partisans of “management” tend to accept or believe is that in the majority of cases the economy’s internal mechanisms can be relied upon to accomplish the required adjustments as smoothly as they can be accomplished and that the best contribution policy can make is to provide a framework within which they can operate with comparative freedom. They either miss or are too preoccupied to care about the fact that maximizing economic growth depends on an orderly adjustment process over time, not precipitate swings and reversals.

B. Recessions

This, however, is not the whole of the matter. A consideration of major importance is whether slowdowns in the rate of real growth turn into recessions. Recessions are defined here as a negative rate of real growth—i.e., an absolute fall in the level of real GNP from the previous year. Of the sixteen cases in which the economy decelerated, five became recessions. These were in 1954, 1958, 1970, 1974 and 1975. In three of them, concerted policy in the preceding year was restrictive. In the other two it was neutral, but monetary policy was on the restrictive side in both of these instances as well. Thus, the common denominator in terms of policy was deceleration in the rate of growth in the money supply. The other common denominator was that both prices and interest rates were up in the year when the restrictive monetary policy was applied.

These two factors help isolate the range of conditions under which the recessions occurred, but they do not provide a complete explanation inasmuch as there were eight other cases in which they also were present without a recession having taken place. What is needed to differentiate the recession cases from the non-recession cases is consideration of the magnitude of the rate of real growth in the policy year as well as its direction. An analysis of this factor shows that when the rate of real growth was above 4.0%, a recession followed in only one instance out of eight despite the fact that the rate represented a deceleration and the rate of growth of the money supply was also decelerating. The exception case was in 1974. Once again, it seems plausible to put this down to the circumstances of the oil crisis—embargo followed by a quadrupling of the price. Conversely, when the rate of real growth was below 4.0%, a recession followed four times out of five. The exception here was in 1957. In 1956 the growth rate was a low 2.1%. In 1957, the rate fell further—to 1.8%—but did not turn negative. The year after that it did. On balance, then, if the absolute rate of real growth had been used as a predictive factor in the thirteen cases when the direction of that rate was also down and monetary policy was on the side of restriction, it would have called one recession which did not materialize, missed one which did, and predicted four correctly.

C. Interaction between Interest Rates and Money Supply

Throughout this analysis, interest rates have been treated as an internal adjustment mechanism while upward and downward adjustments in the rate of growth of the money have been defined as being a matter of policy. This distinction is somewhat artificial, for the monetary authorities can seek to exercise control over either or both of them and there is a connection between them. Nevertheless, the distinction can be justified functionally. Interest rates will rise and fall in response to economic conditions, particularly to the rate of inflation, even if the authorities do not intervene in the money market or change the discount rate. On the other hand, if they do intervene, it makes a difference whether their action is principally directed towards influencing interest rates themselves or towards controlling the growth of the money supply. Additionally, it is possible for them to operate on the money supply directly by taking action concerning reserve requirements.

Accordingly, the choice of policy tools is fairly wide. Depending on the particular tools employed and the target to which they are directed, changes in the rate of growth in the money supply may or may not feed back to cause changes in the opposite direction in interest rates, and vice versa. The data show that out of a total of twenty-eight cases, interest rates and the growth rate in the money supply moved in the opposite direction, as might have been expected, twenty-two times, but they moved in the same direction six times. Most of these exception cases took place when the money supply was accelerating. Such an acceleration occurred twelve times. In seven of the acceleration cases, interest rates declined, but in the remaining five they rose. By contrast, fifteen of the sixteen cases in which the rate of growth of the money supply was decelerating were associated with a rise in interest rates. This would indicate that when the pace of monetary expansion is quickening interest rates may well move independently, while the effect when it is slowing down is quite definite.

D. Policy Conclusions

This leads to several tentative conclusions concerning monetary policy. The first is that interest rates should be used as a guide to policy rather than be made its objective. By leaving interest rates relatively free and open to determination by the forces at work within the economy itself, they—along with prices—can be used to regulate and help predict the direction of the economy. With this information in hand, the appropriate choice can be made with respect to accelerating or decelerating the rate of growth in the money supply. For this purpose, regulating the general direction of change would seem to be more important than achieving a precise numerical magnitude in the rate, which can be so easily confounded by changes in velocity.

The second conclusion is that, for the most part, the direction of change should be the one which offsets the thrust
of fiscal policy. If fiscal policy is stimulative, then monetary policy should be restrictive; if fiscal policy is restrictive, then monetary policy should be stimulative. This will produce a combined policy for which the net thrust is neutral, and this seems the one best calculated to maximize real growth over a succession of years as distinct from maximizing it in any particular year. However, an exception needs to be made to this rule when fiscal policy is stimulative but the conditions for a recession are present—i.e., accelerating prices and rising interest rates accompanied by a decelerating growth rate of less than 4.0% magnitude. Then, it is better to concert monetary policy with fiscal policy in the direction of stimulus and face the risk of slightly accelerating inflation rather than run the very high risk of creating a recession which a restrictive monetary policy would entail.

The third conclusion is that the margin within which monetary policy can operate is constrained by the direction that fiscal policy takes over a succession of years. As long as fiscal policy shows a frequent alternation between running surpluses and deficits, it can be offset by monetary policy through alternations in the opposite direction. But if fiscal policy should produce an unbroken series of deficits, monetary policy could not indefinitely continue to offset it. Similarly, it could not indefinitely continue to accelerate the rate of growth in the money supply if fiscal policy should result in an unbroken series of surpluses. Under either of these latter two conditions, monetary policy would become progressively deprived of its freedom and be compelled to move in a direction which would result in a concerted policy in one or the other direction.

The most obvious import of these data is that the timing and phasing of policy, either through inadvertence or misconception, has served to magnify the amplitude of fluctuation experienced by the economic system. It would appear that at least four of the recessions have been policy-induced. Most probably the recession of 1974 could not have been avoided because of the shock of the oil crisis. This was neither anticipated nor was there any effective response that policy could immediately make. But the other recessions were brought about as a result of efforts to fight a threatening rise in the rate of inflation. These efforts, in the context of the times, are understandable. But this does not ratify them as being appropriate. They represented a drastic reinforcement by means of policy of the downward course on which the economy had already been launched through the rise in prices and interest rates which had occurred independently. Curtailing the rate of growth in the money supply on top of this only added fuel to the fire.

What would have happened if monetary policy had not taken this track—if, instead of having turned restrictive, it had remained expansionary? This cannot be known for certain, of course. On the fact of it, it would have exacerbated the inflation. This is the orthodox view. But the evidence here is that the added impact on inflation would have been slight, the economy would have decelerated anyway but not gone into a recession, and that the rate of inflation and interest rates would then have turned down of their own accord, albeit perhaps more slowly. These are the more likely consequences when the economy is interpreted in terms of its being at least partially a self-regulating feedback system.

What is at issue is whether the results achieved by the employment of drastic policy measures are proportional to the loss of real growth and attendant deprivation that they inflict. In this case, the specific question is that of whether inflation can be fought effectively by means of monetary policy. But an equivalent question can be asked concerning the joint use of monetary policy and fiscal policy to stimulate the economy; namely, do not the gains in real growth achieved in the short run by such policy have to be paid for by the creation of virtually irresistible pressures to swing the economy to the opposite extreme, as per the above, which more than destroys such gains and, very likely in addition, leaves a legacy of inflation being institutionalized at a higher level?

E. Aggregate Control Policies and Inflation

If prices are an adjustment mechanism, they are also more than that. For the past decade, the rate of inflation has been an abiding concern. It is one thing for the rate of price increase to accelerate to, say, 3.0% then fall back to 2.0%. It is another for it to oscillate in the range of 5.0% to 10.0%. The difference between these two sets of figures provides a rough guide as to how far inflation has become institutionalized since the 1960's.

When monetary and fiscal policy are concerted in the same direction, there seems to be a definite association with prices in the year in which the policy is applied but the relationship is the reverse of what might be expected if policy were the cause of the price behavior. This can be seen from the fact that in the nine cases in which joint policy was stimulative, prices decelerated seven times and moved up only two. Similarly, in the eight cases in which policy was restrictive, prices accelerated seven times while they slowed down only once. In the eleven cases in which joint policy was neutral, the price behavior was indeterminate, prices moving up eight times and down three. These results are more in keeping with the notion that policy was induced by the existing state of prices—along with the general state of the economy—than the other way around.

When the analysis is shifted to the results in the year following the application of policy, the relationship changes. Prices then show an acceleration seven times and a deceleration two times in the wake of concerted policies of stimulus. However, for joint policies of restraint, the effects are considerably less determinate. Prices accelerate in the majority of cases here as well, moving up five times and going down in only three. For the neutral policies, the relationship is murky too, with prices accelerating in four cases and decelerating in seven.

Thus, as far as these data go, the ability of monetary and fiscal policy to control the direction of the price level appears to be highly uncertain. For this same reason, predictions of price behavior based on policy are also uncertain. Nor is this situation appreciably improved when considerations of magnitude are introduced. Neither the magnitude of the rate of growth in the money supply nor the surplus or deficit in the government sector appear to be connected in any straightforward way with either the direction or the magnitude of the rate of increases in the price level. It thus seems reasonable to conclude that inflation is
not the consequence of just monetary and fiscal policies but that other factors enter the picture in an important way.

Some of these factors are clearly external. The most significant is the level of prices imposed by the OPEC cartel. With the demand of oil being effectively inelastic in the short run, the monopoly prices transmit a powerful inflationary impulse to the economy. Dealing with this, it would seem, would require political or other measures directed at the source of the problem. But, instead, domestic programs of taxation and conservation have been proposed. Unfortunately, physical output requires physical input. Until the technological relationships embodied in the present structure of industrial production can be shifted—a process that will require new investment on a massive scale—every increase in real GNP cannot avoid being accompanied by a more-than-proportional increase in imported oil. Thus, a growing GNP implies a continuation of inflationary pressures, but policies pointed towards simultaneously restricting the inputs and making them more expensive while doing little to encourage increased supplies would almost certainly make such pressures worse.

Other factors are internal and structural. They lie beyond the scope of the present analytical framework and the broad monetary and fiscal policies with which it has been concerned, but they can be briefly indicated. They fall into one or another of two general categories. There are those which, like the energy proposals, tend to raise prices while restricting output; and those which entail claims against the available total of goods and services by segments of the population which make little or no contribution to their creation.

To the former category belong environmental controls, minimum wage laws, and agricultural price supports. In key sectors of the economy monopolistic unions are able to compel inflationary wage settlements while the existence of corporate oligopolies make it possible to pass them along in the form of sharply increased prices. In the latter category is the vast complex of welfare and social benefit programs which divorce reward from effort and make claims on the nation's economic substance a matter of legal right. These programs seek to accomplish a broad variety of social objectives. Some of them, no doubt, are necessary and some may be praiseworthy. But, whatever their merits or rationales on other grounds, their collective effect economically is to press demand up to and beyond the limits of supply to create a gap that is then filled by an upward movement of prices.

If these factors were stable relative to the growth rate in real GNP, the rate of inflation could be similarly stabilized to the extent that it was not stoked by outside developments. But this does not appear to be the case. They derive from deep social and historical currents which are expressed through a constantly increasing use of political power to mandate the disposition of economic goods. To this, the economic system can and does adjust. The rate of price increase—along with interest rates and the rate of real growth—continues to accelerate and decelerate, but at ever-higher levels for the floor and ceiling.

Therefore, conceptually at least, the structural causes of inflation should be separated from those which may arise from aggregate regulatory and control prices. The broad monetary and fiscal policies which have been analyzed here are important for regulating the pace of economic growth, but their quantitative dimensions are only partly relevant for the problem of structural inflation. What is more relevant is their qualitative content and character. Despite the touching faith in the efficacy of aggregate control measures which is displayed by those who are convinced of the overriding importance of monetary policy or fiscal policy, as the case may be, it is towards checking specific policy proposals which, variously, institutionalize increased costs and higher prices, create more open-ended obligations, constrain production by means of regulatory obstacle courses, and foster a culture of dependence and exploitation through expanded incentives for not working that we must look if the underlying bias towards inflation is to be contained.

This is not a task which can be performed by broad monetary and fiscal policies, but the chances of accomplishing it by other means will be improved if the average rate of real growth is improved and such severe swings as recessions are eliminated from the adjustment process of the macroeconomic system—and to these things well-conceived aggregate control policies can make their contribution.
Applied Cybernetics: Management Perspectives

Akira Ishikawa
Rutgers University
Newark, New Jersey 07102

Amitava Ghosal
Council of Scientific and Industrial Research, India

1. Cybernetics vis-a-vis Management

The essence of cybernetics lies in the control of a system which is to be studied; accordingly the way a system is defined in terms of elements and their characteristics determines the working of a cybernetics system. Most management systems (e.g. economic, industrial, social, etc.) can therefore be viewed as cybernetic systems if they can be identified in terms of elements and their control relations. The relations which a specific system has with the external world, called the environment, should also be taken into consideration. According to Stafford Beer (1966), “The core of cybernetic research is the discovery that there is unity of natural law in the way control must operate, whether the system is animate or inanimate, physical or biological, social or economic.”

Though the word ‘Cybernetics’ can be traced to a Greek origin, cybernetics in modern science was introduced in its present form by Wiener (1948). It has been defined in various ways in various forms, but the most general definition so far has been the one given by Stafford Beer (1966): “The new science of cybernetics is the science of control and communication—whenever these occur in whatever kinds of systems.” Coiffignal (1958) defined the functions of a cybernetic approach as that of providing the art of approaching the solution of various problems through studying respective systems and prescribing how to act under various possible circumstances. Any problem of decision-making is, according to Coiffignal, done through a cybernetic approach by managers and executives, who are constantly intrigued with the problem of “If this, then what?”

The first step in a cybernetic approach is to delineate the system from which the problem has arisen. The problem is then formulated in terms of the elements of the system in a quantitative manner (as far as possible). The decision-mechanism of how to act under various situations is prescribed after analyzing the control features of the system. When we study a problem in the way described above, we also understand how changes in various elements would lead to different outputs calling for different decisions. Our knowledge of the system is complete when we know the mechanism of determining the output from the knowledge of input elements, their behavior, and the possible feedback effects of the output elements on the input elements. The dynamic features of the management problems is better understood, through a cybernetic approach (see also Ghosal, 1976).

2. Applied Cybernetics

Applied cybernetics is the branch of study which enables us to identify a system and its behavioural features, viz. input-output mechanism or feedback effects, and make decisions accordingly through a cybernetic approach. Thus we define the problem in view of terms of a cybernetic model and study the input-output mechanism in order to develop a decision-mechanism under various possible situations. This paper is concerned with developing the cybernetic approach to problems in economic, industrial and a few social spheres; it does not deal with problems in biocybernetics, which deals with applications of cybernetic approach in biological, biomedical and physiological problems (the literature on which is extensive, see Klir and Valach, 1965). Most of the problems in management science lend to deeper understanding through a cybernetic outlook. Stafford Beer (1966) puts it aptly: “If Cybernetics is the science of control, management is the profession of control. Hence we may recognize the subject of management cybernetics as a rich provider of models.”

The art of looking at a problem through a relevant system is an important feature of applied cybernetics. The examples given in this paper indicate that a problem when viewed through a system, is sometimes seen to be different from the apparent problem. Thus, an appropriate reformulation of the problem is the first requisite to the determination of a reasonable solution.

3. Examples.

Formulation of problems through a cybernetic approach can be appreciated through the following examples. The first step, as explained in Section 1, is to define the system and then to understand the mechanisms of self-regulation through an overview of the system. All the examples are taken from economic and industrial fields.
(i) An Inventory Problem.

A manufacturing plant keeps an inventory system of its finished products, which are mostly machine parts. During recent months the inventory has built up beyond expectation, despite the fact that neither wholesale prices nor the level of production have been increased.

While studying the problem, the system was defined in terms of production units (the number of various components being manufactured), consumer demand, advertisement mechanism, price structure, and sales behavior. A technical appraisal of the demand showed that there was a drop in demand for 80 per cent of the products due to technological change, that is, the consuming industry shifting to a different style of production, while on the other hand there was a substantial increase in demand for 20 per cent of products—these had no inventory at all. The marketing department was not aware of this change, and had advertised the 80 per cent of the products which had dropped in sales and increased in inventory. The reformulated problem was whether the production unit could adapt to a change in production structure by manufacturing more of the items which were showing better sales potential resulting from a small technological change. In other words, it was a problem of implementation with respect to feedback of changing demand structure on the production system.

(ii) Educational Planning Problems.

In the fifties a planning study in a developing country indicated that industrial production there for the next decade would suffer if the education system did not increase the number of engineering graduates by at least four times. The policy was implemented by starting a number of high-level engineering schools. During the first 10 years industry benefited substantially through the availability of qualified engineering personnel within the country. However, the increasing trend in production of engineering graduates continued; and in the early seventies it appeared that there was an overproduction of engineers. The increase in industrial development was not commensurate with that of the production of engineers. The result was that many fresh engineering graduates were unemployed. A plan for industrial development called for opening of new engineering schools; the effect of new schools on the industry at large was significant, because the industry had the benefit of qualified personnel who would otherwise have had to be hired from foreign countries at a higher cost; the later effect was, however, unemployment among engineers. A mechanism for monitoring the requirement of engineering personnel in industries and transmitting this information to the educational system, which could increase or decrease admission programs, could be worked out on the basis of a cybernetic system. The solution, however, might be difficult to implement.

(iii) A Social Problem.

A region in a developing country experienced a severe food crisis. To combat it, the authorities rushed in food supplies (composed primarily of grains from neighboring regions). A statistical survey made a few months later showed that about 25 per cent of the population were starving, even though there was no shortage of food in the market. These people simply could not afford to purchase grains, and certainly not high-cost protein items, due to their low income. A quick improvement of real income is a far more serious task than that of rushing food to a region.

(iv) Forecasting Problems.

Forecasting in economic problems also presents a good deal of complexity which can be better understood through an appraisal of the underlying cybernetic system. While forecasting on the basis of a past trend, we assume that the trend will continue in the future. Growth in economics is not akin to growth in biological systems—sustenance of growth depends on the efforts made in producing capacities, procuring resources, etc. in a problem of predicting air-traffic in a developing country, it was found that the traffic depended more on the airlines' capacity (the number of aircraft in service) than on other factors. Economic factors like indices of national income or regional economic development gave an indication of the potential demand, which was substantially greater than the available capacity. The problem of forecasting air traffic can also be made from the appraisal of the economic system, from which we can obtain the forecast as an output when various economic indices serve as inputs. These problems will be discussed more in detail in a separate paper.

The examples given above help us in realizing the control mechanism of systems relevant to respective problems. Most of the real-life problems are dynamic in character, and the realization of a system's behavior helps us to work out a control mechanism. We conclude this paper by defining a system in a layman's language.

(v) Corporate Planning Problems.

As various business functions, such as production, finance, marketing, personnel, and research and development, have become more complicated and autonomous, an increasing need has arisen to plan systematically by coordinating and synthesizing those functions.

The establishment of a Corporate Planning Office or Department in many corporations has been an attempt to accomplish systematic and overall planning to eliminate the disorder, confusion, and conflict among different divisions or departments easily nurtured on the basis that their duties and responsibilities are not always compatible. The cybernetic approach in the process of corporate planning has been a remedy for these problems, if not panacea, because it attempts to continually measure the effectiveness of functional relationships so that the corporation will reach the highest possible state of accomplishment. Kooit and Bradspies (1972), Ishikawa and Smith (1975), and Boudens (1975) advocate, particularly, the incorporation of feedforward or anticipated control concepts and tech-
niques to solve corporate planning problems successfully, as compared with feedback control concepts and techniques which have been applied by corporations for many years. The authors highlight the design and creation of a feasible, preventive corporate planning system that has to be continually assessed not on the basis of the variance between the planned and actual performance, but on the basis of the variance between the planned and forecast (estimated) performance. Emphasis is placed on the continual redesign and implementation of planning systems through the use of intelligent, interactive, and self-developing corporate planning and control model systems.

(vi) Other Problems.

Cybernetic concepts and techniques have been almost ubiquitously applied to diversified areas in business administration. Particular emphasis has been made on man-machine interaction problems, in which the construction of a man-machine interaction system by the use of systematic top-down design technique is introduced, (see Losbichler and Muhlbacher, 1974). Conversely, Millar (1972) advocates substituting the machine-technique for the man, rather than concentrating man-machine interactions. Another emphasis has been in the area of industrial automation, in which cybernetic control systems are designed and incorporated into inventory control and management systems (see Gross and Harris, 1973, and Siroyezhin, 1968), and the possible consequences of being adaptable modular devices and industrial robots are analysed, (see Heginbotham, 1973). Attention has also been given to the application of artificial intelligence techniques to programming decision-making and stock market analysis (see Felsen, 1975).


A system is an ensemble of elements, some or all of which are interrelated. For identifying a system, we have to know its behavioural characteristics, which are represented by (i) the manner in which various elements within the system are internally related, and (ii) the manner in which the elements react to any external influence. The external influence, in cybernetic language, is called the environment. The effects of the environment on the system are stimuli, while the effects of the system on the environment are called responses. The response of a system to any stimulus is dictated to a great extent by the way the elements are organized within the system.

A system may be classed under any of the following three categories:

(i) It may be a closed system, implying that there is no effect of the environment on the system.
(ii) It may be an open system, implying that there is always an effect of the environment on the system.
(iii) It may be a partially closed system, in which case the environment affects only a single subset or a few subsets within the system.

We may also conceive of a subset of the system being closed to another subset of the system. One system may comprise a number of subsets or subsystems, while the entire system may be a subset of a larger system. A very large system, the economy of a country, or even the planned structure of a big firm may be called a mega system. An algebraic description of a system is given in a separate paper. A non-mathematical reader may refer to Klir and Valach (1965) for excellent exposition of the concept of a system.

5. Systems View vis-a-vis Cybernetics

From the discussion of foregoing sections we find that there is a great similarity between systems view, as we understand it in the sense of systems theory (see Churchman, 1968, for an excellent overview of systems approach), and the cybernetic approach. In fact, it should be so, because cybernetics is nothing but the science of systems. The key to the solution of a problem is to look at it through a relevant system, and to follow the steps referred to in Section 1. A flow-chart of the cybernetic or systems approach to problem-solving is given in Figure 1.

![Figure 1. Flow Chart depicting the Systems (Cybernetic) View.](image-url)
the problem so formulated is obtained in relation to the data collected for relevant characteristics for the system. A solution thus obtained is again matched with the apparent problem, the system definition and possibly also the real problems. If necessary, some modifications may be made, data updated—such a chain continues particularly when the problem is a long-range one. In applied cybernetics, as in a systems approach, a problem is viewed in respect to the totality of relevant systems, and the art of looking at the problem is sometimes more important than deriving a solution for the apparent problem in isolation from the systems consideration.

6. Operations Research vis-a-vis Cybernetics

When Blackett started the Operational Research Group during the Second World War as a problem solving aid to the Allied forces, he applied a systems view to most of the problems undertaken by his team. With the proliferation of applications of operations research (O.R.) in industry, economy, social spheres, etc., in the post-war period, the spirit of O.R. (as originally conceived) was undermined through narrow specializations of O.R. workers. Consequently, highly sophisticated models were developed for intricate practical problems. No doubt—though many of these models had excellent applications as well—in many cases problems were solved for an isolated subsystem without having consideration of the impact of a bigger system. Too much emphasis was being given to optimization, and comparatively little to the problems of balancing of elements or the effect of mutual feedbacks within the system in view. Great advances have no doubt been made in the direction of model-making (particularly of small systems), the study of mathematical properties of a class of stochastic systems, optimization (particularly within static systems), simulation techniques, numerical appraisal of various problems, etc. Operations research studies, as practiced at present, are in many cases problems conceived for subsystems. It is necessary to stress the importance of systems view in O.R. studies, as done by pioneers like Blackett, Ackoff, (1972), Beer (1966), etc. In fact there is no conflict between O.R. and cybernetics: most of the problems in O.R. need a cybernetic (or systems) approach for appropriate formulation, which makes the basis for model-building, data search and analysis. Applied cybernetics is therefore highly relevant in performing O.R. studies.

It has been stressed by Beer (1966) that many of the control problems in a system can be identified by studying self-regulation mechanism among elements within the system. A cybernetic model takes into account all possible forms of self-regulation within a system. An O.R. study is always enriched by information on the self-regulatory mechanisms.

