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**Manuscript** submissions should be sent electronically (in MSWord or Rich Text File format) to the editor-in-chief Michael Paetau <Michael.Paetau@sociocybernetics.eu>). In general, please follow the Chicago Manuel of Style; citations and bibliography should follow the current journal style (APA). Normally, articles should be original texts of no more than 6000 words, although longer articles will be considered in exceptional circumstances. The Journal looks for submissions that are innovative and apply principles of General Systems Theory and Cybernetics to the social sciences, broadly conceived.

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SOCIOCYBERNETICS traces its intellectual roots to the rise of a panoply of new approaches to scientific inquiry beginning in the 1940's. These included General System Theory, cybernetics and information theory, game theory and automata, net, set, graph and compartment theories, and decision and queuing theory conceived as strategies in one way or another appropriate to the study of organized complexity. Although today the Research Committee casts a wide net in terms of appropriate subject matters, pertinent theoretical frameworks and applicable methodologies, the range of approaches deployed by scholars associated with RC51 reflect the maturation of these developments. Here we find, again, GST and first- and second-order cybernetics; in addition, there is widespread sensitivity to the issues raised by "complexity studies," especially in work conceptualizing systems as self-organizing, autocatalytic or autopoietic. "System theory", in the form given it by Niklas Luhmann, and world-systems analysis are also prominently represented within the ranks of RC51.

The institutionalization of sociocybernetic approaches in what was to become RC51, the Research Committee on Sociocybernetics of the International Sociological Association, began in 1980 with the founding of an ISA Ad Hoc Group and proceeded with the organization of sessions at succeeding quadrennial World Congresses of Sociology. The eventual RC51 became a Thematic Group and then a Working Group. Finally, in recognition of its extraordinary success (growing from some 30 members in early 1995 to 240 in 1998), the group was promoted to the status of Research Committee at the 1998 World Congress of Sociology in Montreal.

Over these past two decades, sociocybernetics has attracted a broad range of scholars whose departmental affiliations represent the entire spectrum of the disciplines, from the humanities and the social sciences through the sciences, mathematics and engineering. Furthermore, the many countries of origin of these RC51 members attest to the wide international appeal of sociocybernetic approaches. Within this highly diverse community, there is wide agreement on some very general issues, for instance, on developing strategies for the study of human reality that avoid reification, are cognizant of the pitfalls of reductionism and dualism, and generally eschew linear or homeostatic models. Not surprisingly, however, there are also wide divergences in subject matter, theoretical frameworks and methodological practices.

Many have argued that models developed for the study of complexity can be usefully appropriated for the study of human reality. Moreover, however, the emphasis in complexity studies on contingency, context-dependency, multiple, overlapping temporal and spatial frameworks, and deterministic but unpredictable systems displaying an arrow-of-time suggest that the dividing line between the sciences and the historical social sciences is fuzzier than many might like to think. What is more, in the humanities, the uniquely modern concepts of original object and autonomous human creator have come under serious attack. The coincidence of these two phenomena substantiate the impression that across the disciplines there may be observed a new concern for spatial-temporal wholes constituted at once of relational structures and the phenomenological time of their reproduction and change.

In this context of rich history and exciting possibilities, the Research Committee on Sociocybernetics of the International Sociological Association extends an open invitation through the Journal of Sociocybernetics to all engaged in the common quest to explain and understand social reality holistically and self-reflexively without forsaking a concern for human values--human values not construed simply as a matter of individual ethics, but conceived as an integral part of a social science for our time.
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NOTES FROM THE EDITORS

The current issue of the Journal of Sociocybernetics brings to awareness again a text by Gordon Pask first printed in the year 1965. Bernard Scott, deeply familiar with Pask’s ideas and concepts for a long time, was so kind to make available the document and to add an introduction to Pask’s arguments and comments.

As a scientific paper Roberto Poli’s text on self-reference is published. The text extends some arguments given in the JOS 1 (2009) issue on aspects of Niklas Luhmann’s sociological systems theory. A technical paper by John Raven and Luciano Gallon uses the methodology of system dynamics to analyse socio-cybernetic forces controlling the operation of the “educational” system, with a focus on how these factors are to be conceptualised and measured.