REFERENCES

Abstract

This paper discusses the task confronting computer modelers as they seek to introduce use of socioeconomic models into the decision processes of large social units. The paper draws heavily on experience gained in design and development of Regional World III (RW III), a 26-region world model. The history and structure of RW III are discussed in the second part of the paper.

Part I. Agenda of the Modeler

Decision Process

At an early age a child may pick up a spoon lying near his dish and begin to beat on the dish with it while someone else feeds him. If left alone, he may clumsily attempt to use the spoon to bring food to his mouth. Sometime later he is using the spoon to feed himself. This sequence or its analog takes place in the life of most human beings. Over some period of time the child decided the spoon was not merely an object which was there. He decided it could be used to serve his needs. The decision process grew with the child's decision. The child did not merely decide to use the spoon. He decided to use it as a fairly efficient means of eating food. An object in the environment was appropriated into the act of eating.

Adults confront decisions in similar fashion. The mind picks out common elements of successive decision situations and builds an internal pattern in which these common elements are treated like objects which are incorporated into the broader task of arriving at decisions.

Abstracting in Decisions

At some point, the common elements in a series of decision situations may be more relational in character than referential. That is, it is no longer the isolated elements of a pattern which recur and are incorporated by the mind into a pattern for decision making; it is now the manner in which the elements are related, spatially or temporally.

This step of abstraction is followed by another in which patterns and even networks of patterns are incorporated into the decision process in the mind. Decision making at this level is making use both of abstraction and logical structuring.

Conscious Abstraction

When the mind consciously uses abstraction to arrive at a decision the naivete of childhood is replaced by the patterned, repeatable, abstract, logical thought which our society attributes to adults.

Furthermore, our society has fostered the study of systems of patterned, repeatable, abstract, and hopefully logical thought in disciplines we know as mathematics, philosophy, engineering, economics and the like. Moreover, the problem-solving techniques of the society have given rise to a technology which is able to assist individuals in the use of patterned, repeatable, abstract, logical thought.

Libraries, lexicons, records, sensing devices, computer systems become objects in the environment which the mind seeks to incorporate in the decision process which has in part been made so infinitely complex by the growth of this very technology.

Admittedly, we cannot say that the mind incorporates these objects directly into the decision process, but aspects of them are used to reach decisions.

Mechanized Abstraction

Technological development has led to levels of patterning, repeatability and abstraction which no man or group of men could duplicate without the technology, due both to time and accuracy requirements. Individuals and small groups of persons have incorporated this mechanized abstraction into some aspects of decision making by creating specialized input and output processes to make the mechanized abstraction available to the levels of thought which the mind developed earlier.

Mechanized Abstraction and Large Social Units

Large social units have incorporated the newly-fashioned elements of technology into the broad social decision process in an entirely different manner, quite unlike that prescribed above for individuals and small social units. While the individual moves in his lifetime from concrete to abstract and even to extended abstract thought, society has managed to move no farther than a level analogous to abstract thought, never quite comprehending extended abstract thought. In other words, most social decision processes
The Modeler’s Task

Modelers alone cannot ensure that the potential social advance we have labeled Mechanized Abstraction will become a new element of a broadened social decision process. But, modelers must agitate for broadening of the decision process of society and modelers must make their work available in forms which will be recognized as key elements in the changed environment. Certainly large social models are one of two key thrusts to present mechanized abstraction to society as an essential component of a new decision process. The other thrust will come from artificial intelligence research.

To reiterate, the modeler’s task is:
1. To agitate for a broadened decision process which meaningfully incorporates mechanized abstraction into the decision environment;
2. To make mechanized abstraction available to large social units in a patterned, repeatable, logical way that enhances its likelihood of becoming part of the decision process.

The Task of Conceptualization

To avail himself of mechanized abstraction the modeler must reduce the complex world he perceives to quantifiable abstractions which can be related to one another in logical structures which reduce to loops or chains (graphs or trees). The modeler must recognize that every reduction of perception is just that, a reduction. This reduction will be subject to criticism by every user of his model, every person to whom he would like to present the model as a patterned, repeatable, abstract, logical structure which might be worth incorporating into his (the critic’s) decision process.

The modeler creates new abstractions which have never occurred before because his own perception of social structure and the tools he has at hand to analyze the structure demand this creation. Sometimes the modeler must tailor model structure to existing data.

The modeler will be confronted with the difficult decision of which loops to close and which to keep open. The world he perceives indicates many more closed loops (although the linkages may have small coefficients) than the modeler can incorporate into his structure, due both to limitations on his own time and limitations of the powerful, but not unlimited, mechanized abstraction at his disposal.

The modeler assumes at each stage of model development that the new structure he has created to model his perception of the world will track behavior of that perceived world somewhat better than the older model structure of the previous stage. When tests call that assumption into question, he retraces his steps, modifies the model and proceeds.

The modeler also assumes that model fidelity to the perceived world’s behavior from sometime t₀ in the past to sometime t₁ in the past indicates he has developed a reasonable structure. Next, he compares model predictions of future behavior of the social system with his own assessment of other future predictions and makes a subjective judgment of the model’s relative isomorphism with the perceived world. The two criteria (fidelity to past social behavior and fidelity to presumed future social behavior) become the set of reasonableness criteria to which the modeler repeatedly subjects his model.

In Defense of Computer Models

The last few paragraphs outlined the modeler’s task of conceptualization. No doubt any reader not already predisposed to receive computer modeling (mechanized abstraction) favorably, recognized the many flaws in this procedure. The procedure purports to be a means of tracking the behavior of the perceived world but is subject to many suppositions internal to the mind of the modeler. These suppositions have only the loosest linkage or causal relationship with the world. The all-too-willing critic of computer modeling will now become disposed to ignore the enterprise as futile.

Let us rebut at least some of the more obvious criticisms by demonstrating that analogous decision mechanisms in the social world are no less based on supposition and are very often even more loosely defined. We do admit at this time that a competent human decision maker takes note at least qualitatively of many more factors than do computer models. However, as the modeling art advances, this gap will be reduced and may even, given development of new techniques, become a gap in the other direction; that is, perhaps computer models will be developed which, given proper inputs, may even qualitatively evaluate more relationships than do human decision makers at this date.

Point-by-Point: Modeling versus Conventional Assumptions

After we outlined the modeler’s task of conceptualization, we raised several objections regarding shortcomings of the process. Aside from the present advantage of a qualitative, intuitive examination of relatively more relationships, how does the conventional decision process compare with the modeling process?

Patterning

The modeler (M) makes quantifiable abstractions. The conventional decision maker (C) either makes similar abstractions or makes less-well-defined abstractions according to larger or smaller categories. In the end, however, C
must attempt to close loops or think his way down a logical chain, just as M must. On this score, if M has done his work thoroughly, the sheer record-keeping capacity of the computer rapidly eclipses the capacity of C to remember results of his suppositions. Thus, patterning must be used by M and by C. The patterning of M is more explicit and less subject to error (forgetfulness) than that of C.

Repeatability

M is working with a structure which is repeatable. This is not so important if we merely claim that M can come to the same conclusions for each iteration of the model. Indeed, so might C. However, repeatability becomes important if we introduce the idea of sensitivity testing. Computer models are far more suited to testing using slightly altered structural relationships than are mental models. Thus, M can develop a sensitivity pattern (which inputs or policy parameters affect which outputs relatively more or less) much more credibly than can C.

Abstraction and Logic

The abstractions and logic of M are subject to discussion. They are explicit although, not as explicit as some modelers would contend. The abstractions and logic of C are hidden from view. On the other hand, at the present time it is likely that many persons who fall into the category C have built up a proven decision track record, while the members of class M have yet to prove themselves.

Tailoring the Model to Data

M obviously must have data to proceed. I contend that C is constrained in the same way. Let me cite two examples. C may think in terms of coal production. Yet, in a given situation his data may be just as constraining as the modeler's. A ton of brown coal from the Great Plains or Rocky Mountains may exert no marginal effect on the price of steel and a ton of coking coal from Pennsylvania may exert no marginal effect on the price of electricity on the Plains, yet they may both be statistically lumped as coal production. Our conventional man (C) is not better off than the modeler (M) when dealing with data of this sort.

A second example is from my work with Regional World III (RW III). We find it difficult to trace GNP. But, this limitation stems no more from limitations of our model than from limitations of the official statistics.

Our model tracks "hard" production. Official GNP statistics include the following:

1. Transfer payments: This is a spurious contribution to the indicators of economic activity. If I pay $100 to the government as social security tax and they in turn disburse it to my mother, it counts as $200. If I simply give my mother the money, it counts as $100.
2. Services: If everyone decides to get a haircut half as often, the portion of GNP due to barbering will be cut in half. If a barber goes to a restaurant and tips the waiter $2 the waiter's income is greater and the GNP is greater than if the barber tipped him $1. What economic meaning does the second dollar have if the waiter subsequently goes to the barber shop and pays the barber the same dollar to shave his beard instead of shaving it off himself? I contend that there is none, but we have just seen how the double exchange of the same dollar raises the official GNP by $2. Is C as well off when he works with this fiction as M who ignores it?
3. Imputed rentals: The official GNP imputes a rental value to a building which is occupied by the owner. Thus if corporation BIG builds a plush office building instead of an ordinary one, the GNP is greater not only in the year of construction (justifiably) but also in each subsequent year (unjustifiably).

I contend that the demanding conceptualization process confronting M may force him to evaluate statistics like these more carefully because he must consciously close the loop on some of these abstractions while C, who closes the same loop more intuitively may examine his input data less carefully.

Choosing Structure—Which Loops to Close

When M closes a loop, he consciously accepts the implications of the closure. As C scans possible loops in his own mind the structure he achieves may be much less rigorously examined. It is virtually certain that the quantification of relationships will be much less clearly understood by C than by M.

Model Tuning

In most cases M subjects his model to a repeated series of verification and validation tests. The tests must indicate that the model is responding adequately to M's reasonableness criteria or the model is reprogrammed. Our design procedure for RW III consists in a series of these tests and modifications followed by addition of a new abstraction or closing another loop when we find that we have approached our reasonableness criteria and can do no better with the existing structure. Occasionally we have made such large-scale changes that it takes a long process of tuning to surpass previous model performance. Usually these modifications represent significantly closer approaches to perceived world behavior when the model is sufficiently refined. I submit that by comparison C can only rely on his track record and experience. The design process I have described could be followed sufficiently long, i.e., beyond the working lifetime of any given C so that the track record of C would be rendered useless. The design decisions of M can be passed on to a successor together with an analysis of strengths and weaknesses of the model. The intuition of C is not as easy to transmit.

Policy Suggestions

In the foreseeable future it is likely either that M will not be
A Mutual Acknowledgement of Constraints

Perhaps the most important aspect of the problem confronting society as it is challenged to use computerized abstractions in the decision process is open and mutual acknowledgement of the shortcomings of conventional social decision making and of modeling. This paper has enumerated a number of issues the modeler confronts as he challenges the conventional decision process. I also believe that modelers can further the enterprise by laying out the weaknesses of their methodology and models very openly. Then skeptics and other people will be more inclined to believe them when they tout the strengths of their method and the urgency occasioned by examination of their results.

Part II. Evolution of an Integrated Modeling Approach

History of Regional World III

In 1973 my sponsoring organization, Aid Association for Lutherans (AAL), and I agreed to undertake a Social Modeling Project to investigate the dual ethical challenge of computer modeling of social situations: 1) the challenge to include ethical factors in models; 2) the ethical challenge to society emerging from the changed nature of the decision process under the impact of computer models of socioeconomic conditions.

We come to the work from our own Christian perspective, seeking to offer a challenge to other modelers to deal explicitly with the cited twofold ethical aspect of modeling and seeking to bring some understanding of this arcane new discipline to the Christian community. It is of course important to recognize that this is also a two way street. Christians do at times think of themselves as aliens in a secular culture, but they also comprise a very significant mass of voters in the United States and express their convictions in the affairs of the Republic via the ballot box or voting machine.

Moreover, and most telling, in the vast majority of ethical concerns there is no discernible difference between stands taken by Christians and those taken by the American culture as a whole. Thus, a concern for the quality of human life is pretty much the same whether expressed under the aegis of the Biblical injunction to “Love thy neighbor” or the American banner of inalienable rights, “life, liberty, and the pursuit of happiness.” Empirically, these boil down to helping the poor, seeking to feed the hungry, aid the ill, limiting pollution to a level where life is not seriously degraded by either the pollution or the efforts to limit it (a very difficult argument to settle by any means since we can always find someone more willing to pollute for “economic gain” and someone more willing to shut down the economy for “a better environment”—it may be impossible even to identify empirically the most extreme person at either end of the spectrum since different people’s sensitivities vary according to the topic discussed).

The list of moral or ethical concerns which can be discussed more intelligently by means of data from modeling already includes the areas mentioned above and many more. Eventually the list of ethical concerns which can be modeled at least in part will be very large. Moreover, since every large scale social decision affects almost all life on earth, the ethical impact of computer-aided decision making will be virtually without limit.

We felt that to be credible discussants of modeling we must be credible modelers. Thus, we began by designing a model. After discarding an early, largely multiplicative model, we settled on a regionalized, largely additive model, which is programmed in FORTRAN and conforms in spirit but not in every detail to the methods outlined by Jay For­rister in his writings on system dynamics.

As an example of our design departure from Systems Dynamics practices, although our model is dimensionally consistent, we have not adopted the explicit method of assigning units to coefficients or constants so that equations are dimensionally consistent. These units become implicit in our model and documentation. The primary reason for shortcuts of this nature is the limited staff we have (the two authors of this paper). We could easily spend more time documenting than doing if we did more than inspect our equations for consistency.

We decided on a design strategy based on two primary considerations:

1. Regionalization was necessary because each region would ultimately recognize that survival in a competitive world would require marshalling its own resources or agricultural or industrial strengths to enable it to acquire needed goods from elsewhere;

2. Regions should be composed of nations or groupings of nations since the nation-state and blocs of nations (such as OPEC) seem to be the most clearly identifiable socioeconomic realities of the times.

The model regionalization was constructed as an annually cycled difference equation model with four regions (U.S.A., Canada, United Kingdom, India). As we gained confidence in the operation of the model and learned which data were needed, we added regions until the entire world (except a few Pacific Islands) was included in a thirty-region model. We found the first twenty regions sufficiently representative to do most testing with twenty regions. This saves time and computer space, an important consideration, since we are free riders on the computer belonging to the Aid Association for Lutherans (an IBM 370/158). The twenty regions represent about 85-90% of world population and economic activity. We have restructured the thirty-region world
into twenty-six regions and run tests with all twenty-six (about 99% of the world) to demonstrate the model’s efficacy, but subsequently we again reduced testing to twenty regions for computer space reasons.

Our methodology is sufficiently well worked out that we could further subdivide to 50 regions or more if desired. Although we have done little up to now to demonstrate special relationships between pairs of regions (such as the U.S.S.R. and Eastern Europe) we could modify the trade sector to include information and restrictions of this type.

Possibilities for Special Inter-Regional Relationships
That special relationships among regions can be programmed into our model, which is now called Regional World III (RW III), is demonstrated by the emigration/immigration portions of the population equations. These migration equations enable us to include as input data the regions to which would-be emigrants from a region are allowed to go and in what numbers (as a fraction of the total pressure for emigration). Emigration pressure is presently calculated as a fraction of total population in the region people are seeking to leave. This fraction is a function of the difference in nutrition levels between the region people seek to leave and regions to which our policy input data allow them to go. These equations will be modified to reflect emigration pressure due to income differences as well. This modification is one of a number of desirable changes which are catalogued but not yet incorporated in our model due to manpower limitations.

Model Structure
Intra-Region Calculations
The model is structured to begin with data describing the initial states of each region (say 20 regions). Food production, resource production (depending on demand and reserves) and targeted industrial production are computed. These calculations are followed by a series of calculations which compute import demands and exports available.

Import/Export Demand/Supply
Demands and exportable products are summed into world totals by category.

Exports
After imports are made, exports are calculated on the assumption that each nation sells a fraction of the world imports proportional to its portion of exports available. Obviously, this overlooks special situations such as U.S.S.R. — Eastern Europe where certain commodities will be traded only within the special two-party relationship.

Allocation
In the event a region does not receive all the oil it sought in the marketplace in a given year, a subroutine allocates the shortages according to present allocation priorities. The shortage is distributed according to the indicated allocation policy decision among the four basic economic sectors: Industrial, Agricultural, Technology, and Other.

Production
After noting what export goods are sold, and allowing for any resource shortages encountered, the model updates tentative production calculations made earlier in the cycle to reflect actual exports and production.

Population
Near the end of each cycle, population is recalculated. Population calculations are presently based on regional calculations of crude birth and death rates and emigration/immigration. Greater accuracy could be achieved by introducing age-specific distributions and birth and death rates for each region, but time has not yet permitted this refinement.

Sectorization of Regional Economics
Regional economics are presently subdivided to show grain equivalent production, animal protein equivalent production, reserves and production for coal, minerals, and oil and industrial production (IP). IP is further broken down into Industrial Base (production capacity), Agricultural Equipment, Advanced Technology, Other (buildings, transportation, military, consumer goods, etc.), Overhead (consumables, throwaways, chemicals, etc.), and Industrial Exports.

Overhead is discarded each year. The other categories are stored and subjected to depreciation each year. An earlier model version, RW I, included separate categories for Military, Consumer Goods, Service Capacity (transportation, buildings, etc.), and Renewable Resource Production Capacity (hydroelectrics).

However, paucity of data forced us to cut back the number of sectors until such time as available data and manpower permit more credible broadened coverage. Again, as with the number of regions, there is no apparent obstacle except processing time and manpower to limit the number of economic sectors in the model.
Miscellaneous Categories Included in The Model

We also include calculations indicating pollution units per square kilometer, training per capita (education), and credit. In addition, numerous secondary abstractions are included to aid in calculation of primary variables.

Aid: Ethics Demonstrated

To demonstrate the feasibility of indicating ethical decisions in the model we have included provisions to distribute food and monetary aid automatically according to predetermined algorithms and policy-setting coefficients. We can also send aid on an ad hoc basis from one region to another.

Future Indicators—A Tentative Programmed

Ethic Considering the Future

We have recently added a series of output variables which indicated each region’s viability for the future. These variables are printed out and used to indicate the relative future viability of a single region under two sets of policies (two test runs of the model compared) or the relative viabilities of two regions under the same policy (a single test run).

Test Capabilities of Regional World III

Policy Testing

Numerous policy options (about forty in addition to the region X region migration policies) are offered as part of the input data set. Aside from migration policies most single-region policy tests require insertion of one or two lines of coding and a recompile of the model.

Sensitivity Testing

In addition to Policy Testing described above we have developed a supplementary sensitivity program which can vary any of a number of model-internal policy options. The potential policies are inserted as coefficient multipliers and set to 1.0 when not in use. In this manner a series of sensitivity tests can be run under control of the adjunct sensitivity routine which affords standard output as well as sensitivity calculations.

Sensitivity Averaging

Because slight time shifts can radically alter the apparent sensitivity of an output variable to a change in an input or a policy variable, we have developed a method of sensitivity averaging which displays the average sensitivity of several (10) variables to a change in an input parameter or policy variable over a period of 1-20 years following a policy change. The policy-change year may be the base year or any other test year. The averaging period may begin at the policy-change year or some subsequent time.

The high, low, and mid-year sensitivity for the averaging period are displayed with the average value. If these additional values cast doubt on the reliability of the value for average sensitivity, we can use an alternate program package which calculates cumulative sensitivity.

Cumulative Sensitivity

Cumulative Sensitivity is calculated by summing the annual changes in the output variable for the test period and comparing this sum with the change in the input parameter or policy variable for the same period. This method is used only when the average method is shown by dispersion of average, high, low and mid-year values to be unreliable.

Plotting

An auxiliary plotting routine has been developed to display graphically any of a large number of selected outputs. These outputs can be displayed on common or individual scales and a broad range of choice is offered. Thus for example, the nutrition level in India can be displayed on a plot which also shows oil consumption in the U.S.A. Moreover, the results of two different tests can be plotted on the same page showing graphically the relative efficiency of two socioeconomic policies in achieving their desired goals.

Input-Output

All inputs are made via video terminals. Output can be via video or hard copy. The model can be operated in the time-sharing mode, permitting policy intervention in mid-test, but when we do this we have heavy negative impact on other system users so during the past year all operation has been in the batch mode.

Ethical Aspects in Regional World

The power of RW III to test and permit evaluation of ethical concerns lies in its broad capability to test varied inputs and policies and to display contrasted outputs in ordinary tabular form, as sensitivity relationships, or as graphics.

Ethical Impact of Modeling

Ultimately the ethical impact of modeling will come in a changed decision process which uses this vast enterprise of mechanized abstractions as a primary, but not sole, tool in evaluating a continually broader range of socioeconomic and even perhaps more purely social policy decisions.

The nature of our times and the socio-political pressures which are mounting almost everywhere demand that more advanced methods of decision making be used for our larger social units.
If we can keep alive the discussion of ethics during the critical developmental years of the process, we shall have been well rewarded.

**Summary**

We have indicated in broad outlines the conceptualization problem facing the modeler. This was contrasted with the problems facing the conventional decision maker. We then indicated a potential for incorporation of computer-based social models into the social decision process. This was followed with an outline of the development and structure of Regional World III which we developed as a working tool to enhance discussion of the ethical implications of computer-based social modeling.
Can War Be Abolished?

N. A. Coulter, Jr.
Department of Surgery — School of Medicine
University of North Carolina
Chapel Hill, North Carolina 27514

A monster of such evil mien
As to be hated needs but to be seen
But seen too oft, familiar with her face
We first endure, then pity, then embrace.

Alexander Pope

Introduction

In his thought provoking study of the psychological aspects of war and peace, Jerome Frank points out the important role that habituation plays in blunting our awareness of the dreadful dangers of nuclear weapons (Frank 1967). "Survival in the wild," he observes, "requires the ability not only to detect tiny changes in the environment, but also to stop detecting them if nothing happens—if an animal kept on attending to every stimulus, its capacity to sense possible fresh dangers would be swamped. Therefore, continuing stimuli, except painful ones which represent a continuing danger, rapidly stop registering, thus freeing the sense organs to pick up new ones...As a new form of destructive power the Hiroshima atom bomb, with an exposure equivalent of twenty thousand tons of TNT, created considerable apprehension. Since then, the size of available nuclear weapons has about doubled annually. We should be terrified, but because of habituation and insensitivity to the remote, we are not." Since Frank wrote these words, the nuclear arms race has continued, and more and more nations may soon acquire these weapons. It is easy to understand why. Nuclear weapons may be perceived as decisive in war; and national leaders, concerned with the security of their countries, feel they must have them.

It is also easy to predict that, unless some basic change is made in time, sooner or later a nuclear war will almost certainly occur. Reliance upon abstract doctrines like "mutually assured destruction" may comfort those having this awful power at their disposal; that such thinking is actually taken seriously by those in power only adds to the risk. Most wars start because some leader miscalculated. (Was there ever one in which this did not happen?) The Kaiser was certain that German mobilization would deter the Russian Tsar. Hitler wanted war, but he was sure he would win it. Complacency added to habituation is a formula for disaster. The only sure way to prevent a nuclear holocaust is to abolish war itself.

I do not choose to contend with those who argue that wars are inevitable, or that the cause is hopeless. Human survival is too important and the risk is too great. I choose instead to try to think this problem through, and, together with others of like mind, to find a solution and to do what I can to put this solution into effect. This journal, according to our editor, is to concentrate on "the cybernetic approach to extremely complex systems;" and our president has urged that our society "provide leadership...for the humanization of systems." Surely the abolition of war is a fit subject for our efforts! And, after all, such inhumane institutions as cannibalism and slavery have been abolished, almost everywhere in the world. Why not war?

The purpose of this article is to present some ideas which may contribute toward the abolition of war, in the hope that others will add their contributions as well. I am not unaware of the immensity of the task we face. That is all the more reason to redouble our efforts.

A New Approach

It seems clear that the United Nations cannot abolish war, despite its dedication to that purpose. It lacks the authority, the power, and the will to do so. This is not said to disparage this organization, which continues to play a valuable role in the management of international conflicts, and does many other useful things that are too little known. But something more is needed. Conventional diplomacy cannot be relied upon either. Again, the honest efforts of statesmen to reduce international tensions merit our support. But 8000 wars in 5000 years is not a testimonial to the effectiveness of diplomacy. The road to every war is paved with the failure of diplomatic efforts to prevent it.