The editorship was recently passed over to Michael Paetau who will start the collection of papers for the next JOS volumes soon. The journal is planned to be subsumed under the Open Access Journals family.

Also the editorial board changes and we thank the members of the old board for their kind support.
Abstract. The paper presents the basic elements of Niklas Luhmann’s theory of social systems and shows that his theories follow quite naturally from the problem of the reproduction of social systems. The subsequent feature of the self-referentiality of social systems is discussed against the theory of hierarchical loops, as developed in particular by Robert Rosen. It will be shown that Rosen’s theory is more general than Luhmann’s. The nature of anticipatory systems and the problem of conflict are used as testing grounds to verify some interesting articulations of the general theory of hierarchical loops.

Introduction

During the past fifty years, the idea has been frequently advanced of connections linking wholes and their parts, generating loops that tie together parts and wholes in such a way that the fragmentation of the whole always implies loss of information. To mention only some authors, Bateson, Capra, Hofstadter, Luhmann, Maturana, Rosen and Varela are advocates of this idea. These parts-whole connections form what we shall call ‘hierarchical loops’. When parts pertaining to a hierarchical loop are separated from their whole, they behave differently (and may have a different nature) from the way in which those same parts behave within their whole.

Hierarchical loops must be carefully distinguished from horizontal loops. The latter are well-represented by feedback and autocatalytic cycles, where elements of the same kind interact with each other. Non-linear phenomena mostly rely on horizontal loops.

Unfortunately, the above-mentioned scholars—with the remarkable exception of Rosen—do not usually distinguish as sharply as necessary between horizontal and hierarchical loops. This unfortunate state of affairs—quite typical, however, of newborn, still unfolding ideas—has contributed to obscuring the scientific importance of hierarchical loops.

The present Quaderno focuses on Luhmann’s contribution to the theory of hierarchical loops, and the wholes to be analyzed are social systems.

Before at least some of the details are presented, a preliminary outline of the underlying main problem addressed by Luhmann will be useful. The shortest answer to this problem—“How is a society at all possible?”—while correct, is nevertheless too short to be helpful. To
give some exploitable benefit, this answer must be 'unpacked' to some extent. The following two pieces of information are helpful.

First, Luhmann constantly developed his theories from within a systemic perspective. The above question should therefore be reformulated as “How are social systems at all possible?” This reformulation makes Luhmann’s basic question more determinate, because it explicitly refers to both the general categorical framework to be exploited to provide an answer, namely general systems theory, and the specific types of systems that are under analysis: social systems.

Second, while social systems raise many problems which warrant study, one of them is so central that its clarification is required if a reliable, robust theory of social systems is ever to be developed. This is the problem of the reproduction of a social system. ‘Reproduction’ here does not have the usual biological meaning of the generation of a new individual. Within the theory of social systems, reproduction should instead be understood as the capacity of the system to maintain its identity against the continuous flux of its members.

Luhmann is understood better as soon as his theory is seen as a step within one of the main strands in the evolution of sociological thought. Social systems are systems able to outlive their members – new individuals are born, others die off, yet others move from one social system to another. All these modifications notwithstanding, social systems show some kind of stability which, for the most part, is independent of the continuous transformation of the underlying set of their members. As said, this problem is called the ‘reproduction’ of a social system.

The most obvious answer to the problem of the reproduction of social systems has been provided by Pareto: the reproduction of a social system (its temporal continuity) is brought about by the reproduction of the individuals that happen to make up the system. As obvious as this answer appears, it nevertheless raises a problem. In fact, it was Parsons who realized that the reproduction of individuals cannot be assumed as a properly sociological category. While the reproduction of individuals can be seen as a socially conditioned problem as one wishes, it nevertheless remains an essentially biological affair. In order to avoid reducing social problems to biological problems, and in order to answer the question of the reproduction of a social system satisfactorily, one must find an authentically social type of reproduction. Parsons’ answer was that the reproduction of a social system is provided by the reproduction of its (social) roles, i.e. by the reproduction of the patterns of action that are typical of that system. The reproduction of a social system is therefore the higher-order outcome of the reproduction of roles (patterns of action). This answer gives a much firmer basis to social theory. This is not the end of the story, however. Luhmann later came to realize that roles or patterns of action are themselves in need of a firm basis, because roles are implementations of perspective points, interests, values, and – more generally – of meanings. In its turn, the reproduction of roles implies the reproduction of their meanings. In short, the reproduction of a social system is grounded in the reproduction of meaning.