What is needed, I am convinced, is nothing less than a cultural evolution of the human mind and society which will make war unthinkable as an option in human affairs. To paraphrase Another Mother for Peace: If somebody tried to give a war, nobody would come. How can such a cultural evolution be brought about?

Difficult though this task may be, the dedication of our efforts to this end is far more hopeful than an anxious reliance on our leaders to make progress in the latest round of SALT talks. It gives us all something to do. No single person can check this inexorable drift toward nuclear suicide. But each of us can do something toward that urgently needed cultural evolution. And the combined efforts of many of us, in all lands, will have a cumulative effect. Our leaders
are really the helpless ones; they are prisoners of their roles. But we can, through cultural change, re-define their roles. In the last analysis, it is really up to us.

Cyberneticists are particularly well suited to contribute effectively to this cultural evolution. The analysis of complex systems with multiple feedback loops and interactions is a major area of interest in cybernetics. Furthermore, the brain-computer analogy, while admittedly controversial, is a very rich source of new ideas and research paradigms for studies of the human mind and human behavior.

Synergy—An Idea Whose Time Has Come

The term "synergy" is as old as the Greeks, and the concept it denotes is older still. It has long been used in medical science to denote the cooperative action of two or more agents—such as two drugs, or two muscles acting about a joint, or muscle groups cooperating in the maintenance of posture and of poise in movement. The term was originally used in chemistry to denote the action of two catalysts whose combined effect on the rate of a reaction is greater than the summed effects of each used separately. Recently there has been a marked expansion of interest in synergy in a variety of fields (Maslow 1971; Craig and Craig 1974; Hampden-Turner 1974; Fuller 1975; Coulter 1976; Haken 1973).

Why is this idea so important?

As Hampden-Turner points out, the term "synergy" has several meanings, all of which are important. Etymologically, it means "working together." Hampden-Turner gives three interdependent definitions:

1. Synergy is the fusion between different aims and resources to create MORE between the interacting parties than they had prior to the interaction.
2. Synergy is created by the resolution of apparent opposites and social contradictions.
3. Synergy grows out of a dialectical and dialogical process of balance, justice, and equality, between persons and groups, and between the ideas and resources they represent; such synergy always exists on multiple levels.

Fuller has emphasized the key role played by synergy in producing a whole that is greater—or other—than the sum of its parts. Something new emerges, something that can exist only at the higher level of organization made possible by synergy. This is manifested in the gestalt phenomenon in psychology; but it also appears in other systems. It is sometimes called "synergism."

My own definition is simple. Synergy is any property of a system that promotes two or more functions, processes, goals, etc., while impeding none. Also, in metaphor: synergy is the electric surge of the mind when it leaps from "either-or" to "both-and."

Synergy thus emerges as a master concept with an infinity of possible applications. It can serve as a simple, basic focal point for applying our efforts to bring about the cultural evolution so urgently needed to establish the social climate which will make war unthinkable. Every action that promotes synergy in human affairs contributes to this evolution. And everyone can do something to promote synergy. We don't have to wait for world leaders to act, or wring our hands helplessly if they do not. Each of us can do something.

The Modes of Function

For cyberneticists and others in the intellectual community, one thing that can be done is to collect and develop ideas and techniques that promote synergy and to communicate them as widely as possible. In the remainder of this article I will present a few such ideas for consideration. My intent is synergic: both to communicate these ideas and, hopefully, to challenge readers to develop and communicate others.

The first of these ideas is the concept of the Modes of Function. This was originally inspired by Hughlings Jackson's concept that the human nervous system is organized in a hierarchy of levels of function. However, I have modified this notion considerably, and it is applicable to human groups and social processes as well as to individuals. The lowest mode of function is called the Identic Mode. This is the mode that is operative in classical (Pavlovian) conditioning (as well as in operant conditioning). A bell rings. Meat is placed in a dog's mouth. Saliva flows. This process is repeated several times. Then, the bell is rung, but no meat is given. After a precise interval, saliva flows. A conditioned reflex has been established—a linkage between the sound of the bell and the flow of saliva.

The Identic Mode also predominates in the phenomena of hypnosis. The hypnotist says, "When I snap my fingers, you will scratch your right ear." Snap. Scratch. A linkage was established between the snap and the scratch. Magical thinking, advertising, propaganda, neurotic and psychotic mental processes, etc., all involve the Identic Mode of function. It operates in every human nervous system. Ordinarily the individual is unaware of it. But it also can be observed in group and social processes. Racial prejudice, for example, is not primarily a neurosis of individuals. It is embedded in the social matrix. Those afflicted with racial prejudice (as opposed to its victims) identify a person with chocolate colored skin as being "inferior" or "morally degenerate" or "a threat to our way of life," because such linkages (or identifications) are part of the perceived consensus. Customs and taboos are also usually Identic in Mode.

The next Mode of Function is the Reactive Mode. This is the mode of a person (or group) driven by strong emotion, such as fear, anger, or sexual desire. An individual in such a mode thinks in stark colors; everything is either black or white, for or against, good or evil, etc. The enemy of my enemy is my friend. Capitalist pigs and communist creeps. There is no discrimination of degrees between extremes. Beliefs are rigidly held, not subject to rational dialog; facts that don't fit are ignored or explained away. It should be emphasized that not all emotional states are reactive in mode. It is quite possible to be afraid and keep one's cool. Love does not have to be blind. Indeed, in the Synergic Mode (described below), thinking and emotion mutually reinforce each other in a harmonious way.
Above the Reactive Mode is the Uniordinal Mode. In this Mode, a person is rational in outlook, and able to see degrees between extremes. Beliefs are not rigidly held, and the mind can change if a contradictory fact is shown. However, the individual views events from a single perspective—his own—and acts to achieve his own goals without considering the goals and interests of others.

In the Multiordinal Mode, a person can view events from two or more perspectives at once. A witness to an argument between two parties can see the merits of each side without favoring either. A parent can understand how a child feels and still see the necessity of bedtime. A person can act to achieve a short-term goal without losing long-term perspective. It is possible to see both the forest and the trees.

But seeing both sides does not alone enable one to integrate them. In the Synergie Mode, an individual not only views from multiple perspectives; he also focuses on synergies among these perspectives. He acts not only to achieve his goals, but modifies his actions to facilitate the goals and interests of others affected by those actions. A group operating in the Synergie Mode experiences a relationship of openness and trust, of mutual understanding and mutual aid, that enables it to achieve far more than it could operating Uniordinally.

In social processes today, in almost all societies, the adversary mode predominates. A great deal of energy is invested by contending parties in competition, rivalry, conflict, and acrimonious struggle. A victory by one party leaves it spent while the other covertly plots revenge. The same amount of energy could equally well be invested using the synergetic mode as a basis for interaction. It is possible to create all-win situations in which all parties benefit. It is not only possible, it is highly desirable. It is not only desirable, it is easy—a lot easier than some may think. Synergy is potential everywhere. All one needs to do is look.

But synergy is not evident to an individual or group functioning in the Uniordinal or Reactive Modes. In order to perceive or create it, it is necessary to view and to act in the Multiordinal Mode, and then to search for or create synergies.

By viewing, analyzing, and evaluating events and actions from the standpoint of the Modes of Function, one gains an overall perspective that is otherwise absent. From this perspective, one can recognize the Mode of another person, group, or social process. Knowing the Mode, one can then interact appropriately—suiting the action to the Mode. It is not usually feasible to reason with someone who is functioning in the Reactive Mode. But one can create a situation providing an outlet for the emotion to discharge harmlessly, reducing its intensity so that the Uniordinal Mode turns on. The overall objective of a person or group dedicated to synergy in human affairs is to use ideas and techniques which enable parties to climb the ladder of the Modes of Function up to the Synergie Mode.

**Synergetic Power**

One of the major contributions of the Craigs is the identification of two kinds of power. The first of these is the kind familiar to us all, a combination of the carrot and the stick, called Directive Power. It has five components:

1. A power wielder—the initiator.
2. An object or target of power—the responder.
3. A goad or punishment—the "stick" used by the power wielder to coerce the responder.
4. An incentive—the "carrot" used by the power wielder to motivate the responder.
5. The behavior path—the activity of the responder desired by the power wielder.

Directive Power is so prevalent that many people take for granted that it is the only form of power that can be used. (Indeed, this belief is tacitly encouraged by Directive Power wielders because it induces a feeling of impotence in responders, making them more responsive.) Most human organizations are edifices of Directive Power. They are arranged in hierarchies, with "bosses" at one level using Directive Power on those directly below, and submitting to Directive Power from those immediately above.

Synergetic Power is a basically different kind of power that is available to everyone, no matter what his position may be in Directive Power hierarchies. Indeed, it transcends those hierarchies. Synergic Power has been defined by the Craigs as "the ability to engage others in joint efforts that increase the satisfactions of all." It differs from Directive Power in the concern it expresses for the interests and goals of the responders. Instead of carrot-and-stick, the initiator relies upon two-way communication to establish rapport with the responders. Based on this rapport and his own goals, he then proposes for consideration a desired behavior path which will promote the interests of the responders, as well as his own. He listens to the response (continuing two-way communication) and modifies the desired behavior path as indicated, encouraging and accepting suggestions by responders that are synergic to his goals. Since the responders participate in the decision-making process, the final decision is as much theirs as it is his. Their commitment to action is thus far greater, all other things being equal.

The degree of Synergetic Power achieved by the initiator is determined, not by his capacity to reward or punish the responder, but by his ability to match the desired behavior path of the responder to the responder's interests and goals. This ability in turn depends upon the Mode of Function of the initiator, the responders, and the communications and interactions that occur. It is critically important for the initiator to operate in the Synergie Mode as much as possible. But it is also important for responders to do likewise. If the responders operate in the Uniordinal Mode, for example, the degree of synergy that can be achieved is limited. On the other hand, if the responders operate in the Multiordinal and Synergy Modes, the effectiveness of the group is greatly amplified.

Synergetic Power makes possible a new kind of organization—a heterarchy as opposed to a hierarchy. A prerequisite for a heterarchy is that all its members operate in the Synergie Mode as much as possible, and that Synergetic Power is used. The structure of a heterarchy is flexible and changes to meet the needs of the actions undertaken. Any
member of the heterarchy may take an initiative, using Synergic Power to enlist the participation of others. When and if a decision is reached, he then becomes the leader of the project; but all participants share responsibility for its achievement. Another essential feature of a heterarchy is the synergic involvement of all members in at least one project at all times (except in an emergency or for other good reason). Such a commitment is natural if each member operates in the Synergic Mode; it is vital if the heterarchy is to achieve much. Given such an involvement, a heterarchy can accomplish far more than the summed efforts of its members were they acting individually. These two requirements lead naturally to a third: the development and use of ideas and techniques which promote synergy. Problems and obstacles will inevitably be encountered, both in the internal processes of the heterarchy and in its interactions with other individuals and organizations. These problems can be solved if techniques for promoting synergy are available and are effectively applied. If such techniques are not available, it then becomes necessary to create them. This does not guarantee that all problems encountered will be solved. But it offers best hope that they will be.

Synergic Power can also be used effectively to resolve intergroup conflicts. When such a conflict emerges, both groups characteristically shift into adversary mode. An enormous amount of energy is spent in struggle, each trying to gain at the other’s expense. The same amount of energy might equally well be spent in resolving the conflict using the Synergic Mode. The Craigs describe techniques for achieving this which they call the “All-Win Program.” For details their book should be consulted.

**A Program for Action**

War is the ancient scourge of mankind. It has been dominant in human affairs in every century since the dawn of history, and the twentieth century has been the bloodiest of them all. And it continues to be: millions of people have been killed in wars since World War II, and the use of nuclear weapons has been seriously considered on several occasions since Nagasaki. Hundreds of billions of dollars are spent annually on armaments, and the nuclear arms race continues. This is not a record that inspires confidence. We must not permit habituation, complacency, and feelings of impotence to blind us to the stark reality of the situation. What is being done now is clearly not enough; something more must be done. The honest efforts of world leaders and others in positions of Directive Power to prevent wars and reduce international tensions merit support. But these efforts, at best, deal only with symptoms, not underlying causes. They buy time. Meanwhile, far too little is being done by men and women who have the intellectual capacity and knowledge to gain a better understanding of those causes and to develop and apply techniques for eliminating them. As Weizenbaum (1977) recently observed: “Things have come to a point where it has become the duty of the intellectual to speak the simplest and plainest truths....The plain and simple truth is, the large-scale science and technology in the whole world, not just in the United States, is mainly in the service of killing people. Almost all the people I went to school with, for example, have spent...their careers...in building devices whose fundamental purpose is to kill people. This is simply a fact.” It is an appalling fact.

In this article, I have presented a few ideas which, I believe, can contribute to a synergic cultural evolution that will ultimately make war unthinkable. But more—much more—is clearly needed. The dedicated, sustained efforts of a million scientists and intellectuals, on a scale at least comparable to efforts now devoted to war and weapons development, are urgently needed. I earnestly hope that Cyberneticians will take a leading role in catalyzing such efforts. War has become too deadly to be left to the politicians.

**REFERENCES**

Cybernetic Design for a Totally-Automated Teaching-Learning Process

V. G. Drozin*
Bucknell University
Lewisburg, PA 17837

I. Intrinsic Deficiencies of a Conventional Teaching-Learning Process

The basic contradiction of the educational process is between the individual nature of learning by each student, who represents an extremely complex, dynamic, unique, probabilistic system, and the group character of teaching conducted in a class consisting of such students. A teacher in a classroom does not know and certainly could not remember the learning characteristics of each student in a class, particularly that student’s potentialities, interests, rate of processing audio-visual information, etc. In addition he cannot constantly control the academic performance and the concentration level of each student in a class. Even if the teacher could know the learning characteristics of each student and could constantly control his learning and the level of his concentration, the teacher would be physically and mentally incapable of delivering to each individual student the material best satisfying the need of that student in the form most suitable for his learning. This shows that even the best possible living instructor cannot conduct an efficient teaching-learning process which takes into account the needs of each student.

It is not difficult to see the introduction of teaching machines and programmed instruction [Skinner (1956), Crowder (1960)] as well as computer assisted or managed instruction [Bitzer (1970), Suppes and Morningstar (1970), Cooley and Glaser (1969), Flanagan (1967), Stolow (1965)] still left the teacher, with all his intrinsic limitations, in control of the teaching-learning process. It seems that the total automation of this process is the only way to resolve its basic contradiction.

II. Conditions Needed for Automation of a Teaching-Learning Process

We define a totally automated teaching-learning process as one in which a living teacher does not communicate with a student involved in the process of learning and does not directly observe the behavior of the student; only disturbances in the functioning of apparatus and their abnormal readings are signalled to a supervisor.

A process can be automated only if it is sufficiently described. Applied to the teaching-learning process of a given student, this means the knowledge of his learning characteristics: his "learning profile." The learning profile includes all the relevant information about his learning, such as the rate at which he processes audio-visual information in a given field, his concentration span, change of concentration level during the day, likes and dislikes, family background, material he was exposed to and his retention of the material, his typical electroencephalograms (EEG) and electrooculograms (EOG), etc. Knowledge of the learning profile of a student will permit his advisers to work with him to establish his educational goals and the curriculum for reaching these goals. The learning profile from the moment the student enters the educational process, its changes, and what he learned and how well, should be recorded. In addition, the monitoring of the level of concentration of the student while he is learning and a check of his learning performance deliver the information necessary for effective and efficient control of the teaching-learning process. Finally, a variety of lessons in the selected curriculum and a variety of means of their delivery, matching the variety of learning responses of the student, is another condition needed for an effective control of the teaching-learning process of this student. If all these conditions are fulfilled, the teaching-learning process for a given learner can be considered as sufficiently described.

The cybernetic method of control of a teaching-learning process consists of determining the deviations of the actual learning performance and level of concentration of a given student from the anticipated performance and level. The next steps in the application of the cybernetic method require making decisions on how to eliminate the deviations, and executing the decisions until deviations are eliminated. The decisions and their executions should be based on the knowledge of the learning profile of the student. In a totally automated teaching-learning process of a given student, all these controls are exercised by a correspondingly pro-
grammed combination of regular computers, mini- and microcomputers, interfaced with corresponding devices.

III. Cybernetic Design of a Totally Automated Teaching-Learning Process

Teaching-Learning Process

Figure 1 shows a simplified diagram of the automated teaching-learning process of a student. The computer (2) with its several inputs and outputs serves primarily as a controlling subsystem, although it may be used by the student for computational and other purposes, but not for actual delivery of lessons since it is much too costly and inefficient for this purpose. One of the inputs contains information about the learning profile (3) of the corresponding student, his curriculum or list of learning materials (lessons), and his activities for a certain period of time, which have been set up by a group of experts with the participation of the student himself. The curriculum may contain the lists of:

- diagnostic and developmental lessons to discover the student's potentialities and develop them correspondingly,
- lessons acquainting the student with both the way in which all our knowledge is subdivided, and how and where to find needed information,
- preparatory lessons acquainting students with material needed for understanding the information offered in different branches of knowledge,
- lessons acquainting the student with world cultural heritage, and
- professional lessons designed to prepare him for professional life.

Although the task of development and implementation of such a curriculum for each student is enormous, it would eliminate the repetitious and wasteful effort of many thousands of teachers currently doing essentially the same work in different schools.

The curriculum should be optimized in respect to all types of lessons due to the limited time available to the student. The library of lessons (5) should consist of several depositories. Most frequently used lessons should be located in the lesson library of a given learning institution, while less frequently used lessons should be centrally located to serve one large or several small states, connecting with all learning institutions in the serving area. The lessons rarely used should be placed in a centrally located library and serve the whole country via television transmission by satellite network. In addition, the student should use the facilities of the automated library from which he can obtain the information specified in the program of the computer. All these depositories of learning material should form a National Educational Network. This network should eliminate the artificial division between all kinds of learning institutions such as schools, colleges and universities.

The means of lesson delivery (6) are various sound and picture reproducing devices, such as black and white or color television, tape and cassette tape players, or video tape players. The lessons would differ with regard to their length, the voices in which they are recorded, and the selection of audio-visual aids, so that their variety would fit to a reasonable extent, the variety of students' learning profiles. The computer should be programmed (3) to select the lessons (5 and 6) and means of their delivery (7 and 8) corresponding to the pertinent learning characteristics of the student, to the information about his present state of concentration (9) and to his learning performance (9) during the preceding lesson. While the student is working on a given lesson his learning behavior would be compared with that recorded for a group of similar students (4) while they were in the process of studying the same lesson. Depending on the student's concentration level and his learning performance, the computer would be programmed either to select a remedial lesson or to give the student a rest period in form of sport activity or specially designed relaxation exercises. The computer's program may use information about the weaknesses of the student, his likes and dislikes to reward him for exceptionally well done work or publishing him for intentionally poor learning in the way which proves to be most effective.

After finishing a certain part of his curriculum the student would participate in seminars and teleseminars conducted by outstanding instructors, or would perform laboratory, musical and other exercises. After necessary preparation the student would spend part of his time in civic and social activities, in getting acquainted with technological processes, and in observing the activities of various professions, especially one he intends to pursue later, etc. This should help to eliminate the existing gap between the institutions of learning and the society.

IV. Advantages of an Automated Teaching-Learning Process over a Traditional One.

If we would substitute on Figure 1 the student (1) by a class, the computer (2) by an instructor, variety of lessons and their deliveries (5-8) by a lesson prepared and delivered to a class by the same instructor, regular checks on the learning performance of the student (9) by occasional quizzes; if we would eliminate monitoring the student's concentration level, the performance of similar students (4) as
well as the knowledge of the learning profile, the goal and the program of learning to reach this goal specially developed for this student (3); then we would get a diagram of a traditional teaching-learning process. The comparison of the suggested automated teaching-learning process with the traditional one shows that:

1. No living teacher can keep in his mind as much information (3) about the learning characteristics and development of a given student, from kindergarten to any given moment, as a computer.

2. Each lesson in the lesson library (6) is the product of a creative effort of a team of outstanding instructors who would spend many hours on the preparation of a single lesson. There is a variety of lessons dealing with the same subject but using different approaches and lengths of presentation.

3. No one teacher has at his disposal all the means of delivery of lessons available on an automated system (8). The lessons can be delivered in different voices and by different audio-visual means. Specially trained actors may be invited to record some programs.

4. In no way can any teacher control a student’s learning performance (9) and his level of concentration (10) as effectively as it is suggested in this design.

5. No human teacher can possibly make a decision about the selection of a lesson and means of its delivery using all the information from the learning profile of a student (3), feedback about his learning performance, and his level of concentration at the time of learning.

6. The most experienced teacher cannot accurately and consistently match the performance of a given student with several others of similar learning characteristics (4).

7. No one teacher can match the capabilities provided by the use of a computer in respect to motivation of the student. The reward or punishment of the student is based on the knowledge of his weak and strong points, interests, etc. (3). The arsenal of a computer in rewarding a student is practically unlimited, ranging, depending on student’s age, from giving him his favorite lollipop or showing the film and cartoons he likes most, to permission to participate in desired seminars or sport activities.

The high efficiency of learning provided by this teaching-learning process would allow students to increase their rate of learning several times. This is especially important for industrialized countries where the amount of information is increasing exponentially, while the educational process is using essentially the same method of class teaching that began many hundreds of years ago.

Naturally, we will need additional laws protecting the secrecy of information about the students. Every disclosure of such information would be severely punished.

V. Research and Development needed for Building a Prototype of the Automated Teaching-Learning Process

The teaching part of the design can be implemented after relatively small developmental work. Video cassettes for television sets, in black and white, are already commercially available. They can be used as the basic form of delivery of the lessons, supplemented by the existing sound-producing devices, film and slide projectors, and by logic circuits for establishing the required sequence of presentation of learning materials. Automatic loading of cassettes into television sets, and turning every piece of equipment on and off through computer controlled devices can be developed right now without too much difficulty.

The learning side of the design, however, requires a great deal of research. The monitoring of student’s level of concentration requires extensive basic research and development, since not much systematic work has been done in this field so far. There is already, though, good evidence as shown in several examples below that certain changes occur in the brain waves (shown on electroencephalograms) of a person during his or her learning. Bry and Daniel (1967) found that several parameters of alpha waves exhibited by students who received high grades in college are persistently different from those of students with low grades exposed to the same testing condition. Namely, the students with low grades were unable to completely suppress their alpha waves even during mental exercises.

Brain wave research done by Montor (1973) on two troops of cadets in the U.S. Naval Academy also indicated significant differences between low and high grade students with respect to their alpha waves when they were resting or involved in solving problems.

Khomskaia and Kabardov (1975), using ten normal subjects, found that substantial changes in synchronization between EEG waves recorded from different parts of the brain took place during the presentation and memorization of ten words.

Since eight percent of all people do not show any alpha waves, other waves such as beta waves on electroencephalograms should also be studied. Reading is one of the most important learning activities. Therefore the study of electrooculograms (EOG) recording the movement of student’s eyes during the process of reading should be very helpful characteristics of learning. Galvanic skin responses may also provide information about a student’s behavior during the process of learning, particularly about his concentration level. In addition, monitoring the movement of a student’s limbs while he is learning may provide information about his learning behavior. This can be done using the principle of electromagnetic induction or the change of capacity of the working place of the learner due to his movements. A student may train himself to raise his level of concentration when provided with feedback in the form of his EEG when his level of concentration is dropping.

This author is presently conducting research on monitoring the level of concentration of a learner by correlating his alpha wave activity, shown on an EEG, with his EOG. The recording of EEG and EOG is done on a 3-channel polygraph while the student is sitting in a soundproof, electrically and magnetically insulated booth of 8 x 8 x 6 feet using an electronically programmed teaching device. The purpose of the research is to be able to diagnose how well the student learned a particular piece of material, just by looking at his EEG and EOG during the time he was learning, and verify the diagnosis by asking questions about this material. The
major problem so far is to identify particular characteristics of brain waves which could serve as indicators of certain learning states of a given student, and to automate the process of identification of these states using inexpensive technical devices linked to a computer.

The monitoring of the learning performance of the student is another field where a great deal of basic and applied research is needed, although at the beginning the already developed electronic devices for checking a student's performance could be used. More research should be conducted to provide for an easier communication between the student, the television screen and the computer.

A special field of research should be that on the learning profile. What is the minimum information about a student which is sufficient for designing his curriculum and for checking the efficiency and effectiveness of his learning? How should one code this information so that the deviation of the anticipated pattern of behavior from the actual one will be easily used for decision making about the selection of the next lesson? Such questions can be answered only after some research is done with a prototype.