The following points may clarify the discussion thus far:

• The Pareto—Parsons—Luhmann series clearly shows an increasing transition towards higher levels of abstraction. In order to find better answers to earlier proposals, sociologists have had to delve into deeper and deeper waters.

• The process of reproduction does not imply lack of variation. On the contrary, reproduction is precisely the process that allows the generation of bounded (and therefore, possibly viable) variations.

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Parsons and Luhmann have detached the reproduction of social systems from their material bases. Both roles and meanings, indeed, are far from being material entities.

The last remark requires a further comment: what these scholars have shown is that the reproduction of social systems is not governed by the reproduction of their underlying material bases. Needless to say, “not being governed” does not imply “being existentially independent”. Put otherwise, social systems do need a supporting material basis. However, the important result is that, once such a basis is somehow given, the reproduction of the higher system does follow its own relational laws. While neither Parsons nor Luhmann were able to deal with this major ontological problem, which can be properly articulated only within the framework provided by the theory of levels of reality ((Poli, 2001),(Poli, 2007)), they nevertheless had the merit of both raising the problem and disentangling some of its intricacies.

The units of meaning used by a social system for its reproduction are communications (Luhmann, 1986). Building on (Bühler, 1934), Luhmann sees communication as essentially based on information, utterance and understanding. Information is the selection of what has to be communicated; utterance is the ‘how’ of the communication; understanding refers to what the receiver grasps from the previous two aspects of a communication. In more traditional terms, the first two components of communication can be read as its content and form. The real novelty comes with the third component: the understanding, which implies that “not the speaker but the listener decides on the meaning of a message” (Baecker, 2001, p. 66). For Luhmann, none of the three components on its own is a communication. Only the three components together form a communication. From this it follows that a communication can never be attributed to any one individual (Seidl, 2005, p. 29). Communications – as Luhmann defines them – are from the very beginning social acts. Moreover, communications can be accepted or rejected. This further aspect, however, is already part of the next communication. Communications generate further communications, which generate still further ones. For Luhmann, a social system is the autopoietic system of communication, where communication is the unit of reproduction of a social system.

The paper is organized as follows: Sections 2 and 3 sketch the evolution of systems theory and provide the basics of autopoiesis. Sections 4-7 present the aspects of Luhmann’s theory of social systems that are relevant to our discussion. Section 8 introduces Rosen’s (M,R)-systems. Sections 9-11 develop the theory of anticipatory systems and Section 12 briefly applies the theory to the problem of conflicts. Section 13 presents the idea of higher-order complexity. Finally, Section 14 calls attention to some of the underlying philosophical problems, and Section 15 concludes with a structural comparison between Luhmann and Rosen.

The Evolution of Systems Theory

The evolution of systems theory can be read in different ways. Here I shall adopt a structural viewpoint according to which the evolution of systems theory exhibits three main phases of development. The first phase in the evolution of the theory of systems depends heavily upon ideas developed within organic chemistry. ‘Homeostasis’ in particular is the guiding idea: A system is a dynamic whole able to maintain its working conditions. In order to define a system, one needs (1) components, (2) mutual interactions; (3) the environment in which the system is situated; (4) a boundary distinguishing the system from its environment.

The main intuition behind this first understanding of dynamic systems is well expressed by the following passage: “The most general and fundamental property of a system is the interdependence of parts or variables. Interdependence consists in the existence of determinate relationships among the parts or variables as contrasted with randomness of variability. In other words, interdependence is order in the relationship among the components which enter
into a system. This order must have a tendency to self-maintenance, which is very generally expressed in the concept of equilibrium. It need not, however, be a static self-maintenance or a stable equilibrium. It may be an ordered process of change – a process following a determinate pattern rather than random variability relative to the starting point. This is called a moving equilibrium and is well exemplified by growth” (Parsons, 1951, p. 107).