Simultaneously with research and development on this design, the solution of the problem of manpower should be started. Indeed, a totally new blend of educational professions will be needed. School and college administrators, educators, curriculum specialists and instructors should be trained in the technological aspects of the suggested design so that they can meaningfully conduct an automated teaching-learning process.

VI. The Problems of Automation

The cost of automation and of the creation of National Educational Network, and its maintenance, cannot be estimated now. The first reliable estimates could be made only after the prototype of a completely automated system is built and tested under various conditions. The advantages of the automation as listed in section IV should outweigh the risks involved in costly research and development of the prototype. Whatever the cost of automation of the whole educational enterprise, it would, once accomplished, pay off better than any other investment, since this is an investment in the development of the mind. Besides a vastly increased rate of learning, it may actually mean large savings, for the present curriculum of a 4-year college could be learned in one year. It should become a project of all industrialized countries since all of them urgently need and will strongly benefit from a much more effective and efficient teaching-learning process.

The automation of the teaching-learning process, one of the most complex processes in our society, will most probably bring with it "fall-out" in the form of automation of a great number of services from household cooking, supermarkets and restaurants to medical diagnostics and care and librarian services. The thousands of computer terminals in learning institutions, during the time that they are not used by the regular students, may be used by other people for continuing their education, since the education of individuals in a society of constantly increasing complexity should be a lifelong process. Finally the terminals can serve as a communication link between the citizens and the government at all levels, supplying the government with a tremendous amount of feedback information needed for political and economic decision-making.

The problem of unemployment due to mass scale substitution of living instructors by automated systems could be dangerous for the society. However, the development of a prototype of the automated teaching-learning system needed for this process and its practical implementation on a mass scale would take many years, which would make the transition with a minimum hardship, assuming the work on automation will start right now. Besides, many creative instructors will be needed for preparing new and revising old learning material, conducting seminars, setting and revising a student's curriculum and occasionally monitoring the work of some students. Presently, among the representatives of creative professions such as composers, entertainers or writers, only the work of outstanding teachers remains unrecorded; without a material trace. Due to automation, their creative work will be made available to millions.

A comparison of a traditional teaching-learning process and an automated one should dispel all fears of "dehumanization" expressed by those who reject technological involvement in education. It is the automated teaching-learning process which treats the student as an individual and provides him with the type of teaching which best develops his unique potentials.

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Proceedings of the Symposium
"Toward the Human Use of Human Beings: A Cybernetic Approach to Assessment of Children"
held at the 143rd Annual Meeting of the American Association for the Advancement of Science in Denver, Colorado; February, 1977

Introduction to the Papers
Presented at the Symposium

Frank Baker
SUNY at Buffalo
Buffalo, NY 14214

The articles published below are based on presentations originally delivered at the 143rd Annual Meeting of the American Association for the Advancement of Science (AAAS), Denver, Colorado, February 23, 1977. I was privileged to preside at the symposium which had been arranged by Dr. Mark N. Ozer, and the papers which follow derive from this symposium’s exploration of the cybernetic issues of control and feedback information as they relate to the human interaction involved in the assessment of children.

In recent years, the behavioral sciences have turned increasingly to general systems theory as a source for major theoretical development. One would expect that cybernetic theory, which has been so important in the development of general systems that some people have almost equated the two, would have had more impact on social psychological models. Although certainly cybernetic theory has had an impact in modeling human cognition and learning, some have balked at extensively applying cybernetic concepts in the analysis of human interaction because of an identification of cybernetics with the language of machines.

While the identification of cybernetics as principally applicable to mechanistic engineering problems and tending to focus on the interaction between people and machines has interfered with more extensive applications of cybernetics by behavioral scientists, recognition of the usefulness of control and regulation in understanding the communication and information flow in complex social systems continues to offer the tools for attacking difficult problems which have not been adequately dealt with previously. The papers presented at this Symposium deal with such a problem, i.e., the assessment of children. In recent years, psychological assessment has come under attack from a number of quarters. While the details of the debate are quite complex, one of the essential themes underlying much of the controversy is that the testing situation places the individual being examined in an essentially powerless and passive role. The examiner determines the question and also the right answer. The capacity of the individual being assessed to develop an answer is not examined. The process is essentially static and most testing situations are limited in terms of their adequacy to assess an individual’s capacity for development. As the papers that follow attempt to show, cybernetic concepts offer a means for developing new models of the assessment interaction providing a sharing of control and stimulating child development in the process of assessing it.

Over a decade-and-a-half ago Wiener called for interdisciplinary studies of human behavior, an effort which continues to provide a challenge to a growing group of scientists from various disciplines concerned with human problems and interested in the practical applications of cybernetic concepts. The participants in the symposium also come from a variety of disciplines. They offer what follows in the hope that this will add in some small way to the movement to apply cybernetics in encouraging the human use of human beings.

The traditional view of the assessment process has treated the individual being tested as someone who is manipulated by the examiner. The power relationship is such that the person being examined is viewed as essentially powerless while the examiner is viewed as requiring complete control over the testing situation.

Applying a cybernetic approach to assessment offers a model for the revision of the power relationship. Effects of the process of examination on the person being assessed become important aspects of what the assessor examines. In order to sample the process of child development, the examiner must now stimulate it. According to this view the individual being assessed must become aware of some reciprocal effect upon the examiner as a stimulation of what happens in the natural process of growth and development. Assessment is viewed as more nearly an interactive process between the individuals involved.

No longer is the person being examined merely subject to the examiner. It becomes possible to make such reciprocal effects explicit by providing feedback as to the value of the input provided to the interaction. Feedback regarding the reciprocity of the relationship is the crucial parameter that distinguishes the human use of cybernetic concepts.

Even rather young children can be viewed as actively par-
participating in such reciprocal interaction. For a long time
those who described social development in infants viewed
them as essentially passive recipients of social stimulation
and as having significant relationships only with their
mothers. Recent research has revised this view and infants
have been shown to participate actively in interaction with
their mothers and also with their fathers and siblings.

The first paper by Tronick and Brazelton focuses on the
joint regulation of infant-adult interaction and explores two
person face-to-face interaction for the analysis of communica-
tion between mothers and small infants. Employing a pro-
cedure which involves videotaping an infant in interaction
with its mother, these authors analyze mother-infant inter-
action. Their findings indicate that the adult interactant,
being more able to modify her configuration of temporal,
performatory, and processing characteristics, is able to co-
ordinate them with the features of the infant's configura-
tions. When such modifications do not take place, rather
than a stable coordination, disjointedness may result. Apply-
ing this research to the assessment of newborn behavior,
they find that such an assessment, in order to be success-
ful in eliciting the best behaviors of the neonate, must con-
sider the sharing of control and feedback and the infant's
adaptedness to a communicative system.

In the second paper, Mark Ozer presents an interactive
method for assessment of children with developmental diffi-
culties. In this procedure feedback is provided by the adult,
not only on the degree to which a specific task has been
accomplished, but also regarding the process by which the
task was accomplished. The informational feedback pro-
vided allows the child to gain the means by which a larger
group of tasks may be accomplished. Dr. Ozer describes
his procedure for sharing of control and information as con-
tributing to the enhancement of the process of development
of the child.

Sigel and Cocking in the next paper propose a feedback
model for assessing intellectual functioning in children.
Rather than using the conventional methods of mental abil-
ity testing in which the same test and same procedure are
used for everyone alike, they suggest the use of a clinical
method of assessment based on the model of intelligence
proposed by Piaget. This procedure employs an interview to
provide feedback for both the child and the examiner and
thereby provides an opportunity to identify not only what the
child knows but also how the child arrives at solution of
problems.

In the fourth paper, Bernard Brown discusses cybernetic
testing as a broad, new paradigm for psychological tests.
He suggests that cybernetic tests would have a number of
advantages over traditional testing methods and while they
would not replace standardized tests, they could provide a
compliment to these traditional tests. Specific examples of
cybernetic tests are presented as well as a discussion of the
philosophy and values which underly traditional tests. The
old testing paradigm as contrasted with the cybernetic
model is shown to place more restrictions on children and
how they think and act. A cybernetic test is described as
allowing some greater freedom in communication and pro-
moting a psychology of interaction and a theory which not
only accommodates change but which also provides for
greater equality in relation to culture, race, sex, and age.

In the final paper, William T. Powers provides a broad
overview of cybernetics and the assessment of children. He
finds that the picture which derives from control theory
comes surprisingly close to the picture derived by Piaget
from direct study of child development. First considering a
fully-organized adult organism, Powers shows that the child
is not able to perceive variables which the adult can and that
it is necessary for the adult to arrange the local environment
to help the child connect perceptual consequences of
behavior. He points out that similarities among disturbing
events are not what result in similar actions, but rather that
different disturbing events affect the same
task was accomplished. The informational feedback pro-
vided allows the child to gain the means by which a larger
group of tasks may be accomplished. Dr. Ozer describes
his procedure for sharing of control and information as con-
tributing to the enhancement of the process of development
of the child.

In summary, the papers which follow demonstrate that a
cybernetic approach to the assessment of children can pro-
provide a useful way to stimulate new insights into the human
interaction which takes place in such assessment. Apply-
ing cybernetic concepts to the analysis of the assessment
process suggests basic revisions which should take place in
how children are examined regarding their development.
Furthermore, it is evident that such a perspective has strong
potential for pointing the way to further useful and exciting
research which should be undertaken into human nature.
The dependency of the human newborn on nurturing "others" to help him adjust to his new environment (Sander et al., 1975) has led us in the past to view him as helpless, chaotic. More recently, we have been impressed with the richness of his behavioral repertoire at birth which provides him with the capacity to elicit appropriate responses from his environment and to regulate the timing of these responses from a nurturing caregiver. The communicative system with which the newborn infant is provided and which insures reciprocal interaction with the adults around him has become the focus for our studies. For, within this social interaction he seems to learn to regulate his physiological systems as well as his neurological and behavioral responses. Thus, his capacity to elicit and to regulate environmental input ensures his survival and provides the base for his future development. It is via the system of reciprocal social interactions between caregivers and young infants that the infant has an opportunity to establish his own base for affective and cognitive acquisition, and to establish an identification with culture, family and other individuals. Our objective has been to characterize the structure of this reciprocal system—its predictable patterns, its rhythm and its behavioral components (Brazelton, et al., 1975; Tronick, et al., 1979).

We have chosen face-to-face interaction as our system for analyzing the communications between mothers, fathers, and small infants. This system places each of the participants under the greatest demands for communication. Our studies indicate that it is, in fact, a reciprocally organized system in which each partner in a dyadic communication makes skilful adjustments in response to the displays of his partner.

The task for two communicants is for each to understand the message carrying displays of the other and to modify his responses accordingly in order to respond to his partner’s expressed goals while fulfilling his own goals. This demands a kind of sensitivity and intersubjectivity which is at the base of reciprocity. Our goals have been to examine the infant’s capacity to respond to his partner’s actions, to describe the process of mutual regulation and to describe how control is shared in an interaction.

Procedure

Our laboratory is set up for videotaping an infant and other using two cameras with a split screen image which is time locked through a digital timer onto a single video tape recorder. Figure 1 presents a schematic of the laboratory with its two cameras, infant seat, and mother’s seat. The infant is placed in the seat and the mother comes from behind the table to seat herself in front of him order to play with him for one to three minutes of interaction. She then leaves for 30 seconds and returns to perform another condition from a prearranged counterbalanced order.

The recorded image looks somewhat like the schematic figure in Figure 2: the infant on one side of the screen, mother on the other and the digital time display across the

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bottom. From this recording we categorize the infant's direction of gaze, vocalizations, smiles, head and body position. For the mother we categorize facial expression, vocalizations, head and body position and hand movements. The tape is scored by two trained observers over one second time intervals as the tape runs at 1/7th normal speed. Reliability on each category is above .85.

The Infant's Reaction to Feedback Distortion:

To examine the extent to which the infant modifies his behaviors in response to his partner's actions, we asked the mother to remain still faced in front of her infant for one minute (Tronick et al, 1978). The interaction is between a 74 day old infant and his mother. Let me first briefly describe one period of their normal interaction. It presents a typical sequence of initiation and mutual orientation, greetings and play dialogues. Initially the infant is looking off but mutual orientation is quickly established followed by two greetings with big smiles by mother and infant. A play dialogue ensues with the mother making a burst-pause manner and the infant vocalizing during the pauses. This reciprocity is characteristic of successful interaction. About 50 seconds into the interaction a disengagement occurs with the mother looking at the infant's feet and the infant looking away. But this disengagement seems to activate the infant and a play dialogue follows until the mother leaves.

Now let me describe the same infant when his mother is still faced. The change is dramatic. There are initial greetings but they are not followed by play dialogues but rather by a sobering and growing waryness by the infant. Again as the mother enters the infant is looking off. Mutual orientation is quickly established. A greeting occurs, a second one follows but it appears cut short. The infant sober's and his movements are jerky and non-rhythmic. He reaches out toward her. Then he stares at her and with a sigh turns away. When he looks back he falls forward. His mother supports him but he remains sober. He then turns his head away from her but still looks toward her with a sober face. Again with jerky movements, he turns full side away. He comes back with two foreshortened eliciting smiles, his head partly off the midline. When there is no response his arms move jerkily and he soberly continues to watch her.

The differential responses made in the still face condition and the normal mutually regulated face-to-face interaction support our conceptualization that the infant modifies his own communicative displays in response to the feedback provided by his partner. If the system is violated by a partner's non-reciprocity the infant will respond in an appropriate manner in an attempt to get the interaction back on track. In the still face condition the mother's expressive displays and en face position is initiating and setting the stage for interaction, but her subsequent lack of response indicates a disengagement or withdrawal. The infant is trapped in a contradiction; he initiates and greets, but then turns away, only to attempt to initiate a response from her again. Clearly he detects and responds to this distortion of the normal feedback in the interaction and his final withdrawal indicates some of the limits of his capacities.

The Mutual Regulation of Attention and Affectivity:

In order to describe the process of mutual regulation of interactions we scaled on an a priori basis the expressive behaviors of each communicant to reflect the degree of their attentional and affective involvement in the interaction. The scaled scores for the infant and adult are then compared to each other in order to describe the form of the regulation taking place in the interaction.

The scaling of affective and attentional involvement is straightforward. For example, when the mother gazes intently at her baby we know she is more positively involved in the interaction than when she looks off to one side for a prolonged period. When the infant smiles we infer that he is in a more positive affective state then when he frowns and arches his body and looks away from the adult. The scaling of these displays is based on our observations of interactions and is founded on the knowledge which we share with our subjects as members of the same species. The process is guided by Darwin's (1872) principle of antithesis: that opposite emotional states are expressed by displays that are opposite in form. Accordingly, positive involvement is expressed by upright straight-on postures while negative feelings are expressed by slumping and turning away.

The descriptors within each behavioral modality are evaluated on scales which specify their expressive connotation from the extreme of negative involvement to the extreme of maximum positive involvement. The most negative display of attention and affectivity are assigned a rank of 1, the neutral point a rank of 5 and the most positive displays a rank of 9. Table 1 presents examples of infant and mother behavioral descriptors assigned to the end and mid ranks of each behavioral modality scale. Table 1 illustrates the procedure, but it is not the Manual which contains a set of several hundred statements used to specify the rank of each possible behavioral descriptor based on its affective quality and duration. The following are descriptions of two interactions which we analyzed for the joint regulation of interaction:

Figure 2: Schematic drawing of split screen video image of infant and adult engaged in face to face interaction.
| Table 1 — Scales for Infant and Mother Behavioral Modalities |
|-----------------------------|-----------------------------|-----------------------------|
| Name                        | negative extreme (1)        | neutral point (5)            | positive extreme (9)          |
| Infant vocalization         | crying                      | no defined neutral          | gurgling and laughs          |
| Infant direction of visual  | prolonged look away         | interrupted looking         | concentrating on mother      |
| attention                   | with head complete side and eyes directed away | with a glance of 3 to 10 seconds duration and head either toward or part side | with a towards look of 10 or more seconds with head aligned towards |
| Infant facial expression    | cry face with eyes narrow or closed, mouth opened with tongue exposed, contraction of eye orbits, eyebrows oblique | neutral expression with eyes normal width, mouth slightly open or tightly closed, no tension evidenced in cheeks, eye orbits or brows | broad smile with mouth opened in broad smile, cheeks elevated, eyes neutral to closed, eye brows flattened |
| Infant body position and    | leaning forward and doubled over, head either down by legs or off to one side with only crown exposed to mother | neutral and relaxed with body resting in upright position against molded cushions in chair, body vertical axis in mid line | leaning forward with back straight with 45° angle between legs and trunk |
| movement                    | very large sustained movement of limbs (see text) | no or little self-generated movement with at most one or two limbs moving in small arches for less than 3 seconds | very large sustained movements of limbs (see text) |
| Infant limb movement        | abrupt angry shout          | little or no vocalization for a relatively brief (less than 10 second) period or narration with some evidence of "baby talk" adjustments but with no sustained rhythmic pattern | burst of sound that seems to "peak" over rest of burst-pause pattern must be a major shift of modulation and pitch |
| Mother vocalization         | abrupt handling of infant involving a sudden large shift in his body position | no movement or display of hands | Intense movements on infant body or face with sustained emphatic rapid rhythm, e.g., stroking of face; tickling |
| Mother (hand) movements     | angry face with eyebrows oblique and draw downward, lips tense and extended laterally | bright face with eyes normal width, mouth neutral, eyebrows neutral, cheeks elevated, little movement or animation of facial features | fully animated face with maximal display of at least one facial feature, e.g., broad full smile, "superlook" imitation of infant’s face, "coo" face |
| Mother direction of visual  | gaze directed completely away from infant for more than six seconds | away glances of less than 3 seconds directed completely off infant’s face or body | no defined positive extreme rank 7 = looking at Infant for 7 or more seconds |
| attention                   | not visible to infant       | frontal (towards) infant with no movement | nuzzling infant with head touching infant |
| Mother head movement and    | neutral sitting posture with trunk leaning slightly forward stand still | movement forward and resulting posture of trunk leaning forward and head very close |
| position                    |                             |                             |                             |
| Mother body position and    |                             |                             |                             |
| movement                    |                             |                             |                             |
Interaction I, an 86 day old girl:

The baby is sitting quietly in the chair. She is looking away from her mother with her chin tucked and her head turned partially away. She appears guarded. The mother enters with a smile and repeats "Hi! Hi!" in a tense high pitched voice aimed at capturing the baby's attention. Then she holds the baby with both hands and with rhythmic light hand movements attempts to get the baby to orient towards her. The baby remains turned away during these maneuvers. The mother continues in her efforts but her voice becomes tenser, and as she lets go of the infant her face becomes sober. The baby's face sober, and she remains averted. The mother begins to talk to the baby in an adult like fashion. Some of the tenseness diminishes as her voice gets lower and softer, but it lacks modulation and excitement. She again holds the baby and smiles tentatively while shifting her body from side to side in an attempt to capture the baby's gaze. But the baby remains turned away with a neutral face. The mother stops talking. Her face lacks animation. At this point the baby looks toward the mother although still partially slumped. The mother's face brightens and she is now talking softly. The baby turns away but then looks back at her mother at first with a grimace which slowly becomes brighter. Her arms and legs cycle excitedly toward the mother. The mother moves in closer to the infant, talking softly with a bright facial expression. The baby smiles, sits upright and moves arms and legs in large smooth arcs. The mother starts talking in a modulated baby-talk manner while gently holding the baby. The baby subsides and looks away while the mother continues to maintain the contact with talking and touching. The baby does look back briefly but then turns away again and slumps into the chair. The mother is unable to recapture her attention for the remainder of the interaction.

Interaction II, an 82 day old boy:

From the second of entry of the mother into the infant's field of vision they are looking and smiling at each other. They keep looking at each other but their smiles become more neutral, but this brief decrease is followed by second smiles. A third cycle down to neutral and up to smiling follows. With each smile the baby moves arms and legs excitedly and then stills as he becomes more neutral. The mother moves in closer as she smiles and then away as he becomes more neutral. Following the third cycle the infant vocalizes for two seconds, pauses, then vocalizes again. His face is bright and he keeps looking at the mother. She too keeps looking at him. Her face is bright and she vocalizes in a burst-pause pattern that becomes more and more modulated as he keeps on vocalizing. She is gently holding the baby throughout this period. The infant then stops vocalizing and looks away but his head remains or oriented towards her and he keeps on sitting in an upright position. Initially his face is neutral but then it becomes briefly sober. The mother also becomes more neutral. Her voice loses the highly modulated burst-pause quality and she looks away from his face to his body. They then begin again the cycle of looking at each other, vocalizing and smiling. This "conversation" characterizes the remainder of the interaction.

To evaluate the extent to which mutual regulation occurred in these interactions we assessed the relationship of the affective and attentional involvement of each mother-infant pair. To do this we summed the ranks of the behaviors of the mother and infant. The mothers summed scale score was made up by adding together the ranks of six of her behavioral modalities: facial expression, head position, body position, hand movements and vocalization. The lowest scaled sum score is 6, indicating complete disengagement. The highest scaled sum score is 54, indicating complete excited engagement, and the neutral score is 30. The infant's summer scale score was made up by adding together the ranks of four behavioral modalities: facial expression, visual attention, body position and vocalization. Each of these has a range of 1 to 9. Also, amount of movement with a range of +4 to —4 was used in the sum score. It was added to the sum score when the infant's facial expression was positive and subtracted when the infant's facial expression was negative. Thus the infant's maximum scaled sum score is 40, indicating complete excited engagement. The infant's lowest scaled sum is 0, indicating a crying disengagement, and his neutral score is 20.

The sum scores for each mother-infant pair are graphed in Figure 3. These graphs indicate the flow of the affective and attentional involvement of each communicant.

Visual examination of the graphs shows both similarities and unique qualities. Clearly there is a discrepancy in the affective levels of involvement of the mother and infant in Interaction I as contrasted to Interaction II. But for both interactions there are increasing and decreasing cycles of affective involvement. There is a waxing and waning from negative to positive levels and it appears that there are limits on the duration of either very positive or very negative states. There are periods of time in which the partners seem to be moving in the same affective direction, i.e. times starting at a and g in Interaction I and times starting at k, m, and n in Interaction II, and periods in which the partners are moving in opposite directions, i.e. times starting at c and b in Interaction I and the time starting at j in Interaction II. The cyclic quality of these affective cycles, the directionality...
of the affect and its temporal characteristics all suggest a homeostatic system that maintains the level of affective involvement of each partner within certain limits.

From second to second the form of the mutual regulation is specified by the relationship between the infant’s (I) and mother’s (M) increasing involvement (+), decreasing involvement (−), or non-changing involvement (o) as measured by the scaled sum scores. There are nine possible combinations that can be reduced to changes that are Conjoint (I + M +, I−M−, IoMo) as regards affective change, Disjoint (I + M−, I−M +) in affective direction, Infant Leads (I + Mo, I−Mo) and Maternal Leads (IoM + , IoM−).

Figure 4 demonstrates that the proportion of different kinds of simultaneous affective changes was different between the two interactions. In Interaction I there is a relatively even sharing of leads between the infant and mother. A large proportion of time was spent moving in a conjoint affective direction and only a small proportion of changes were disjoint. In Interaction II the mother makes the greater proportion of leads. Almost half the time is spent moving conjointly and only a small proportion is disjoint. These differences in the proportions between the two interactions reflect individual differences in the regulatory aspects of the two interactions. These conjoint changes in affective flow make up the larger cycles of acceleration and deceleration between positive and negative affective states. They reflect the second by second regulatory “decisions” being made by each partner.

The Sharing of Control:

a. Who Leads and Who Follows

To determine how control was shared in the interaction we examined what an unchanging partner did in the second immediately following (t + 1) the occurrence of a partner’s change in affectivity. The partner could follow, i.e. change in the same affective direction at t + 1 as was his partner’s change at t = 0, or Miss, i.e. not change at all at t + 1 even though his partner changed at t = 0.

Figure 5 summarizes the data for the mother’s changes at t + 1 given the events I + Mo or I−Mo at t = 0. In Interaction I the mother Misses a large proportion of infant changes and Diverges more than she Follows. In interaction II the mother Follows her infant’s lead most of the time and Misses more than she diverges. Figure 6 presents the same analysis for the infants, i.e. the infant’s change at t + 1 given the events IoM+ or IoM− at t = 0. For both infants the proportions are relatively similar. Misses are most common with Follows and Diverges relatively equal. If anyone Follows it appears to be the mother.
The Sharing of Control:

b. Who Adjusts?

The lag analysis can be applied to the Disjoint events $(I + M, I - M +)$ at $t = 0$, i.e. what does a partner do at $t + 1$ given that he/she was moving in a different affective direction than their partner at $t = 0$. Figure 7 presents the data for the mothers of each interaction. Similarly to the

![Diagram](image)

**Figure 7**: The mother's response to disjoint changes in affectivity, i.e. her change in affectivity in the second following the joint event $I + M$ or the event $I - M +$.

data for leads the mother in interaction I shows a small proportion of Follows while the mother in interaction II shows a large proportion of Follows. Figure 8 presents the same analysis on the infants. The infant in interaction I Follows more

![Diagram](image)

**Figure 8**: The infant's response to disjoint changes in affectivity, i.e. his/her change in affectivity in the second following the joint event $I + M$ or $I - M +$.

than the infant in interaction II and both show a high proportion of Divergences and Misses. Again, as with the Leads, if anyone is likely to Follow, it will be the mother.

### Discussion

The narrative descriptions of each interaction and the different analyses applied to them present a detailed picture of the regulatory qualities of each interaction. Interaction I is characterized by a large discrepancy in the attentional and affective level of mother and infant. This quality is captured in both the narrative and the graphs of the scaled sum scores. The analysis of simultaneous changes in affect showed a large proportion of shared leads and a low proportion of disjoint events. The lag analysis resulted in a low proportion of Follows and a high proportion of Divergences and Misses by the mother, with some change in the infant's performance.

The regulatory qualities of interaction I were different. As evidenced in the narratives and scaled sum scores, there was little discrepancy in the affective level of mother and infant. There was a large proportion of conjoint affective movement with the mother enacting the greater proportion of leads. The lag analysis showed that the mother followed the infant's lead a large proportion of time and diverged or missed with a low frequency. The infant showed little change in the lag analysis.

For us these differences express individual differences in the regulatory qualities of the interaction. These differences may arise out of a difference in goals in the two interactions. Interaction I may be regulated toward the establishment of a mutually of control while interaction II is regulated toward the following of the infant's lead. These differences may be produced by the differences in the individual characteristics of the infants and mothers in each interaction as they mesh together. Either goal may be "good" and most likely will result in different outcomes during an interaction.

There is a great need to establish ways of assessing mother (caretaker)-infant harmony given that the infant's development takes place within this context. We think that these kinds of micro-analyses will be useful in producing assessments of maternal sensitivity, interactive synchrony, and how they affect the infant's development of autonomy.

The lag analysis indicates that in mother-infant interaction the greater proportion of adjustments in behavior are produced by the mother. The infant does not appear to follow and adjust although he is able to do so is evidenced in the still face experiment. This produces a paradoxical situation in which the mother, because of her ability to regulate her behavior, has to give up a large measure of control to the infant and follow his lead. But who is in control, infant or mother?

A way out of this paradox is to regard the interaction as a system. The interactants, adult and infant, because of different levels of development, have different configurations of temporal, performatory and processing characteristics. The qualities of the interaction are determined by the extent to which those configurations can be coordinated. In this case the adult, the more developed participant is more able to modify those configurations to coordinate them with the features of their partner's configurations. This results in stable coordinations. When such modifications do not take place instability or disjointedness results. The mother in
interaction II follows her infant's changes more than the mother in interaction I. The infants look relatively similar. There are clear differences in the stability of these interactions but only long term observation will show if those qualities characterize the features of their relationship.

The one second lag analysis is an indication of the temporal constant for the processing of information and reaction to it that is operating in the system, especially for the adult. The temporal lag may be different for the infant and we are investigating other possibilities. We have noticed that adults, in interacting with the infant, slow down their normal rate of behavioral change and also exaggerate their actions. These adjustments indicate an implicit knowledge of the infant's processing and performatory limitations. Furthermore, we think that these temporal characteristics will show individual differences and genetic/cultural differences as well. Thus there is nothing universal about a one second lag but rather that different temporal constraints or constants are operating for individuals of different developmental, genetic and cultural backgrounds and that the interactants have to modify their configurations to produce appropriate interactions.

In doing the lag analysis we used the scaled sum scores. Those summed scores reflect the affective intention of a communication and are made up of clusters of behavior. When we have tried to relate single expressive behaviors to other single behaviors, such as smiles to smiles, either at the same time or with lags we have found little or no relationship between them. Thus we think that information is exchanged between two communicants. That the information is carried by a set of substitutable clusters of behaviors, and that single behaviors that would fit into stimulus response formulations are inappropriate.

These views of control sharing and feedback and of the infant's adaptedness to a communicative system have strong implications for the assessment of infant behavior. In developing an assessment of newborn behavior we have found that for such an assessment to be successful in eliciting the best behaviors of the neonate it must be viewed as an interactive, reciprocal process. Successful assessment is similar to successful interaction and requires a sharing of control. Thus an assessment of an infant's capabilities cannot be separated from his reciprocal reactions to the behavior of his partner.

This means that the infant is always being assessed in a context, be it alone in an infant seat or face to face with another person. There is no such thing as a neutral environment. The infant is always interacting with it. Second, assessments can only be performed when the infant is ready and when the environment is ready to follow the infant's signals. The infant cannot be made to do anything. As capable as he is, he is not yet capable of that kind of following. Thus in our Neonatal Assessment we speak of optimal administration which translates to mean that the examiner performs events only at times when the infant signals his readiness. Finally, because of the necessity of the social environment to the infant's development and his adaptedness to that environment the assessment of his ability to interact with other persons will most likely provide the most information about his capacities.

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The Interactive Assessment: A Process of Child Development

Mark N. Ozer
George Washington School of Medicine
Washington, D.C. 20008

The assessment of the child with developmental difficulties must reflect more clearly the goals of such assessments. The goal is to determine how to enhance such development. The question I wish to address is how the assessment procedures may not only sample the process of development but, in so doing, help to enhance it.

The data derived from the developmental assessment has traditionally focused on what the child is able to do. This data has, in most if not all instances, been concerned with the categorization of underlying traits of various sorts. Attempts have been made to look for causes for the child’s functional difficulties in terms of faculties such as short term memory, auditory verbal association, etc. Where those such as Piaget have emphasized the progression of development, they have nevertheless focused on the levels of organization that have been reached. In a recent critique of Piagetian theories of cognitive development, Riegel (1976), points out that such stages or states of equilibria are assumed to be the natural state. “The child’s development [is seen] as a succession of plateaus at which the operational and cognitive structures are in balance...[L]ittle attention is given to the question of how transitions are initiated and executed.” Yet it is the process of growth that is the ultimate concern of the assessment. How can data be derived concerning the process of change as well as of the various equilibria reached?

The content derived from the developmental assessment is but one aspect. A complementary concern is how such assessments are carried out. Assessments of brain function have traditionally been done within the constraints established by the British neurologist Hughlings Jackson. His description of the brain as “a sensory-motor machine” was a deliberate attempt to treat phenomena materialistically in order to study disease of the nervous system. “States of mind” were to be distinguished from states of the nervous system. The two occur together but there was to be no interference of one with the other (Englehardt, 1975). A mind-body parallelism was explicitly set up. The examination procedures were based upon the premise that one could measure objective functions in an objective fashion. Neither the state of mind of the subject or the examiner need interfere with this activity. All expressions that imply interaction between mind and body he called scientific blasphemy.

Nevertheless, it has long been understood that the reflex arc is inadequate even as a hypothetical construct to explain the function of a living organism. Reflex action at any one point in time and place is the outcome of that point with the remainder of the organism and its history. “Each reflex must be considered the functional expression not of a single level, but of the whole...[and] according to a given situation, the past and future of the organism” (Sherrington, 1906). The application of these principles to the examination procedures is exemplified by the work of Bender and associates (1952,1955). They emphasized the effects of concurrent stimulation and level of consciousness in the performance of the subject. Weinstein (1966) further emphasized the social context of the examination in terms of the past experiences of the subject and the content of the questions in the assessment of brain injuries. These examination procedures focused on the opportunity for change in the behavior of the subject when one changed the conditions. The organism was viewed no longer by the reflex model alone but as a more nearly integrated whole at least in terms of the potential for growth.

The examiner is at least being made aware that the subject’s behavior may vary and is an active participant in the process. The subject however remains that. The functions one may be measuring were no longer considered fixed and objective but the individual remained an object to be manipulated. Another parameter must be introduced if one were to reflect a more accurate model of the nervous system. We do not believe reflex action to be the true model of the dynamics of the organism, “Unless...[it is] the outcome of the activity of the whole...and not of one of its fragments...and a functional instrument for self-preservation and self-realization” (Reiss, 1950). The additional parameter is that the individual must also become aware and that the examination become an interaction or dialogue. To the degree to which one wishes to sample the process of development one must actually simulate it. To the degree to which one wishes to simulate the process of development one must stimulate it as well. The child must not only be seen to change by virtue of the examination but the child must also see himself to have changed. The process by which this mutual awareness arises is one in which each becomes aware of how one is making change in the other. One learns about oneself by seeing that the other learns from you. One learns about oneself by seeing that you are teaching the other.
The Child Developmental Observation (CDO)

A 15 minute protocol has been designed as a model for the interactive examination of children with developmental problems. The title, Child Development Observation, reflects the fact that development goes on during the course of the interaction and that such development is observed by those involved. Indeed the product of the interaction is awareness of what occurred. The examiner and the child carry out a task in which the child is to learn something. That thing is relatively unimportant. Prototype tasks drawn from a test battery may be used or more usefully a task drawn from some real life concern such as writing his name or tying laces etc. The successful accomplishment of the task is but a context. A more relevant objective is the learning of how one did so. The examiner provides a number of alternative strategies by which one may vary the situation in terms of both input and feedback conditions. As an example, one may vary the channels of input, the time provided or the degree of the salience of the stimuli. Within each category, there are a number of options that may be specified. For example, one may vary the channel of input in terms of vision, hearing, touch, movement or combinations of such. One may vary the time frame in terms of repetition, segmenting the task of instructions, shortening the duration to completion, etc. One may vary the salience of the stimuli by reducing the number of competing stimuli or enhancing the intensity of the stimulus directly, etc.

The character of any particular interaction will vary in terms of the number of strategies offered and will of course vary somewhat in terms of the requirements of the task used as the context. With some children, the objective might be for the child to be aware of but one such strategy. One may also specify the level of awareness. The lowest degree of participation is for the child to agree non-verbally or by saying "yes" to the use of a strategy such as being shown what he is to do. The next level of awareness and participation is for the child to repeat in an echoic fashion what is to be done. He repeats "show me!" after having been told that idea. Another level of participation and awareness is to state the idea "show me" or "let me see it" freely on his own. With some children, the objective of the interaction might be for the child to state one strategy at a free level. The communication system obviously may also vary and is not necessarily one of oral communication but has been manual with deaf children (Gawlick, McAleer & Ozer, in press).

As an example, a four year old child in a Head Start program is to learn how to use his belt to hold up his trousers. The task was selected because it was a concern of the child's teacher and parent. It was considered useful for him to look at the belt as he fastened it and that was the strategy that was to be emphasized. The child "agreed" to the task and "agreed" to the idea of being shown by nodding. The adult commented on the agreement as follows: "Thank you for agreeing to look!" and then showed the boy how to do it. He did a portion of the task and did put his hand approximately where he had been shown. The adult commented "You got the belt buckled part way. Would it be O.K. if I showed you again? Can you say 'Show me'!" This time the child was able to repeat the statement. The adult now commented "Thank you for saying 'Show me so you can see it with your eyes'! The child now looked for more than a fleeting glance and the adult showed him how to do it. He again was only partially successful with the belt buckle but more nearly so than before. The adult again commented on the portion he had done and also stated that you seemed to do better when you asked me to show you and you looked. "What would work?" asked the adult. "What worked before, what did you say to me before?" The child was now able to freely say "Show me!". The adult now commented again on the idea mentioned by the child and the level of participation achieved: "Thank you for telling me to show you so that you can see it. That was a good idea you had". The child now looked for a longer time and indeed was able to get the belt buckled. "What did you tell me that worked for you?" asked the adult. The child now again is able to freely express the idea of looking. He is asked to draw the eyes on a picture and take it with him to his desk. He is asked to rehearse the idea by telling it to his teacher who is present or his mother or both. They are instructed to respond to his idea and a plan is made for him to use that statement at least once a day with each.

The issue here is not only that the child learns something; it is that he learns something about himself. The specific idea used of looking of course does have some relevance to other situations but is merely a case in point. Indeed he did begin to look. It was however in the context of his asking to see it and not when he merely agreed to be shown. It was he telling the adult that he wished to see it and the response of the adult indicating that he was heard that permitted the boy to tell himself to look. The adult served as a means of helping the child to become more aware of the idea. It was his awareness as exemplified by the degree of participation that began to make the statement operational for him.

Discussion

Feedback is provided by the adult initially of the degree to which the context task has been accomplished. Such feedback as to results (FR) is necessary but not sufficient. The crucial feedback is not of the specific behavior accomplished. The numbers of potential behaviors that are to be accomplished in the life of the child are very large. The crucial feedback is of the process by which the task was accomplished. Such informational feedback (FI) provides the child with more specific and more manageable means by which the larger number of tasks may be accomplished and over the longer periods of time that the life of the child may encompass (Land, 1973). The more specific the idea used, the more likely it is that the idea could be used to affect one's environment. The more specific the idea used, the more likely it could then be used to affect oneself as well. The term "let me see it" has the potential of being used to control one's own behavior as well as that of another.

The additional parameter which this model of the developmental process includes is the level of participation and thus awareness that the child provides vis a vis the adult. Feed-
back is provided as to the degree of participation (FP). Such participation is modeled here in terms of language. Luria (1971) has emphasized the value of language as one means of representing experience to oneself. He quotes Vigotsky as concluding that "human mental development has its source in the verbal communication between the adult and the child and a function which is earlier divided between two people becomes later the means of organization of the child's own behavior". Language serves both to represent as well as regulate one's actions. It is the transfer of such regulation increasingly to the child in the Child Development Observation which models the increasingly reciprocal process of child development.

This principle of interactive assessment has been designed as a component of an ongoing process of creative problem solving involving the child, his parents and teachers (Ozer & Dworkin, 1974). It is an integral part of a system for delivery of service to individuals with handicapping conditions of various sorts and provides a commonly agreed upon approach to permit communication between various types of professionals and between such professionals and their consumers (Ozer, 1975).

It has been suggested that the assessment of the child with developmental difficulties be concerned with the process of development rather than the more static measures traditionally done of levels of performance. If one wishes to sample the process of development, one must bring it about. If one changes the child, one may now measure the process of change. One may measure for example the number of new ideas the child begins to use within a specific time span; the degree of independence in their use; the degree to which they are applied to novel situations. This protocol of interactive assessment has been designed as a replica of the ongoing process of development which goes on in a variety of settings and across time. As the child grows, he may be expected to increase the number of ideas and their specificity to his own needs. It has been my experience that once the principle has been established of a dialogue, the child then begins to contribute to the dialogue ideas unforeseen by the adult. It is this last aspect that may be the true measure of development—the creation of new ideas.

The emphasis that Cybernetics has placed on the issues of control and information offers an opportunity to explore the implications of such issues for the process of child development. It is the sharing of control and information that is being modeled. It is feedback concerning this reciprocity that distinguishes the use of cybernetic concepts to meet human needs.

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A Cybernetic Approach to Psychological Testing of Children

Irving E. Sigel
and
Rodney R. Cocking
Educational Testing Service
Princeton, New Jersey 08541

In this paper we will present a model for assessment of intellectual functioning as an alternative to the conventional psychometric approach. One of our purposes is to demonstrate that the alternative is consistent with feedback conceptualizations.

Purpose of Testing

Conventional mental ability assessment involves the use of the same test and the same procedure for everyone with no allowance for variation. The assumption is that the use of the same test and the same procedure allow comparison of various individuals' performances to each other, thus enabling the examiner to rate the child's status relative to his peers. Piaget summarizes the traditional approach to testing as follows:

Psychological tests are used to evaluate individual's ability. The tests, standardized in form and in administration, pose questions so arranged as to satisfy the following requirements: first that the question and the conditions in which it is submitted remain the same for each child, (and) second that each answer be related to a scale or schedule which serves as a standard of comparison both qualitative and quantitative. The advantages of this method are indisputable in diagnosing children individually. (Piaget, 1972, p. 3)

If, however, a purpose of testing is to understand "how" the child arrives at solutions to problems or the kind of knowledge he has about a problem, conventional procedures are not useful. Piaget, for one, objects because, "When working under stereotyped conditions which the test method demands, only rough (superficial) results can be obtained, which though interesting in practice, are too often useless as theory owing to lack on context!" (Piaget, 1972, p. 3).

The decontextualization which Piaget mentions is an issue of separating information from its related contexts; (we are not discussing the issues of taking items out of test batteries—a problem for people who work in test standardization). The lack of context, decontextualization, provides the child no way of anchoring the information in the context appropriate for comprehending the item. For example, asking a child to select a number of blocks from an array of blocks may be more difficult than asking the same child to select the same number of crackers from a basket of crackers. The number of crackers has a context and apparently has more meaning (Sigel, 1974). Thus the information obtained from conventional tests may be limited to a particular context. This raises related testing issues.

For the first issue there is the approach to testing which argues that learning which is context-specific is not "real" knowledge. By such a definition, a concept of "generalization" is the criterion of knowledge; that is, wide range applicability. Second, there is, among developmental psychologists, a view which is concerned with the parameters of learning and knowledge applicability. This second view argues that while a standardized test allows one to assess decontextualized knowledge, and hence tests a wide-range of generalizations, the standardized procedure is limited because it does not shed any light at all on the specificity of knowledge. A second limitation of the standardized testing program which developmentalists are concerned with is the issue of "interrelatedness of knowledge." Piaget studied this problem as décalage (Piaget & Inhelder, 1971), both horizontal and vertical. Briefly, these décalages describe how theoretically related mental processes vary across knowledge domains and across age periods of development. Standardized procedures allow one to assess presence or absence of bits of information, repeated over age periods. They do not, however, describe or explain changes in how the human thinks about subjects of similar inquiries ontogenetically.

Decontextualization of information may result in "wrong" answers, since most test items require a thought answer. But the "thinking" of thought questions is lost. For example, the following problem comes from the Stanford-Binet: "What is foolish about this? A man was found dead with his hands tied behind his back and it was said, he shot himself." Only one answer is acceptable. There is no instruction for the examiner who presents the problem to the child to use any other response. Yet if the purpose of the test is to identify how the child thinks, every response is a useful
datum. By comparison, Piaget gives the following illustration: “... in trying to find out how a child conceives the movement of the sun and moon the question may be asked, ‘What makes the sun move?’ The child perhaps answers ‘God makes it move,’ or ‘The wind blows it, etc.’” (Piaget, 1972, p. 3). Piaget uses these answers to define the child’s knowledge level and how the child conceptualizes the answer. Such answers would be ignored in conventional tests since they are wrong. Yet such responses can be of value in telling us how the child thinks and conceptualizes such a natural phenomenon. By ignoring incorrect answers as revelations about a child’s mental ability, little is learned about the child’s thought processes or his conception of the problem.

The conventional test, then, employing a number of decontextualized items and using convergent answers, seems to be based on the following assumptions:

(1) The child is a passive responder in the testing situation, responding to each of the inquiries put to him.
(2) Each response reveals the knowledge level.
(3) The process of how the child arrives at the answer is irrelevant.
(4) Incorrect answers are not relevant data.
(5) Correct answers signify the same thing for all respondents.

### Rationale for an Alternative

The assumptions underlying conventional testing are rejected because they do not reflect characteristics of the developing human organism. Thus, before proceeding with the description of our model, those assertions defining the person should be specified.

(1) The child is an active organism engaging each new experience by assimilation and concomitant accommodation—features that are as characteristic of living beings as breathing.

(2) During the process of assimilation-accommodation the individual constructs and reconstructs experience. These constructions reflect an internal logic which interacts with external demands. The child builds his knowledge from actions and reactions to various experiences. In this way the child builds a concept which serves as a guideline against which objects (persons) can be grouped, compared, appraised, evaluated, judged. That is, multiple cognitive operations are employed.

(3) Cognitive processes which we call intelligence are hypothetically conceptualized as a structure, “a metaphor to describe the relationships among mental actions or transformations involved in ways of thinking” (Sigel & Cocking, 1977, p. 23).

(4) Development proceeds by stages, where each stage is necessary for the construction of the next. Thus, performance is limited by the stage the child is at.

(5) Since the child constructs knowledge from encounters within specific contexts, and since the child develops in an invariant sequence of stages, and additionally since contexts influence the understanding of ideas, objects, people, it follows that the knowledge available about a given experience will vary depending on when and how the problem is posed. Our example of “What makes the sun move?” will be answered differently at each stage of development.

(6) Finally, to quote from Piaget: “Life is essentially auto-regulation” (Piaget, 1971, p. 26) from which follows “That knowledge is not a copy of the environment but a system of real interactions reflecting the autoregulatory organization of life” (Piaget, 1971, p. 27).

These six assumptions regarding human development then call for a different model of assessment and a cybernetic model is congruent, since a cybernetic model is essentially a feedback model involving internal regulators which govern responses. In fact, Piaget himself eloquently describes the appropriateness in these words:

It [cybernetics model] is... a natural to use... The great advantage of such a model is that it makes it possible to analyze constituent processes and not just the results or performance as is often the case with other models (Piaget, 1973, p. 52).

The assessment procedure employed by Piaget to analyze the constituent processes is similar in kind to the clinical interview employed by psychiatrists as a means of diagnosis. The method is called “Method Clinique,” i.e., clinical method. It is experimental “in one sense that the practitioner sets himself a problem, makes hypotheses, adapts the conditions to them and finally controls each hypothesis by testing it against the reactions he stimulates in conversation” (Piaget, 1972, p. 8).

This method of interview is our method of choice for intellectual assessment. We shall have more to say about it later. Relating the clinical method to the basic six assumptions, it is apparent that the examiner is working within a feedback model, constructing his concepts of the child and reconstructing them on the basis of feedback relative to the child’s performance on the task.

The interviewer is not the only active, constructing participant in this model of the evaluation situation. The examiner’s actions and reactions are intimately related to the child who is being interviewed. After the interviewer poses problems, e.g., “What makes the sun move?” the child, possessing similar organismic characteristics as the interviewer, interprets each question and then proceeds to give answers. This is the opening gambit of a series of interactions between the interviewer and the interviewee. Thus, there are feedback loops operating for both the interviewer and for the child. Momentarily, we shall consider the contingencies of these feedback loops.

Before proceeding with a detailed example of the clinical method, let us clarify two important issues. First, every test attempts, as we said, to evaluate what the respondent knows. If the sole purpose of the interview is to determine what knowledge the interviewee has, then items of a convergent type are useful, e.g., to learn if the individual has a particular bit of knowledge of history, a question such as “When did Columbus discover America?” or “When is George Washington’s birthday?” is appropriate. If, however, the evaluation is to discover how an individual thinks, how certain is he of that knowledge, then the conventional method is not, in our opinion, useful because it does not allow us to examine which processes are involved in solving the problem.
The Clinical Method Approach

Once the problem is posed to the child, where the selection of the problem is based on relevant epistemological grounds, the individual child utilizes and applies his own cognitive apparatus to solve a problem. The task for the interviewer is to obtain reliable and trustworthy data. This is indeed an uncertain situation in contrast to conventional tests which usually pose a highly structured, precise question, leaving the respondent little choice in how to answer. The burden for the clinical interviewer is to know how to carry out not only a careful inquiry but also a careful evaluation of the respondent’s explanations. Piaget has said:

The greatest enemies of the clinical methods are those who unduly simplify the results of an interrogatory, those who either accept every answer the child makes as pure gold or those on the other hand who class all as dross. The first, naturally, are the more dangerous, but both fall into the same error, that is, of supposing that everything a child may say during a quarter, half or three-quarters of an hour of conversation, lies on the same psychological level—that of considered belief, for example . . .” (Piaget, 1972, p. 9).

Thus, the first caveat proposed by Piaget is that the examiner listen to the response which serves as data (feedback) to the examiner so that he can order (regulate) subsequent questions to get the relevant information (be on target). Thus, the examiner is actively constructing the child’s response, forming and reformulating hypotheses about the child’s cognitive status.