The main result achieved by the first phase of development of system theory has been the proof that the system as a whole is defined by properties not pertaining to any of its parts – a patently non-reductionist view. Global equilibrium, say, is a property of the whole system, not of its parts.

The definition of a system as the whole resulting from the interactions among its components, however, contains a number of hidden assumptions. Subsequent developments of system theory have sought to address and understand these hidden assumptions. There follow the main assumptions hidden within the initial definition of a system:

• The first assumption is that all the system’s components are given in advance, before its constitution. The underlying idea is that the system collects and organizes elements that are already there. We shall discuss this problem under the heading of the system’s constitution.

• The second assumption places all changes on the side of the environment. What about systems able to learn and to develop new strategies with which to cope better with survival or other problems they may encounter? Systems endowed with this property will be called adaptive.

• The third assumption becomes explicit as soon as the problem of the historical continuity of the system through time is addressed. What happens when a new component enters the system or is generated internally? What happens when a component is no longer part of the system, or dies out? As we have already seen, this group of questions can be summarized as the problem of the reproduction of the system.

The overall outcome of constitution, adaptation and reproduction is complexity, although this of a type rather different from any of the mainstream conceptualizations of complexity (Poli, 2009).

The first two assumptions have produced an extensive body of literature, whose main results can be summarized by distinguishing two different types of both constitution and adaptation. The two forms of constitution are the bottom-up type of constitution from components of the system (that are already available), and the top-down constitution from (a previous stage of) the system into its components. This latter form of constitution again assumes two guises: as constraints on initial conditions and the phase space of the system components, and as the development of a new organizational layer of the system.

In their turn, organizational layers are a structural condition needed by developing adaptive systems. In fact, an adaptive system needs both (1) rules governing the system’s interactions with its environment and with other systems, and (2) a higher-order layer that can change such rules of interaction. These changes may be purely random, or they may follow pre-established, or acquired, patterns. In this regard, a hypothesis can be advanced which claims that the main difference between non-living natural systems on the one hand, and living natural systems, psychological systems and social systems on the other, is that the former have only one single organizational layer of interactions; the latter, more complex, systems have at least two layers of organization: the one governing interactions and the one capable of modifying the rules of interaction.
Furthermore, the persistence over time of living systems is made possible by multi-
stability – a form of dynamic stability to perturbations that prevents the destabilization and 
rapid disappearance of such systems.

The third of the three above-mentioned assumptions is the most important one. Indeed, the 
unfolding of the third hidden assumption – the problem of the system’s reproduction over 
time – has dramatically modified the entire landscape of system theory. The theory of auto-
poietic systems is possibly the best-known result connected with the problem of systems’ re-
production. In this regard, it is worth considering that the theory of autopoietic systems is 
itself in need of further generalizations. The simplest generalization of these is well repre-
sented by Niklas Luhmann’s theory of social systems. The second possibility is well repre-
sented by Robert Rosen, who some twenty years before the birth of the theory of autopoietic 
systems proposed what he called (M,R)-systems (from Metabolism and Repair), which subse-
quently developed into the theory of anticipatory systems (Rosen, 1985). As it results, 
Rosen’s theory is both more general and more precise than the theory of autopoietic systems. 
In what follows, after a short description of autopoietic systems, I shall first sketch some as-
pects of Luhmann’s theory of social systems and then present Rosen’s proposal.

**Autopoietic Systems**

Autopoiesis is the capacity of a system to reproduce the components of which it is com-
posed. A multicellular organism thus generates and regenerates the very cells of which it is 
composed; a unicellular organism generates and regenerates the components of the cell ((Ma-
turana & Varela, 1980), (Maturana, Autopoiesis, 1981)).

Autopoiesis dramatically modifies systems theory. An autopoietic system does not start 
from pre-given elements, neither does it assemble them. Furthermore, autopoiesis does not 
come in degrees: either a system is autopoietic or it is not (in due time we will see why this is 
so). For an autopoietic system, the classic distinctions between system and environment and 
between closed and open systems acquire a new valence. Autopoietic systems are self-
referential systems, meaning that the system’s relational self-production governs the system’s 
capacity to have contacts with its environment. Put otherwise, the system’s connection with 
its environment is no longer a kind of immediate and direct relation between the system and 
its environment but becomes a reflexive relation, mediated by the self-referential loops that 
constitute the system itself.