The child, the recipient of the problem, provides a solution which the examiner must evaluate: Does the answer fit the examiner’s expectations or not? Further, is the child’s response the child’s conviction or does it reflect his submission to the authority of the adult examiner? Rules for classifying the child’s responses and procedures for evaluating the intensity or solidity of the child’s conviction must be created. One method of testing the solidity of a conviction is the use of a counter suggestion. A second method is to pose the same problem in another context or in a potentially contradicting way.1

While the examiner is engaged in gathering information which influences his subsequent interrogation, the child is also gathering information. The child is presented with a problem he probably never thought about in any active way. Presented with such questions, e.g., “What makes the sun move?”, the child probably invents an answer. This invention occurs during the inquiry, but an answer does not arise sui generis. Piaget points out that such answers, “… imply previously formed schemas, tendencies of the mind, intellectual habits” (Piaget, 1972, p. 13). The child’s response influences the examiner’s subsequent inquiry, and if he’s a skillful interviewer, he will avoid suggesting an answer. The very fact that the child’s response does not terminate the inquiry is conjectured as having a direct effect on the child’s construction of the situation. Feedback from the situation occurs at two points: the first is when the child becomes aware of his answer to a novel question, since he had to transform the inquiry into a verbal reply. This may pose a problem since it is possible the child does not have quite the words to say what he wants to communicate to the adult. This internal act of transformation is feedback with the constraints defined by both the child’s language comprehension and usage levels. Since his response immediately results in a follow-up question from the interviewer, a second set of messages is possible. To wit, did he (the child) give the right answer, did the interviewer understand, etc. Now, another feedback situation is set up—an interaction between the examiner and the child. Each participant’s behavior is contingent on the behavior of the other, and also contingent on the prior set of questions. In other words, once the inquiry is set in motion each answer influences the subsequent interviewer-child interactions. In the following for example, consider each statement, first for its independence.

<table>
<thead>
<tr>
<th>Interviewer:</th>
<th>You know what it means to think?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child (7 yrs):</td>
<td>Yes.</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>Then think of your house. What do you think with?</td>
</tr>
<tr>
<td>Child:</td>
<td>The mouth.</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>Can you think with the mouth shut?</td>
</tr>
<tr>
<td>Child:</td>
<td>No.</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>With the eyes shut?</td>
</tr>
<tr>
<td>Child:</td>
<td>Yes</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>With the ears stopped up?</td>
</tr>
<tr>
<td>Child:</td>
<td>Yes</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>Now shut your mouth and think of your house. Are you thinking?</td>
</tr>
<tr>
<td>Child:</td>
<td>Yes.</td>
</tr>
<tr>
<td>Interviewer:</td>
<td>What did you think with?</td>
</tr>
<tr>
<td>Child:</td>
<td>The mouth.</td>
</tr>
</tbody>
</table>

(Piaget, 1972, p. 39)

As it is easy to see, the answers are not independent, nor are the questions really independent. The example illustrates the interdependence of the feedback loops for both the examiner and the child. It is also interesting to note the interdependence or relatedness of answers for the child—the child’s self-regulated loop. This protocol illustrates how the examiner probed the issue and the child continued in his own way, unaware of the contradiction in his statement. The protocol suggests that the child did not use his own information as feedback to alter his conviction that one thinks with the mouth open (which is not altogether unreasonable in view of the models he has around him). The explanation is that the cognitive structure is so organized that the child is unable to perceive the contradiction. In this case, the child gains little from the inquiry as conducted. It is the examiner who gains from the feedback in this case.

On the other hand, children’s responses can be influenced by their own prior responses, or at least demonstrate shifts in responses during the inquiry. We will focus on this

1See Piaget, 1972, pp. 1-32, for details on the clinical method.
shift when we discuss an example of a child we term "transitional," meaning that he is undergoing a change in the organization of his cognitive structures.

For the model we are presenting it is possible, and even probable, that a feedback looping exists between questions; that is, each response of the child is contingent upon the previous inquiry and the response to the previous inquiry. This interrogatory model is widely discussed among communication researchers (Mishler, 1975). The contingencies established when an adult is in control of the conversation produce a chaining effect of Question, followed by an Answer which is dependent upon the Question, which in turn is followed by another Question that is dependent upon the Answer, and so forth. However, experienced interviewers also acknowledge that children often impose their own questions onto the conversations, and then the dialogue takes a very different form. When the respondent and the interviewer both use questions, an "archiving" occurs. The child often does this to clarify something the examiner has asked, and usually the exchange quickly resumes the "chaining" format. The interrogatory model becomes a feedback teaching/learning model because the conversation is extended through the use of questions. This set of circular reactions proceeds until the interviewer or the child terminates the discussion.

The implications of this analysis are: (1) Conventional testing appears to treat the child as a relatively passive respondent whose answers to decontextualized information are assumed to reflect mental status; (2) While acknowledging the usefulness of such information regarding children's intellectual abilities, the traditional approach deemphasizes the active engagements, constructions, and regulatory processes continually involved in both individuals during the testing. Consequently, a clinical method appears more consistent with the previously outlined organismic characteristics; and (3) The application of the clinical method as described allows for a more comprehensive statement of the child's intellectual level on both qualitative and quantitative planes.

Application of the Feedback Model to a Cognitive Task

One of the key issues in developing procedures to assess children's mental ability is the decision of what the format and the content of the task should be. The format we propose is the clinical method; the content depends on the conceptualization of mental ability. Most conventional (individual) psychological tests assessing intellectual ability are virtually atheoretical. Definitions of intelligence and the euphemisms for mental ability range from simplistic statements, such as, "... Intelligence is what the test measures . . ." (Boring, 1923), to the most complex concept which refers to intelligence as an organization of mental operations that change over time. This latter conception is, in our estimation, developmental in nature and takes into consideration a wide range of human cognitive functions (e.g., classification, seriation, the understanding of relations, etc.). Given this complex definition of intelligence, assessment of intelligence also becomes more complex. How is one to evaluate mental ability when intelligence is considered an organized entity and still maintain the integrity of the wholeness?

Considerable effort is being made to create batteries of tasks which provide an evaluation of the processes children use in thinking. The aim is to identify the stage at which the child is functioning. One of the constructs that Piaget contends is central to the determination of the child's capability to think logically is conservation. Conservation is defined as the awareness that an attribute of an object does not alter, in spite of various physical transformations. For example, a ball of clay does not vary in amount in spite of a transformation from a ball of clay into a flat, pancake shape. Determination of the child's ability to conserve indicates that the child is emancipated from judgments based on appearances, that he is aware of the constancy of an attribute when irrelevant changes take place. In Piagetian theory, emergence of the comprehension and utilization of the principle of conservation develops as a function of experience and biological maturation. Determination of the presence or emergence of such an understanding is accomplished through the clinical interview. We shall present an example to demonstrate how the interview fits a cybernetic model—which at the same time evaluates the child's mental comprehension of an important problem. The protocol can be analyzed to demonstrate particularly how "feedback" functions as a regulator of the behavior of the examiner and of the child. By also pointing out a stage of thinking referred to as "transitional," we hope to show that an evaluation session is often enlightening for the child, as well as for the examiner.

The task is to determine if the child can predict, through anticipation, the level of water when it is poured into a tall, thin cylinder from a wide, short container. The child first is shown two wide, short containers and the examiner asks the child to attest to the equality of amounts of liquid in the two containers. This is the first "feedback" situation for both the child and the examiner. The child judges the amounts in each jar and makes them equal. The next step is when the child is asked "If water from this jar (wide, short one) is poured into this one (tall cylinder), where will it go—higher than the water in the remaining jar, or would it be the same or lower?" To answer this, the child has to do three things: (1) anticipate the outcome mentally because he has no example; (2) compare the height and the amount of water in the "imagined" condition to the original set up; and (3) employ principles of compensation; i.e., the height of the water will be influenced by the narrowness of the cylinder relative to the wideness of the jar. The next step is for the examiner to ask the child to justify his prediction. In this situation, the child's thought is activated by the examiner's posing the question, and he then produces an answer. Since the examiner does not indicate the correctness or incorrectness of the response, the child has no idea whether he is right or not. The child should, therefore, retain his perspective. When the experimenter pours the water into the tall cylinder, the child has the opportunity to notice: (1) whether he was correct (confirmatory feedback) or (2) a discrepancy between his prediction and the physical reality (negative
feedback). The experimenter next asks the child to explain why the water rose to the predicted level or why it did not—whichever the case. The child's answer influences the experimenter's comprehension of how the child understands the problem (feedback). The request for an explanation also provides the child with an experience of transforming the examiner's question into a verbal statement of his own, which is probably a new experience to the child. Inquiry by the experimenter actively engages the child in focusing on the issues in the problem. It is possible that the feedback from this encounter provides information to the child: "...information which proceeds backward from the performance is able to change the general method and pattern of performance, we have a process which may be called learning" (Wiener, 1967, p. 84). In other words, it is possible that the feedback from either the examiner's inquiry or from the child's own action sets up a situation in which the results of past performance are fed back and influence subsequent performance. Thus, a second trial is usually presented. Instead of using only two jars with equal amounts of water on the second trial, two additional jars are used with the following procedure: After attesting to the equality of the amounts in the two jars, one of the jars is emptied equally into two smaller jars followed by the question: "Do I still have the same amount of water in the two smaller jars as in the remaining larger one?" "Why?" The next question to follow is: "If the water in the large jar is poured into the cylinder, how high will the water go?" Again, the same inquiry procedure is used. The child now has a new situation in which to apply the principle involved in the initial trial. If the child fails to grasp the principle, the feedback from the encounters will not change his perspective. It can be said that the processes governing this child's behaviors remain intact, and he did not "learn" during the testing trials. Yet, it happens that on the second trial some children begin to apply the principle, thereby suggesting that feedback from the initial trial modifies their perspective and sets a new organization into motion. These children are the ones we term "transitional," meaning that the testing experiences "induce" principles which are emerging. The only way to be certain of the solidity of the newly learned understanding is to inquire by counter-suggestion. If the child continues to solve the problem, then one becomes more assured that the child understands the principle. What may well be happen-

Summary

The intent of this paper was to propose a feedback model for assessing intellectual functioning in children. We suggest the use of a clinical method for assessment based on a Piagetian model of intelligence, since it provides an opportunity to identify not only what the child knows, but how he thinks and reasons. The interview situation provides feedback for both the child and the examiner. This interaction provides an understanding of what the child knows and, more importantly, how he gets there.

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Cybernetic Testing

Bernard Brown*
Office of Child Development, DHEW
Box 1182
Washington, D.D. 20013

Children grow up in two worlds: the world of the classroom and the world outside—the "real" world. They are tested in both worlds. In the classroom they are tested by measures of the skills and knowledge they have acquired and by their potential for doing well in other classes. But their success in later life depends to a great extent upon how competent they become in dealing with the real world which tests them in a manner almost always cybernetic in character. I would like to illustrate the nature of a cybernetic process by an example from the world of sports.

A football quarterback is about to call for a run into the middle of the line. He sees that the linebacker is moving forward. Instead of a run he calls a pass play and falls back to pass. A tackle on his left comes in too fast so he moves to his right. Then he sees a receiver open down field, looks at the defending back and starts to throw the ball to where he judges his receiver will run. The receiver moves left to avoid the defending back, then right and then left again. The quarterback hesitates until his receiver is in the clear and throws a touchdown. In this example, the quarterback's actions are continuous, adaptive and controlled by many levels of feedback.

As a second example, consider a batter who is thrown a sinking curve ball. He watches the ball curve, estimates its point of arrival, see's it start to sink and readjusts his bat position and his timing. As the ball comes over the plate, he does not swing at the point where the ball seems to be headed. He waits until the ball takes a final dip, sees that the ball is too low and holds his swing. Ball one. He knew how to look at the moving baseball and how not to look; that is, he knew how to control his perceptions.

As a final example, consider a businessman who tries to sell a hat for ten dollars but gets no customers. He lowers his price to nine dollars and sells two a week. He lowers the price to eight dollars and finds that he can sell five hundred but that he will lose money. He then raises the price to ten dollars and makes a small profit but sells many fewer hats. Eventually he finds that his best profit is on a price of seven dollars. When did he start to control his profit margin? When he first encountered resistance. This example and the previous two illustrate some of the characteristics of the cybernetic psychological paradigm.

The purpose of this paper is to present a psychological testing approach based on the cybernetic paradigm. Some of the criticisms which have been leveled at conventional standardized tests will be discussed. The nature of a cybernetic best will then be described. The latter part of the paper will present some approaches to the development of standardized cybernetic tests for children.

Conventional Standardized Tests

Standardized tests have been criticized as testing a narrow range of human behavior which does not draw on abilities demanded in real-life circumstances.

- They demand that a child respond quickly rather than well;
- They stop a child from thinking in ways different from the tester;
- They reflect the tester's—not the child's—view of an appropriate response.

It appears that almost all standardizes tests are based on highly structured stimulus and response modes which greatly restrict the range of competence that a subject may employ when he takes a test. Stimuli are presented to the subject in a unitary fashion and he must respond in a unitary manner. For example, a test item might give a picture of a dog together with four other pictures including one of a bone. The picture of the bone—and only the bone—must be associated with the picture of the dog. The subject cannot question the examiner to find out if a picture of a bird is appropriate because birds are also pets. He receives no feedback to guide his actions. He cannot give partial answers. He can respond to one of four pictures or one of four words, numbers, etc., but he cannot substitute a picture for a word. He must accept the equation: one stimulus equals one response.

There are, nevertheless, many advantages to using standardized tests. They are cheap, convenient, easy to understand and until recently acceptable to most psychologists and most institutions. They are also marketable and profitable. characteristics which undoubtedly contribute to their widespread use and the reluctance of test manufacturers to

*The views and opinions expressed in this paper are those of the author and do not necessarily reflect those of the Office of Child Development, DHEW.
support changes in test design.

Another reason for using standardized tests is that they are reliable—people tend to make the same scores on repeated or equivalent tests. However, we pay a high price for reliability for two reasons. First, reliability assumes stable behavior. It ignores varying behavior even though we are all affected by the weather, by the seasons, by the daily happenings in our lives. Tests are made reliable by rejecting test items which change with the subject’s circumstances. Second, reliability tells us only about how people are like their test scores and not how they are different from their test scores.

Thus there are two questions which we have to ask about whether the essence of a person is captured by standardized tests:

- How much of a person is that part which does not change readily with the external circumstances?
- How much of a person is that part which is the same as the next person?

To answer such questions we can proceed with an elaboration of conventional tests or, alternatively, we can design tests which automatically allow for change and difference.

A central difficulty with IQ and other standardized tests is that their narrow definitions of intelligence and achievement become self-fulfilling prophecies when teachers and school systems judge children by test scores. Worse yet, teachers then design curricula which reward competence in the narrow range of abilities that affect test scores. If a child possesses the competence taught, he is labeled a good student. But some other child with a different competence that would have served just as well in life may be labeled a failure and as a result becomes a failure.

Unfortunately, our universal educational practice is to place the child who possesses the different kind of competence in a classroom designed for the competences of an average child and then tell him that his work is poor and he is not as smart as the next child—all day, every day, for twelve years. After such treatment, just about any theory of child development I can think of would predict that the child’s emotional development will be harmed with terrible consequences for his subsequent intellectual growth.

I believe this situation is very well understood by some of our Black educators who have argued against standardized testing. By and large, they are not against fair and realistic standards and discipline. They just do not want their children to be judged by artificial standards based on a different culture. They do not want discipline which denies a child’s self-esteem and innate competences. They want their children to grow up in an approving atmosphere which instills strength and confidence.

The Cybernetic Paradigm

The development of cybernetics, the science of control, has given us a heightened understanding of how human beings control themselves and others. An understanding of control theory helps explain interpersonal control, including dependence and independence. It permits us to find the time and place where control can best be executed and helps us to attain not only the control of our environment but also freedom from control by others.

The cybernetic model of human psychology has as its focus the control process from which external events and internal psychological states give rise to human action. The control process itself concerns the displacement of psychological state from its equilibrium condition by some environmental disturbance and its later return to equilibrium after being subjected to a restoring force.

The cybernetic model stands in contrast to the behaviorist psychological model which focuses on only two components of the control process—perception and action—or, to use the classical phrase, stimulus and response. The behaviorist must explain the interaction between man and his environment in terms of these two components: the stimulus as a receptive interaction channel and the response as an expressive interaction channel. Although the cyberneticist would see the response as necessarily feeding back to the control mechanism as part of the stimulus and stimulus perception as part of a response to a superordinate demand for psychological equilibrium, the behaviorist endows them with a unitary quality. The stimulus is external, passive and independent. The stimulus may shape the organism but the organism cannot shape the stimulus. Response is also unitary in the sense that it cannot feed back a continuous and interactive influence to the organism. To most behaviorists, it is something of a heresy for a cyberneticist to say that a stimulus is selectively perceived in accordance with internal control system directives or that some of the response usually feeds back as a stimulus which determines a more complex response dimension in an iterative manner.

To the cyberneticist, it is not the stimulus but the controlled perception of the stimulus which evokes the response. Moreover, the control process itself is partly governed by the nature of the response. The perception of a bright light, for example, is mediated by the control of pupil size. Clearly the response of squinting will change as the pupil adapts to the bright light. As Powers (1973) has described so elegantly, this point of view that stimuli are changed by the perceptual process comes naturally to cyberneticists because control systems are governed by adjustments of their inputs and not their outputs.

In the cybernetic point of view, the essential forces which control human behavior involve small and relatively continuous information inputs; i.e., environmental and organismic feedback. It takes little energy to turn the steering wheel of a truck, still less to look at the road. In engineering terms, the classic behaviorist stimulus is a sense input which is transient as opposed to a continuous or slowly changing. It is also an overload in the sense that the organism is presented with a rapidly changing sense input. The transient overload character of the classic stimulus appears to tap only an atypical and essentially limited response repertoire in the organism. In contrast, when presented with a continuous and relatively small stimulus, human beings possess great adaptive capacity. When a flash bulb explodes it causes the eye to blink, but the light-adapted eye has little difficulty in handling direct sunlight.
Toward A Standardized Cybernetic Test

As a first step to a standardized cybernetic test, I will review some of the items presently used in conventional tests which might qualify as components of a cybernetic test. I will then proceed from familiar test items to an additional set of cybernetic items which I have concocted. All of these items meet the following criteria:

- They are scorable. (The child's actions may be translated into numbers.)
- The scores will represent a range of actions. (Potentially there is enough variance so that the test may be reliable.)
- A "correct" response will represent a competence to perform appropriately in a real-life circumstance. (They can be valid measures of social competence.)

Finding appropriate items was difficult. Many conventional test collections were reviewed but only a handful of tests were identified which did not employ the behaviorist paradigm.

What measures of adaptive competence can we envision for a cybernetic test? We can measure (1) goal attainment, (2) equilibrium attainment and (3) adapting to environmental stress. Consider some examples of such measures. We can measure the time it takes a person to reach goal; that is, to equilibrate or adapt. We can measure the number of trials it takes to reach the goal (an adaption curve, if you will, as against a learning curve). We can measure the probability of goal attainment—for example, the probability of putting a basketball through a hoop. We can measure the error between action and result and between result and goal—for example, the closest distance from the hoop that the basketball is thrown.

Tests Which are Partly Cybernetic

An observation test is not a true cybernetic test. When, for example, a child adapting to naturally occurring events in his environment is viewed by an observer standing at a safe distance, the observer sees only what is happening in the child's physical world. The essential action, however, takes place in the mind of the child. If the observer is to understand what is going on he must communicate with the child even if by so doing he destroys the purity of the observation. Obviously we need some compromise between the ethologist whose observations are too external and the cyberneticist whose interactive communication can change the nature of the child. One compromise is to both communicate and observe—separately and simultaneously.

The observational rating scale by Kohn (1972) is designed to be completed by young children's teachers. Some of the items are:

- Child responds freely to suggestion made by teacher;
- Child is able to make his needs known to the teacher;
- Child has difficulty in getting the attention of the group;
- Child dawdles when required to do something;
- Child fails to take part in activities unless urged.

The first two items reflect communicative competence while the last three are "push-back" and reveal the limits to the child's competence. Note, however, that while these items measure a child's cybernetic capability, they do not use a cybernetic process to elicit the information.

Some of the observation questions in the Gair GMVR Program (Gair, 1975) are:

- Can the child freely engage in active games without tending up?
- Can the child thread a needle?
- Can the child control the amount of pressure placed on a crayon when drawing?

There are a number of tests, which might be termed quasi-cybernetic, that are described in Getzels and Jackson's Creativity and Intelligence (1962). One of these tests is the uses test. In which a child is asked to describe the uses for some common objects such as a pencil. He is scored in terms of the number of different uses suggested and their uniqueness. In the word association test, the child is asked to write down as many meanings as he can for a series of words. These tests measure ability to shift frames of reference and to deal with the environment in an original manner. They are cybernetic in that the child does the shifting in accord with memory feedback. The tester, however, does not engage in a dialog with the child. A test of cybernetic behavior is not necessarily a cybernetic test.

In the Make-Up Problems Test, the subject is given some complex paragraphs to read and asked to make up soluble problems from them. It is scored for the number of elements and operations in the problem. The subject must be able to translate information into symbolic form and process the symbols. Again, although ability to ask a question is measured, there is no dialogue.

The Gross Geometric Forms Test assesses creativity. The child is asked to construct pictures from a set of yellow and blue geometric forms. The child is told: "Make something. Use any of the pieces you want... Good,... What is that?... Tell me about it." Scoring is based on the child's ability to produce a number of different ideas; the integration, synthesis and meaning of the ideas produced; and the freedom and capacity to use color, action, embellishment, and symbolic thinking. The Gross test is only quasi-cybernetic. It is not interactive. The information only flows from child to tester. But the competencies used are the child's. Like many creativity tests, the Gross test must perforce leave the child some freedom of expression.

Lynn's Structured Doll Play Test is a projection test which tests more in the cybernetic mode. The child is given some dolls and objects and environments to which the dolls relate: a bathroom, beds, etc. A variety of situations are proposed by the examiner and the child then chooses the dolls and the actions the dolls perform. The cybernetic character of the test consists of presenting a perturbed environment and letting the child choose his own course of action.

Dirlam (1976) has constructed a developmental assessment test of children's free drawings which are rated for composition, dimensionally, meaning and design. In addition, he has analysed children's art drawn after the children
true cybernetic tests could be criterion referenced as an adaptive test. It is to ask: How good is the control system relative to the ideal control system? In archery, for example, the ideal control system would score a bullseye. For example, what is the number of different operations used to complete the task? Such a test would be useful in examining the child’s specific competences. For example, a child might find it easy to duplicate a pattern and adjust the number of lines but might have difficulty in rotating angles.

Another way we can test cybernetically is to ask: How good is the control system relative to the ideal control system? In archery, for example, the ideal control system would score a bullseye. In archery, for example, the ideal control system would score a bullseye every time. Ideal control system effectiveness may be rated in terms of precision of control, the energy consumption required to reach a goal, the adaptability of the system in terms of the different methods it uses to achieve control, the predictability of control and the accuracy of control. This is to say that cybernetic tests may be criterion referenced as well as norm referenced. We can measure the point at which the control system starts to exert itself to restore equilibrium. The beginning of control is when you meet opposition. This is a particular kind of feedback which I prefer to call pushback. In fly-casting, there is no control over the fishhook until the line slack is taken up so that the fisherman can pull on the hook. The pushback point occurs at the time the line grows taut. One way of measuring pushback is to ask a child for a subjective evaluation of a test:

- Did you find this item difficult?
- Which was the hardest problem? The easiest?
- Would you rank these questions by their order of difficulty?
- If you don’t understand all of the question, which part do you understand?

In the NIMH Behavior Checklist there is an item: “Child sets fires.” This is in part a pushback item. It takes a certain competence to set a fire. Development has to have progressed far beyond infancy for such pathology to develop. There is a new toy on the market which is an ideal cybernetic test for psychomotor function, complete with automatic scoring. It is the electronic tennis game which plugs into a television set. It can be adjusted for one player. If the subject is a novice we can measure the time required for the subject to adapt to a given skill level or, if the game is then speeded up, the time to re-adapt to the new skill level. The subject’s eyes and hands can be tested separately. We can vary the speed of the ball, size of the racket, size of the target, and so on. One aspect of control which can be measured with such a system is the precision of control of the subject.

There is also an electronic shooting gallery attachment for TV sets, again with automatic scoring. One cybernetic test of psychovisual coordination is to have the gun fire at a given rate—at say a line of moving ducks. The test can measure accuracy and the time to adapt to some ability plateau and then we can change the speed of the ducks and measure again the time to adaptation. This is an example of a cybernetic test which does not measure individual performance against a norm but rather against optimal function. It asks: “How good is this person’s control system for duck shooting?” It could also ask: “How does shooting accuracy change during an environmental disturbance such as a distracting noise or light flashes?”

The standard test of visual acuity is the Snellen chart. A child is made to stand twenty feet from a chart containing letters of different sizes and is asked to read the smallest letters he can make out on the chart. The normal child has 20/20 vision, which means that he reads the chart as if he were standing twenty feet away. A child with poorer vision might read the chart as if he were forty feet away (he would have 20/40 vision). Mark Ozer and I discussed the possibility of letting the child move back and forth until he was at a distance from the screen at which he feels comfortable. Thus a cybernetic vision test might yield a measure of 20/40 vision at 6 feet. I later spoke to some optometrists and found that in clinical practice very similar methods are used, especially for close-in reading. They are particularly important for children who have to read up closer in order to allow letters to subtend a larger angle in the eye so that they are imaged on a larger area of the retina. Nevertheless, there is no cybernetic Snellen chart procedure which has been standardized.

Walker (1975) has developed an electronic measurement system in which a subject controls the movement of a spot of light on an oscilloscope screen while at the same time
performing another task as a distraction. The system tests the ability to adapt tracking behavior under stress. It was developed originally to test fighter pilots and is now being applied to testing learning disabled children.

Another dimension of concern in cybernetic testing is that of time levels; i.e., the frequencies and times constants of the feedback loops. The error signals are of different sizes and varieties. For each size and variety, the signals are fed back to the person who is adapting in a different time frame; that is, the time constraints of the error signals vary.

One approach to designing reliable tests is to maximize the amount of information recruited by a test item. As adaptive behavior elicits feedback, the feedback signal comes in with some magnitude, direction, variety, frequency, time constraint, information loss, noise, etc. By optimizing these qualities the validity and reliability of the test may be optimized. Some examples may clarify this important point.

Let us consider two similar one-person games as tests: pitch penny and trace-a-circle. We score pitch penny in terms of average distance of a tossed penny from a line and we also score trace-a-circle in terms of average distance of points on the drawn circle from those on the given circle. Now there is a fundamental difference between these two tests. The pitch penny error signals are discrete whereas the trace-a-circle error signals are continuous. It takes a lot of pennies (and a long time) to test pitch penny performance. In contrast, the circle can be traced in a second (the time it takes to pitch one penny); that is, the signals feed back faster in trace-a-circle. The trace-a-circle feedback may be of lower quality and provide less information within a given fraction of a second, but overall trace-a-circle is the more efficient test in terms of the rate of information acquisition. In terms of test reliability, tracing one circle is probably more reliable and time efficient than pitching a half dozen pennies.

There are many games which may be thought of as cybernetic tests, for example golf, tennis or Monopoly. An excellent language test would be a computerized automated Scrabble game. For assessing the competence of a three-year-old I can think of no better test than to sit down with the child and play blocks.

As a final example of a cybernetic test, I refer you to the most widely used of all testing methods, clinical assessment. Even though cybernetic tests are very different from traditional tests, much of what I have presented is not new to the professionals who work with children—to doctors, teachers, or clinical psychologists. In practice, clinicians are cyberneticists. Watch a clinical psychologist test a child and you will find that he almost always asks: "How does the child take the test?" Such a question ignores the American Psychological Association's little green book (1974) in which are prescribed standards for giving psychological tests. Clearly, clinicians can use standardized tests to obtain a different kind of information from that intended by the test maker (Ozer, 1974).

What purpose do test serve for clinicians? Bluntly put, a test is a stress, an environmental disturbance. The clinician uses the testing process to watch the child adapt to stress. One can make the case that it is much kinder to use tests than to use electric shocks. In general, I would agree but not one can be sure that the testing does not actually harm the child when it is done to produce stress. It would seem safer and more sensible to use some more obvious and more completely controlable form of stress.

Discussion

These suggestions for cybernetic tests are not intended as a call for removing standardized tests from the marketplace. That is just not going to happen. For the near future the best we can hope for is to coopt some of the traditional tests. We can, for example, introduce such cybernetic flourishes as changing the environment in which a test is given and demanding more interaction between children and their testers. For example, we could change light levels and noise levels in the room in which the test is given and then look at changes in a child's performance.

Summary

This paper was intended to sketch the broad outlines of a new paradigm for psychological tests. The intent was to develop a basis for standardized tests of cybernetic competence to be assessed by cybernetic testing methods. The cybernetic test would:

- Extend traditional tests to assess higher levels of integration of function including the ability to give, receive, and process feedback;
- Detect competences which are now observable only by sensitive clinicians;
- Ultimately provide a more valid and reliable test of intelligence;
- Complement rather than replace traditional tests.

There is one final reason for considering cybernetic tests, a reason which concerns the philosophy and values which underlie traditional tests. These philosophical underpinnings give rise to an unequal power relationship between the tester and the tested which limits the child's freedom and as a result promotes much of the test bias and inequity which have been cited in the current testing controversy.

The basic testing issue concerns freedom. The old testing paradigm imposes far-reaching restrictions on children, on how they can think and act, on how they can communicate and on what resources they can draw from their cultural backgrounds. The cybernetic model offers the hope that we can test children without such strictures. Cybernetic testing would promote:

- a psychology of interaction;
- a psychological theory which accommodates change;
- a social theory of equality, respect and shared power among persons of different cultures, races, sexes and ages.
Reference Notes


REFERENCES

Cybernetics and the Assessment of Children

William T. Powers
1138 Whitfield Rd.
Northbrook, IL 60062

As a discussant in the symposium concerned with the title of this essay I will present here some general remarks in the nature of background thinking, rather than writing a "scientific" (i.e., authoritative) paper. Behind the background, so to speak, lies a unfinished model of living systems which purports to explain what behavior is, how it works, and what its purposes are: a control-system model which grew out of the work of Weiner (1), Ashby (2), D. T. Campbell (3), H. V. Foerster (4), and others literally too numerous, as well as too poorly located in the mind's reference library, to mention. The subject of assessing children challenges this model precisely where it needs the most development; the model deals almost entirely with the structure of behavioral organization in a competent adult, and has only the merest suggestions, adapted mainly from Ashby, concerning how the structure came into being.

Nevertheless it seem important to have a reasonably complete performance model before one attacks the questions of development. Unless one has some coherent concept of the final product of a developmental process, how can one approach the process itself in an orderly way? It is much easier to understand the actions of a carpenter if one knows that he is building a house rather than a boat. The major triumphs of traditional psychology have all been in the area of learning, while the understanding of what is learned has remained at an embarrassingly elementary level. Human behavior cannot be encompassed in the meaning of the term "response"; all the complexities of behavioral organization are concealed in the names by which one kind of response is distinguished from other kinds. Studies of the acquisition of behavioral organization cannot be any clearer in their conclusions than are the initial assumptions about that which is acquired. To treat all behaviors as emitted responses, or even as the final product of nervous system activity, is to restrict oneself to what Campbell terms a billiard-ball model of an organism. That restriction necessarily restricts theories of development; if such theories are required only to account for the externally-caused motions of billiard balls, their successes deserve only correspondingly restricted admiration. The theory of classical conditioning, for example, is little more than a description of observed relationships between certain environmental events and subjectively-apprehended chunks of behavior, the chunks of behavior themselves being taken wholly for granted. For another example, proponents of operant conditioning treat behavior, however complex, as being emitted by the organism. The role of the experimenter in recognizing certain consequences of motor activity as having a familiar and repeatable form is never considered; appearances, however subjectively defined, are treated as objective reality. For all that scientific psychology may claim about a scientific approach to the study of behavior, that discipline still lacks a coherent definition of behavior. Control theory provides such a definition based on fundamental principles, and in doing so it promises to change all our concepts of what is happening while behavior becomes organized.

The Control-System Model

Control theory deals with behavior not as a simple (or even complex) cause-effect chain running from input to output, but as a relationship that comes into being when a sensitive and active organism is embedded in an environment that transforms actions into effects on what is sensed. Sensory events influence actions, and simultaneously actions—as well as independent events—affect what is being sensed. There is a closed causal circle into which are injected influences both from the external world and from sources inside the behaving system. There is no way to isolate a single causal chain in this total collection of relationships.

To an outside observer who is aware of control phenomena, control processes appear to center around the stabilization of certain aspects of the local environment. Those aspects, known as controlled quantities, are sensed by the behaving system (or subsystem of the whole organism), and are acted upon by the same system, at the same time they are being sensed. The organization of the system is such that the controlled quantity is maintained close to some preferred stated called the reference level of the controlled quantity. All actions that affect the controlled quantity are based on departures of the controlled quantity from its reference level: an error. Since actions always oppose error, and are based on the error itself, actions always oppose the effects of external disturbances on the controlled quantity. The sources or cause of the disturbance is immaterial, be-
cause control requires only sensing and affecting the controlled quantity itself.

The reference-level of the controlled quantity is not determined by the controlled quantity or by disturbances acting on the controlled quantity directly or indirectly. It is specified inside the controlling system. A reference-level is fixed by a kind of perceptual bias in the apparatus that senses the controlled quantity. This bias is often spoken of as a reference signal, a reference with respect to which a given state of a controlled quantity is reported as too little, just right, or too much, on a continuous scale. It is as though there were a reference perception against which the real-time perception is continuously compared, the action involved in control then depending not on the perception, but on the outcome of this comparison process. In an environment which provides regular connections from action to controlled quantity, it is normally possible to create a fixed dependence of action on error which will systematically oppose departures of perception from the reference perception, and oppose such departures so quickly and strongly that they are always kept vanishingly small.

Thus control, in terms of a model of the controlling system, boils down to a process of maintaining a perception inside the system closely matching a reference perception, also inside the system. The means of control consists of acting on the external world and thus influencing the perception in the direction that forces it toward the state of the reference perception. If this influence can be altered rapidly and can be adjusted on the basis of very small errors, the perception will be kept matching the reference perception, even if the reference perception itself is altered by some other subsystem.

When the reference perception remains constant for some time, an outside observer will see clear relationships between disturbances tending to affect the controlled quantity and the system's actions which also affect the controlled quantity. If control succeeds, the controlled quantity will be held nearly changeless; its representation inside the system, which is termed a perception here, will be held in a close match to the reference perception. This can only occur if each effect of a disturbance on the controlled quantity (and hence on the perception of it) is matched by a countering effect generated by the action of the system on the controlled quantity. When that equal-and-opposite relationship exists, and if control is observed it must exist, a spurious appearance of a cause-effect chain is created.

The spurious appearance is that external events cause behavior, with the organism serving as a link in the cause-effect chain. The organism appears to mediate between the external event and the behavioral action. Furthermore, the way in which behavior appears to depend on the external variables that make up the independent event appears to be a description of the behaving system's inner organization. If the amount of action depends on the magnitude of the disturbing event in a linear manner, the organism is seen as a linear transducer.

It is certainly true that there are behaving systems which are organized exactly as this appearance would indicate—but they are not living organisms, nor control systems. When control is involved, the relationship between action and disturbance is descriptive not of the organism but of the environment that lies between action and controlled quantity, and between disturbance and controlled quantity. The effect of each disturbance on the controlled quantity is determined by the physical laws that intervene; the effect of an action on the controlled quantity is determined by a different set of intervening physical laws. If the controlled quantity is held constant, it follows that the action is related to the disturbance according to the respective intervening physical laws. The more precise the control, the more precisely it follows that action is related to disturbance according to external physical laws. Those laws reveal nothing about the organization of the behaving system. The relationship between action and disturbance would be the same for any system which employed the same kind of action in controlling the same controlled quantity. The internal properties of different systems displaying the same control behavior might be radically different from each other, but those differences are not revealed to naive external inspection. The fact that control exists creates a false external appearance of cause and effect, and conceals the true properties of the behaving system.

The bulk of scientific experiments with behavior has dealt only with the spurious cause-effect appearances created by control behavior. It is therefore apparent that control theory is going to have radical effects on the very way in which we do experiments in the attempt to understand human nature. At the very least, control theory demands that we add a new question that must be considered in the design of any experiment with behavior: Is there a controlled quantity, and if there is, what is its current reference level? If there is a controlled quantity, and if its reference level can be observed, the experimental procedures and analysis of data which follow will have little to do with the procedures that are familiar in today's behavioral experiments. There is reason to believe that controlled quantities, once the necessary tests have been applied, will prove to be ubiquitous. They will prove to be the focal point of nearly every behavior.

Hierarchies and Development

Individual examples of behavior can be analyzed in terms of control theory; objective means exist for establishing whether or not a controlled quantity exists, and for determining its reference level, fixed or variable. As soon as a few control behaviors have been thus identified, the concept of hierarchies of control inevitably seems necessary. A simple controlled quantity, such as the position of an organism's limb, is soon seen to be not only a controlled quantity in its own right, but also a means for affecting and controlling other quantities. The actions of a given control system can be seen to serve a clear purpose: that of maintaining the match of perception to reference-perception (in the model), or controlled quantity to reference level (in terms of direct observation). But variations in the reference level can be seen as changes in the preferred state of the controlled quantity, and since the controlled quantity is forced to follow these changes, through the action of the control system, changes in reference level are seen as a means for control-
ling other quantities which are affected by the initially ob-
served controlled quantity. An organism can stabilize a limb
at any position, but by varying the reference position it can
act on objects outside itself, and cause them to be held in
preferred positions, preferred states of motion, or preferred
relationships to other objects. The variations in reference
level can therefore also be seen to serve a clear purpose:
that of controlling higher-order quantities.

The control model thus leads inevitably to a hierarchical
control model, in which higher-order systems act not by cre-
ating muscle tensions but by adjusting the reference-signals
against which lower-order systems compare their own per-
cceptions. A hierarchy of purposes, goals, or intentions thus
appears, along with a hierarchy of perceptual transforma-
tions.

An epistemology of behavior also follows with what
seems equal inevitability. A control system controls pri-
marily an inner representation of the external state of af-
fairs: a perception. The actual external state of affairs that
is stabilized when a given perception is stabilized depends
entirely on the nature of the intervening perceptual trans-
formations of raw sensory stimulation. The organism con-
controls not reality, but constructions created from the detailed
interactions with reality that take place at the membranes of
sensory receptors. Those constructions may some day
prove to have some necessary relationship to external real-
ity or they may not; there is nothing in control theory that
requires a controlled perception to correspond to any uniary external controlled quantity. As long as the effects
of action on the external world follow some regular laws,
and as long as those effects in turn affect sensory receptors
in reliable way, the hierarchy of control could contain self-
consistent perceptual structures at all levels and still suc-
cceed in maintaining control. The laws that appear in the
structure of representations reflect in some way the regu-
larities in the outside world which we must assume, but that
reflection need not be anything like a one-to-one relation-
ship. Indeed, if we believe the picture of external reality
which physicists have constructed on the basis of artificial
sensory impressions, we would have to conclude that the
 correspondence is definitely not one-to-one. In fact, the only
conclusion we can presently defend in this regard is that
when we control certain perceptions, we have no idea of
what our control actions are really doing to the outside world.

The power of the control organization stems from the fact
that actions are based on error, not on stimulation directly.
If an error appears, the system can act to limit it or erase
it, with no information at all about why the error appeared.
Thus it does not matter that we do not know the true nature
of external reality. We do not have to be able to anticipate
disturbances by watching for their causes (although that
sometimes improves control); we can act to contain errors
even though we can see no cause of the error at all. We
can even deal, over a limited range, with drifts in the pro-
PERTIES of the external world; actions will automatically ad-
just to maintain perceptions at their reference levels even
if those perceptions do not always correspond to the same
external state of affairs. We can maintain and control an
orderly constructed reality even in the face of some degree
of external disorder.

This picture which seems to follow clearly from control
theory comes astonishingly close to the picture which
Piaget (5) has derived from a direct study of child develop-
ment, and which von Glasersfeld and colleagues at the Uni-
versity of Georgia (6) have built on Piaget's concepts (calling
their view "radical constructivism"). The convergence of
ideas among modern thinkers must mean something: even
Joseph Weizenbaum in speaking of the relationship of com-
puters to human reason (7), without considering control
theory at all, finds compelling reasons to treat experienced
reality as having been constructed in toto by the brain.
The concept is not new, but its growing acceptance by those
most concerned with technological models of human nature
is new, not to say unexpected. Naive realism is clearly at
the end of its rope.

If there is a hierarchy of control systems concerned with
regulating a constructed perceptual reality, that hierarchy
certainly does not spring into being when a person is con-
ceived. The vehicle for that hierarchy, the central nervous
system, undergoes a continual process of physiological
maturation, and there is also a long process of psychologi-
cal maturation arising from the inner needs of the organism
and the properties of the world through which the organism
must learn to satisfy those needs.

If there are distinct levels in this hierarchy of control,
and I have given some reasons for suspecting that there are
(8), we can expect these levels to undergo a developmental
process depending partly on physiological maturation and
partly on experience, and we can expect to see more or less
recognizable stages of development related to the kinds of
levels that an adult eventually possesses. Control theory
offers a new kind of approach to the analysis of develop-
ment and the assessment of children with respect to their
status in the midst of this process. By studying adult or-
ganization we can hope to identify any universal levels of
organization that exist; with this information in hand, we can
then determine the degree and quality of control a child
possesses at each of these levels at any time of life. We
have now, at last, arrived at the subject-matter of this paper.

The Assessment of Levels

As a format for discussing how an assessment of levels of
control might be organized, let us consider four hypothe-
sical levels of perception: configuration, transition or motion,
sequence or event, and relationship. These are levels 3, 4,
5 and 6 of the model in reference 8.

The term configuration refers to static patterns such as
objects and arrangements of objects (in the visual mode).
Let configuration A consist of two arms being held outward
and forward, spaced apart by eight or ten inches, with flat-
tened palms facing each other. Whether this is considered
a visual, a kinesthetic, or a mixed-mode configuration is not
important; we will treat it as a visual configuration. Let con-
figuration B be the same as A, except that the two palms are
in surface-to-surface contact. In some coordinate system,
configuration A and configuration B could be seen as points
on a continuum of configurations, with the location along
this continuum being specifiable by a single number, or a
single one-dimensional signal. A control system can now be imagined which acts on muscles in both arms to alter the configuration in this one dimension, and which senses the configuration in this one dimension also. The crucial variable is the palm-to-palm distance.

The reference-perception for this control system could consist of a single signal capable of variation in magnitude (frequency of nerve impulses) only. If the perception of actual distance existed in the same form, a neural comparator could respond to the difference between the two signals (one excitatory and one inhibitory), the difference or error signal then being translated into reference-signals for lower-order systems that control muscle tensions. This sketch, of course, bypasses all the technical problems involved in understanding how the visual system can transform the retinal image into a signal representing relative distance between two objects. We simply assume that such a capability exists.

Anything capable of supplying a steady reference signal to this control system could thereby place the palms at any specific distance from each other. If a disturbance acted on one arm, interfering with its freedom of movement, the other arm would automatically make up the difference—given the ability to perceive the relative distance, the remainder of the system design is relatively simple.

One of the propositions of the general model of reference is that reference signals are derived from recordings of past values of the associated perceptual signal. This implies that during the development of a new control system, the first component to become organized is probably the perceptual function; in this example, the ability to perceive two objects in terms of a distance between them that remains invariant under certain transformations of the visual field (such as parallel movements of the two objects). Once such a perceptual signal is present, the organism can discriminate relative distance; that entity now becomes part of the experiential field, whereas before formation of this perceptual function, the same visual field would not have been perceived in terms of relative distances.

The next stage is the recording of actual values which this signal takes on. The perceived distance will prove to occur always between two limits, one with the palms together (zero distance) and one with them as far apart as they can be placed, which is usually just a function of the length of the arms. All recordings of distance-perception will lie between those limits.

Now that recordings exist, particular ones can be selected and "replayed" to serve as reference signals. Since reference signals are selected from recorded instances of actual states of perception, they are free of all distortions that may occur in the visual processes; the control system is not required to produce a particular calibrated external effect, but only to produce a perception that matches a former perception obtained through the same channel. Of course the reference signals selected in this way are also likely to be achievable, since they have occurred before in the form of present-time perceptions.

The remaining components required for control are a comparison process and a process for converting errors found through comparison into appropriate adjustments of lower-order reference signals, those sent to systems that control muscle forces. Since comparison in this model is an elementary process of magnitude comparison that is the same regardless of the kind of perception involved, we can assume that comparators are built-in. This leaves only the step of routing the resulting error signal to the correct lower-order systems that already exist, and making sure that sign-inverters are added as necessary to achieve error correction rather than error magnification. This output-learning phase completes the control system.

The general logical pattern would seem, therefore, to require first that a new perceptual function become organized, then that there be a period of experience with values of the new perceptual signal being recorded, then that a particular value be selected to be reproduced, then the error be successfully converted into appropriate changes in lower-order reference signals. Learning proceeds from perceptual learning, through passive experience and recording (observation), to output learning.

If we were to imagine that this configuration-controlling system was the highest-level control system existing in a child at some stage of development, an obvious problem would arise: if there are no higher-order systems yet, what is selecting the particular past value of perception to serve as a reference signal? This problem exists regardless of the level under consideration. Any proposed solution, obviously, must work whether it is the first level or the tenth that is in question.

In any developing hierarchy, there is always a highest-level system, and unless we propose that all highest-level reference signals are, by default, set to zero (creating avoidance behavior), we must propose some mechanism that is present from the beginning, capable of selecting at least the highest-level reference signals. The mechanism I have proposed (after Ashby) does just that, and in addition contains the mechanisms required to reorganize plastic neural tissue so as to create new effective functions. I call it the reorganizing system.

This is not the place to develop the model of this meta-control system; suffice it to say that its reference signals are assumed to be built-in, and concerned not with behavior but with the state of the organism itself. I mention it primarily to show that as soon as a discussion of development begins, a need is seen for some such system. Through studies of development in terms of a growing hierarchy of control, perhaps we can learn more specifically just what a reorganizing system has to be able to do. For now we will assume that a reorganizing system does exist, and that it selects highest-level reference signals essentially at random (the only criterion being whether, as a consequence, the state of the organism is adversely affected or improved). We can treat this as a trial-and-error or a creative, experimental process.

The outcome of this assumption is that we would not expect to see any systematic patterns in the choice—for this example—of distance between the palms which this new control system would create and stabilize. A child who has just learned to control this dimension of experience would demonstrate control and resistance to disturbance, but it would take place "for its own sake"—not as part of...
any larger pattern.

Now assume that the same development process extends up another level; perception of transitions or motion is developed, and eventually a system is completed which can monitor rate of change of distance. Such a control system would act to maintain a constant rate of approach (or the opposite) of the two palms, the rate being specified by a reference signal corresponding to speed. As a means of controlling speed, the system would alter the reference-signal specifying palm-separation as necessary; a continuous change of reference signal would be required.

Now there would be patterns to be seen in the various choices of reference signals for configuration. Those reference signals would, in fact, change magnitude in an orderly manner from one magnitude to another. The child would be seen pulling his hands apart and moving them together, now rapidly and now slowly. The choice between "rapid" and "slow" and intermediate speeds would now be the one that shows no systematic pattern, for it is now the highest-level choice of reference-signal.

The next level of control would arise from developing perception of an event. If the hands are placed far apart, and then made to approach each other at a moderate speed until they meet palm-to-palm, a noise will result without causing pain: the child has learned to clap. A particular fixed sequence of configurations and transitions, having a beginning, a middle, and an end, makes a new perceptual entity that did not exist (was not represented) before. This event, once recognized and experienced for a while, can be selected as a reference-level, and eventually errors can be translated into changes of reference signals for transition and configuration controlling systems. Then the child can clap. When it claps, and under what circumstances, is un-systematic, for now the event-control level is the highest level.

Finally the next level of perception is formed: the perception of relationships among independent events, transitions, and configurations. There is a relationship between clapping and other people smiling or jumping; since the clapping part is already controllable, the relationship can be reproduced at will, as long as those others continue to react the same way. At the end of this line there is patty-cake and finally applause.

This hypothetical fragment of a developmental sequence is certainly not meant to be taken as a research report; it is a way in which development might take place. The purpose in going through it was mainly to show how the hierarchy could be approached in terms of development, and what present theory would lead us to expect to find. Through the systematic application of disturbances, it is possible to test the hypothesis that any given quantity is under control by an organism, so if these initial guesses are in error, it will be possible to find better definitions of levels of control through experimental procedures.

Cause and Effect

The traditional view of behavior makes it the end-product of a chain of causes and effects running from external events, through the nervous system, to the muscles. External circumstances also provide the modulating effects which can alter the form of this cause-effect chain—that is, the portion inside the nervous system. The control model leads to a different view. The visible symptoms of motor activity in the muscles are not themselves taken to be the central phenomenon; instead, certain consequences which follow motor activity are central. The crucial consequences are those which are stabilized against disturbance, by motor activities, and all consequences which are not stabilized are treated as side-effects. In the old view, behavior is the result of environmental effects on the organism's sensory inputs. In the control-theoretic view, the organism's sensory inputs, or some major subset of them, are determined by reference signals inside the organism, behavioral activities being the means for adjusting those inputs to the intended states.

In a general way, control theory agrees with the old view concerning the interactions which lead to the final form of behavioral organization. The basic motivation for acquiring new organization derives from the organism's own needs, which are fixed by its physical nature and the inherited message in the genes. Learning takes place when these needs are not met. This is a broad and permissive picture; the needs do not have to be confined to purely physiological needs. The message in the genes might effectively require that there be some minimum level of sensory input while an organism is awake; it might even require that experienced realities that are constructed satisfy abstract criteria, such as orderliness or self-consistency. By saying that there is a fixed set of requirements which must be met, one does not reduce the motivation of learning to a matter of physics or chemistry.

Regardless of this general similarity in approach to motivation, control theory and the old approach disagree on the subject of causation. The old view derives from a naive application of the principle of physical determinism; in reality it relies on a crude analogy to Newton's laws of motion. Just as a point-mass moves strictly as external forces dictate, so do organisms move strictly as external circumstances acting on the nervous system and biochemical machine, dictate. Just as Newton's laws hold only in the absence of feedback phenomena and only under strict conservation of energy, so does the old view hold. Furthermore, the old view holds true only for systems that have no internal complexity; systems which cannot compute, or which cannot store information, or in general whose inner activities are less complex than their outwardly visible activities. More specifically, the old view of cause and effect does not apply to control systems. Thus to the extent that organisms act as control systems, the old cause-effect view does not apply to organisms.

The control model makes a distinction which cannot be made under the old paradigm. As has been explained, behavioral actions show a clear relationship to external events when those events are disturbances affecting the same controlled quantity that is affected by the action. Thus there is an effective and partial (although not actual or deterministic) cause-effect relationship apparent between disturbance and action. Over short periods of time, actions reflect (and
The nature of the environment creates certain control. Change of its effect amount of action that must be generated to sensed by the organism (assuming that there is a clear-cut external counterpart of the controlled perception, a counterpart that another observer can recognize). Of the two effective cause-effect relationships, the primary one is that between reference-perception and controlled quantity. Under normal conditions, specifying a reference perception will result in the controlled quantity being brought to a given state. The external environment and specifically the state of external disturbing variables only determines the kind and amount of action that must be generated to accomplish control. A properly-organized control system, with no change of its internal properties, can maintain control over a wide range of external conditions, so changes in those conditions in no way determine the organization of behavior. Only when control fails, in such a way that the built-in needs of the organism are not met, will there be a change in internal organization—and even then, that change is carried out as a result of internal processes and not as the external world specifies. The criteria for terminating change are contained in the organism, not in the environment.

Reference-signals inside the organism specify the states of at least a great number of sensory inputs, or more precisely specify the values of certain functions of those primary sensory inputs. Thus the causes of the experienced world trace primarily to reference signals inside the organism. Since we are speaking of a hierarchy, the ultimate causes must trace to the highest-level reference signals in each distinguishable pyramid in the hierarchy. Since the highest-level reference signals are assumed to be selected in a trial-and-error, creative, or experimental manner under control of a reorganizing system, the ultimate controller of experience is the reorganizing system and the inherited needs it is designed to satisfy.

Once a hierarchy of reference-signals exists, it is then the environment which determines the kind of behavior needed to make perceptions at all levels match their respective reference perceptions. This is not an active, but a passive kind of determinism, in the same sense that the position of the fulcrum of a lever “determines” how one end of a lever will behave when the other end is moved up and down. The nature of the environment creates certain requirements that behavior must meet if control is to be maintained; obviously, all successful control behavior entails meeting those requirements. The requirements alone cannot cause any behavior; they can only establish the kind of behavior that must be produced if a given state of affairs is to be maintained at one of its possible reference levels. The organism’s perceptual structure determines what can be controlled; its control organization determines that perceived quantities will be controlled; its hierarchical structure determines the momentary reference-levels at which controlled quantities will be maintained.

The overall picture of the nature of an organism can be seen to differ under the old view and the control-theoretic view. Under the old view, the organism is a passive manipulator of the environment, forced by external circumstances to act as it does just a billiard ball is forced to act as it does by the impact of the cue. Under the new view, the organism is an active agency which acts on the environment and in relationship to the environment under the guidance of a hierarchy of inner purposes; its experiences do not control its behavior, but just the opposite: its actions exist only to control its experiences.

A control system will adjust its actions, in the presence of disturbances, so as to continue experiencing what it intends to experience. An external observer/experimenter cannot interfere with these basic intentions except by applying disturbances that tend to alter higher-order controlled quantities. If a person is reaching for a glass of water and another person pushes on the reaching arm, there will be little effect on action, for the arm-positioning control system will alter its commands to muscle-force controlling systems so as to cancel the extra load. But if the external observer/experimenter moves the glass of water, the relationship between hand and glass will be disturbed in a way that cannot be directly countered by a change in muscle forces. In that case, the higher-level system experiences error, as it did not in the first case, and alters the reference-signals going to the position (or motion) controlling subsystem. Now the series of hand positions alters in response to the moving of the glass, but in such a way as to keep the event (of grasping the glass) proceeding as before, toward the same final relationship.

Once it is understood that the external observer/experimenter cannot directly interfere with the operation of the control hierarchy, but can only apply disturbances to quantities under control of various levels in the hierarchy, the futility of trying to “control behavior”—by peaceable means—becomes self-evident. The usual goal of attempts to control behavior is to alter the organization of another organism so fundamentally that from then on the other organism will spontaneously behave in a new way. If the effect of attempts at control is merely to disturb controlled quantities, behavior will revert to its old course as soon as the disturbance is removed. The only way to achieve lasting change, other than continuing forever to apply the same disturbance, is to disrupt the other organism’s control altogether, and in such a way that the basic needs of the other organism cease to be met. This will trigger off the process of reorganization inside the other organism, the only process not involving chemicals or surgery that can permanently alter organization.

But even when that is done, the reorganization will terminate only when the organism’s needs are again satisfied—not the observer/experimenter’s wishes. Even with respect to processes that can result in permanent change of organization, the observer/experimenter can act only as a disturbance. If his efforts do not kill or cripple the organism, the end-result will be failure to disturb what matters most to the organism.

Of course there are what logic designers call “don’t-care” conditions. After a major disturbance that does call for reorganization, the organism may be behaving in a new way, but a way which is of just as much value to the organization in every respect as the old way. In this case there
will be no reversion to the old behavior, simply because the new behavior creates no departure from intrinsic requirements. It is not impossible to create a permanent alteration in another organism’s behavior that will persist after the experimenter is gone—it is merely very difficult. It is also unlikely, if the experimenter does not understand that he is dealing with a control system just as complex as he is.

Most of what is called “control of behavior” is nothing more than the natural result of a change in external conditions which requires new actions to continue controlling the same quantity at the same reference level. A great deal of the remainder is nothing more than opposition to disturbance. In either case, reversion to the original conditions will result immediately in reversion to the original actions. In the few cases that remain, control of behavior involves forced reorganization and extremes of deprivation or physical insult. Even in those cases, the nature of the new behavior that is finally retained is determined by selection processes inside the organism, not inside the experimenter.

Control theory leads us to conclude that it is not in the nature of an organism to be controllable from outside, once it is fully organized. All exceptions to this principle entail either the misidentification of opposing actions as necessary consequences of disturbances, or some form of violence or physical coercion applied to the organism. It is my contention that violence and coercion are not consistent either with the goals of science or with the requirements for a viable society. Thus we must view the control of the behavior of coequal organisms (real, not fictitious control) as an impractical goal.

**The Assessment of Children**

The preceding remarks apply to a fully-organized adult organism, not to a child in process of acquiring that final complete hierarchy. Moreover they do not apply to adults who are still in process of growing, in those areas where organization is not yet complete. Thus, in a sense, the foregoing remarks do not apply to any person in an unequalvocal way, since all persons continue to reorganize at least in some respects throughout life. Where reorganization is still occurring, it is the nature of the current external world that determines what the organism must learn to do in order to experience what it intends, and which limits the range of experiences that can be perceived or controlled. At every stage of development, early or late, the organism must learn to satisfy its requirements in the world that exists, by acting on that world, not some world that might be easier to manipulate, more just, or more orderly. The organism learns what it must do in order to acquire and maintain control, whether or not it can explain why a given action has a given effect on perception. B. F. Skinner (9) is quite correct in this regard; quite in agreement with the conclusions of control theory. Behavior becomes organized around its consequences. Whatever contingencies are embodied in the external world, natural or artificial, behavioral actions come to be those which, acting through the given external contingencies, produce the required consequence. The important consequence, in control theory if not in Skinner’s conception, is the effect on perception relative to the intended effect.

As already mentioned and illustrated, a child in the midst of acquiring a control hierarchy is capable of perceiving and controlling aspects of the apparent environment only up to some particular level, in general lower than the highest level at which an adult perceives and controls his own experiences. The adult therefore perceives variables that the child cannot yet perceive, and is in a position to arrange external circumstances so as to influence the kinds of perceptions the child will acquire next, and the kinds of actions the child will employ in order to control those new perceptions. A child may first learn to perceive the event called clapping by seeing it performed over and over with the hands of an adult teacher, or at least an older child. Without such externally-provided examples, the child might or might not stumble across this potential way of organizing event-perception. Few children, for example, learn to clap by banging their thumbs together, although this is perfectly possible to perceive as a familiar event, and then to accomplish.

The adult is also in a position to arrange the properties of a local environment that connect the child’s actions to a given perceptual consequence. If a child is taught to clap while wearing a garment with a string connecting the wrists together with six inches of slack, the child will find it impossible to establish the beginning hand-to-hand distance at a reference level greater than six inches. Thus the clapping event will have to be controlled within the available range, and once learned, that will be “clapping.” If the child is not capable of perceiving the relationship between the string and the limitations on movement, and there must be a stage where this is true, there will be no reason to consider the string an impediment. One learns control within the means available, and the questions of other means that might, under other circumstances, become available is seldom relevant. This is especially true when the perception of impediments or other limitations would require a higher level of perception than the one involved in the current learning process.

These examples, of course, presume a particular definition of levels of perception and control (as well as presuming the existence of distinct levels). Such presumptions are not necessary, except as a pedagogical device. There can be little doubt that children progress from lower to higher levels of learning, whatever “levels” turns out to mean in terms of experiment, and whether or not nature has obliged us by providing clear-cut levels that extend across all modes of behavior. Once the concept of control is clearly understood, the examples will have served their purpose and need not limit hypothesis-making. The point is that in observing children in the process of development, we should be aware that new controlled quantities are being defined as new perceptual abilities develop, and that the actions we can observe are in themselves evidence only of lower-level controlled quantities that have already been mastered.

This brings us to what may be the main difference between the control-theoretic point of view and the older one that is still central in psychology. If scientific psychologists tend to agree on anything, it is that an understanding of
organisms requires the ability to predict their behavior. Control theory leads us to suspect that this aim is basically hopeless. Behavior, in the sense of externally observable measures of activities, does not depend on external circumstances alone. In a given situation, and with a fixed reference level for a given controlled quantity, there will be a regular relationship between disturbances and the actions which oppose their effects. But there is no possible way to predict, in general, all disturbances that might occur, nor is there any way to observe all disturbances that are actually working in a given situation: to do that, one would have to encase the organism in sensors of every conceivable kind, as well as all kinds potentially of importance but not yet conceived. It is simply not possible to anticipate all possible disturbances.

The aim of predicting behavior as a function of external events is hopeless because to do so would entail an endless project for keeping track of disturbances that have occurred, a list that would never cease to grow. Simply generalizing is of little use—classifying disturbances according to superficial similarities. Similarities among disturbing events are not what result in similar actions; only the fact that different disturbing events affect the same controlled quantity is relevant to an explanation of why they all result in the same kind of action. Once the controlled quantity has been identified, one has a true generalization, that will predict the kind and amount of action which will accompany any conceivable event capable of disturbing that controlled quantity.

Furthermore, reference-levels do not remain constant as just assumed. If the reference level for a controlled quantity changes, a disturbance which yesterday called for one amount of action will today call for a greater or lesser amount of action, or the opposite action, or even no action at all. A catalogue of responses to disturbances would continue to be valid only as long as reference-levels did not change; a complete catalogue would be required for each new combination of reference levels. The only way to find any regularities under these conditions would be to deal in terms of average responses to average disturbances, or tendencies to respond to certain fuzzy classes of disturbances. In other words one would be forced away from the quantitative measurement of relationships and into a statistical approach. That is, of course, exactly what has happened.

Control theory, therefore, is not basically concerned with behavior at all. Behavior is trivially explainable once the nature of a controlled quantity is known. This is not to say that a control-theoretic experimenter would never study behavior; it is only to say that the study of behavior is not his primary goal, because once he has achieved the primary goal, identifying controlled quantities, the prediction of behavior becomes relatively easy.

In studying the development of children, it is perhaps more important to understand behavior than when adults are involved, because a child may well be attempting to control some quantity but not yet have found out how to manipulate already-controllable quantities of lower level in order to achieve the higher-level control. Particularly in assessing learning difficulties, it is important to distinguish the aspect of control that is currently defective. The child may have excellent skill in selecting lower-level actions, but a vague, incorrect, or unreliable perception of the controlled quantity. In that case practice will do no good; it is perception that must be clarified. On the other hand, as is commonly the case with reasonably bright children, the nature of the controlled quantity might be perfectly clear, and there might be a perfectly clear intention regarding it, but the child may simply be groping for a way to affect, much less control, that perception. In that case practice may be necessary, or it may be necessary to add control skills at lower levels.

Control theory may find its earliest and most useful application in the assessment of children. One reason is that an assessment or diagnosis in control-theoretic terms is almost necessarily also a prescription for how to overcome problems. It is not very informative to conclude that a child has “dyslexia,” for example—“non-read-ia.” Such a term only describes the behavior that an onlooker finds defective. It doesn’t say what is wrong. Of course in cases like that, psychologists have discovered without the aid of control theory that perception may be intimately involved in such problems, but control theory breaks the possibilities down even further, both into components of control processes and into levels, which may be even more important.

**Conclusions**

The concept of levels of control is not well developed in terms of experimental evidence; the idea of a reorganizing system is even less clearly defined. Nevertheless a reasonably plausible starting point exists from which both of these major subjects can profitably be explored in terms of control theory (which is well-developed). It is not too early to try to bring this point of view to bear in the assessment of children, although it will also be necessary to study fully-formed adult organization in the same terms in order to see where the child stands in the total process. Adopting the point of view of control theory entails some drastic alterations in old ideas of cause and effect, and even ideas about what it is about human nature that we want to understand.

Control theory, at least as it stands today, by no means touches on every interesting problem concerning human nature. It has little to say about cognitive processes or language. It is only vaguely informative concerning the relationship between biochemical processes and central nervous system function. It leaves the problem of awareness essentially untouched. No doubt as more workers participate in its applications, some of these defects will be remedied, but for the present that is of little concern. The main power of control theory right now lies in its ability to help us unravel the complexities of behavioral organization, even if we have no clear model to explain how organization changes.

If, using control theory, we can construct a clearer picture of behavioral organization after the fact, we will become more able to define exactly what has been added or altered when new behavioral organization appears. Such an understanding is the logical predecessor to a clear theory of reorganization, and it would be foolish to try to arrive
at a firm theory of learning before we have a clear picture of what is learned. Simply to identify controlled quantities and keep track of growing hierarchies of control, it seems to me, is enough of a project to occupy a great many students of human nature for a decade to come. The primary immediate problem is not what to do next, but how to persuade scientists to begin this project, and where to find financial support for it.

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About the Authors

FRANK BAKER
Currently, Frank Baker, Ph.D. is Director of the Division of Community Psychiatry and Professor in the Departments of Psychiatry, Psychology, and Social and Preventive Medicine at the State University of New York at Buffalo. Before joining the faculty at SUNY/Buffalo in 1974, Dr. Baker was head of the Program Research Unit of the Harvard Laboratory of Community Psychiatry and a member of the Harvard Medical School faculty for nine years. He is the author of over 60 publications.

T. BERRY BRAZELTON, M.D.
Dr. T. Berry Brazelton has been in active pediatric practice for twenty-five years in Cambridge, Mass. He is an Associate Professor in Pediatrics at the Child Development Unit at Children’s Hospital Medical Center in Boston. This is a post residency training center for Pediatricians interested in normal child development. His research combines an interest in neonatal and premature infant behavior with evaluation of early mother-father-infant interactions. The Neonatal Behavioral Assessment Scale was the result of twenty-five years of investigation with neonates. His books are Infants & Mothers, Toddler & Parents, Doctor & Child, as well as The Family: Can it be Saved, co-authored with Dr. Victor Vaughn.

BERNARD BROWN
Bernard Brown is a Social Science Research Analyst with the Administration for Children, Youth and Families, DHHS. His research activities include longitudinal studies of physical development and of early intervention, early childhood program evaluation, behavior genetics, cybernetics, future studies and policy analysis. Dr. Brown received his Ph.D. from American University in Education (Educational Psychology). His early training was in physics and his early research in nuclear physics and biophysics. His most recent publication is Found: Long-Term Gains from Early Intervention, Westview Press, 1978.

RODNEY R. COCKING
A native of Wyoming, Rodney R. Cocking received his professional training at Boston University, the University of Wyoming, and Cornell University for B.S., M.A., and Ph.D. degrees, respectively. He is currently a Research Scientist at Educational Testing Service in Princeton, New Jersey, where he conducts his research in the Psychological Development Research Division and the Center for Child Care Research with Irving Sigel. He focuses upon cognitive and linguistic development principally, having co-authored recent books in each of these areas. He is currently studying feedback processes in preschooler’s art and their verbalizations during their art construction.
NORMAN A. COULTER, JR.

Norman A. Coulter, Jr. is Professor and Chairman of Biomedical Engineering and Mathematics Curriculum at the University of North Carolina. He received his B.S. from Virginia Polytechnic Institute in 1941 and his M.D. from Harvard Medical School in 1950. Dr. Coulter was postdoctoral fellow in biophysics at Johns Hopkins from 1950 to 1952. He was Assistant to the Associate Professor of Physiology and Biophysics at Ohio State University, 1952-1965. His current interests are teleogenetic system and neural networks, and synergetics.

V. G. DROZIN

Dr. Drozin is Professor of Physics at Bucknell University in Lewisburg, PA., where in addition to courses in physics, he teaches two courses in Cybernetics. He holds a Physics diploma from the University of Gottingen, Germany, and a Ph.D. from Columbia University, New York. Dr. Drozin’s present research interest is the application of cybernetics to social problems and to automation of the teaching-learning process, particularly the correlation between bio-potentials of a learner and his degree of concentration. Dr. Drozin is the editor of this journal.

CHARLES H. DYM

Charles H. Dym is an economist living in Washington, D.C. Through his consulting firm, Dym Frank & Company, he furnishes investment management and research services to banks, insurance companies, and other institutional investors. Prior to starting his firm in 1970, he was with the Advanced System Development Division of the IBM Corporation where he headed an interdisciplinary group specializing in economic simulation models. Mr. Dym did his undergraduate work at Yale and holds a Master’s degree from the University of Pittsburgh. His favorite relaxation is translating the “Commissaire Maigret” stories of Georges Simenon. In addition to his activities with the American Society for Cybernetics, he is a member of the Yale and Cosmos clubs in Washington.

AMITAVA GHOSAL

Amitava Ghosal, Ph.D., heads the Statistics and Operations Research Department of the Council of Scientific and Industrial Research, India and was formerly Visiting Professor of Statistics and Management at the City University of New York. He was the founder-editor of OPSEARCH (Journal of Operations Research, India) and is also a founder of the Society of Management Science and Applied Cybernetics in India and founder-editor of SCIMA. He published two books and about 80 research papers, and has been a consultant in a few countries.

LAURENCE B. HEILPRIN

Laurence B. Heilprin received his B.S. in economics from the University of Pennsylvania in 1928 and his Ph.D. in physics from Harvard University in 1941. After teaching at Northeastern University and The George Washington University Graduate School of Engineering, he became a professor of Computer and Library Science at the University of Maryland. He held this position from 1967-1976 and is now Professor Emeritus of Information Science. Dr. Heilprin received the Award of Merit and the Watson Davis Award from the American Society for Information Science in 1976. He has many publications to his credit and is now writing a book on foundations of information science.

AKIRA ISHIKAWA

Graduate Faculty of Information Systems, Rutgers, The State University of New Jersey. Guest Editor of a quarterly journal, International Studies of Management and Organization, Associate Editor of Cybernetics FORUM, and served as Program Director for TIMS XXII International Meeting. He taught Accounting, Information Systems, Management and Policy Sciences at the University of Hawaii, New York University, University of Texas, Japan-America Institute of Management Science, and other institutions. Post Doctoral study, MIT; Ph.D., University of Texas; M.A.B.A., University of Washington; and Chemical Engineering degree in his native Japan.
FREDERICK KILE
Dr. Frederick Kile is a Lutheran minister (American Lutheran Church) and a systems engineer. He received his Th.D. from the University of Marburg, Germany; his B.D. from the Luther Theological Seminary; and his M.S. in electrical engineering and B.S. in Mathematics from the University of Wisconsin. Dr. Kile is presently Research Consultant for Social Modelling for the Aid Association for Lutherans. He has written extensively on the subject of cybernetics applied to social concerns.

MARK N. OZER
Formerly Chief Resident (Neurology), Mt. Sinai Hospital; Neurologist, USAF Hospital; and Special NIMH Fellow. Assistant Professor, George Washington University (Neurology); Associate Professor (Child Health Development), Assistant Professor (Clinical Psychiatry), University of Maryland. Member: Advisory Board Lab School; Neuro-Education Center; Associate for Child Learning Disabilities; Board of Editors, Journal of Learning Disabilities. Organizational memberships include: Society for Neuroscience, American Academy of Neurology, and Society for General Systems Research. Former President, American Society for Cybernetics. Dr. Ozer received his A.B., Harvard; M.D., Boston University.

WILLIAM T. POWERS
William T. Powers is an independent theoretician and researcher in the area of cybernetics and psychology. He obtained his B.S. from Northwestern University in 1950, and has worked since then as a medical physicist and as Chief Systems Engineer for Northwestern's Department of Astronomy. He is presently in transition to a career as a "student of human nature" writing and conducting experiments with his own computing system in his home.

ARNOLD J. RABEHL
Arnold J. Rabehl received the Bachelor of Science degree in mathematics and physics at the University of Wisconsin — Eau Claire in 1969. Following service in the U.S. Army and study in business administration, he has worked as a programmer/analyst at Aid Association for Lutherans (AAL), Appleton, Wisconsin, designing and implementing software systems for insurance related research activities. He has also been the chief analyst for the AAL social modeling project and has been co-designer of a series of world models.

IRVING E. SIGEL
Currently Distinguished Research Psychologist at Educational Testing Service, Princeton, investigating cognitive development — working from a constructivist conceptual model. Taught Developmental Psychology at Smith College, Michigan State University, Wayne State University, and State University of New York at Buffalo. At Merrill-Palmer Institute conducted research in cognitive style and the development of classification behavior. He is a fellow of the American Psychological Association and the Society for Research in Child Development. Among his recent publications (with colleague Rodney Cocking) is Cognitive development from childhood to adolescence: A constructivist perspective. Dr. Sigel received the B.A., Clark University, Ph.D., The University of Chicago, 1951.

ED TRONICK
Ed Tronick received his Ph.D. at the University of Wisconsin in perceptual development. His early research interests concerned the specification of infant perceptual capacities to perceive objects and motion. This led into broader concerns about infant development, especially in the area of social and emotional development. In that context, he has hypothesized that the infant-caretaker interaction is a jointly regulated system within which the infant develops autonomous means of control. From this perspective he has studied the development of the communicative capacities of infants and the structure of face to face communication in normal and abnormal mother-infant pairs.
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