As far as autopoietic or self-referential systems are concerned, the guiding relation is no 
longer the “system environment” duality, but the “system system” intra-relations, or 
automorphisms. For autopoietic systems, the classic difference between open and closed sys-
tems – where open means that the system’s boundary is porous and lets both the system and 
its environment exchange matter and energy – acquires a new and different meaning: while 
openness maintains the previous meaning of exchange with the environment, closure now 
means the generation of structure, understood as the set of constraints governing the system’s 
internal processes. Closure (or structure), then, organizes the system as a holon, or integral 
whole. The guiding connection changes from the system-environment connection to that be-
tween the system and its own complexity, understood as the system’s capacity to adjust its 
own functional organization and internal structure.

**Luhmann’s Theory of Social Systems**

Luhmann generalizes the theory of autopoietic systems to psychological and social sys-
tems. According to Luhmann, both psychological and social systems are autopoietic systems, 
i.e. both are dynamic, autonomous, self-referential systems able to produce their own ele-
ments. To tell the truth, Luhmann says very little about psychological systems and focuses almost all his efforts on the understanding of social systems.

We have already seen that Luhmann is better understood as contributing to an already ongoing strand of sociological thought. Taken at its face value, the Pareto—Parsons—Luhmann connection shows the evolution, internal to sociological theory, of the problem of the reproduction of social systems. To repeat: according to Pareto the temporal continuity of a social system (its reproduction) is based on the (biological) reproduction of the individuals that make up the system; Parsons moved to a properly social kind of reproduction and claimed that the reproduction of a social system is provided by the reproduction of its (social) roles (patterns of action); finally, Luhmann noted that the reproduction of the roles that structure a social system requires the reproduction or reconstitution of the meanings attached to those roles.

Apart from the evident increase of the level of abstraction shown by the three theories, quite a few substantial consequences derive from them. Here are some of the most apparent.

The three mentioned theories are more and more dynamically flexible. Biological reproduction presents such an overtly slow pace of change that we can leave it aside. More interesting are the other two cases. The social reproduction of roles, in fact, exhibits a pace of change remarkably faster than the pace of the biological reproduction of individuals. Parsons notes that roles form a system of roles in which they interact with each other. What is reproduced, therefore, is the system of roles and their mutual dependencies. Luhmann notes that Parsons’ reproduction of roles contains a hidden assumption, namely that the meanings of the roles remain the same. Provided that the roles’ meanings remain constant, the system of roles and their dependences admits only limited variations. On the other hand, as soon as one accepts that meanings are themselves in need of being reproduced, the system acquires a further degree of flexibility. To provide an obvious exemplification, consider family roles over the past few decades. According to Parsons, there is only a limited number of ways in which family roles can constitute the viable, stable subsystem ‘family’, and in which this subsystem can interact in a viable way with other social subsystems. By adding the layer of roles’ meanings, Luhmann makes explicit the fact that the specific meanings of, say, being a father or mother change and these changes add new variations to the way in which family roles make up the system ‘family’.

The second important outcome arising from the series of the three theories we are considering is connected to the question of the basic units of a social system. The question is: Of what is a social system made? Or: What are the elements that make up a social system?

The question is much less trivial than appears. Pareto’s answer is the less surprising one: A social system is composed of individual human beings. Agents are the system’s units of reproduction.

Parsons’ answer, instead, is that roles are the units of a social system, not agents. Luhmann continues along the path opened by Parsons by adding meanings as the units of reproduction of roles.

To avoid mixing up different threads, it is mandatory to distinguish ‘society’ from ‘social system’. As Parsons explicitly says, “a society is composed of human individuals, organisms; but a social system is not, and for a very important reason, namely, that the unit of a partial social system is a role and not the individual” (from the discussion between Ruesch, Parsons and Rapoport, as reported by (Grinker, 1956, p. 328). Note the explicit link between ‘society’ and ‘organisms’, which implies that ‘society’ is understood more as a biological than a sociological term.

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The proposals of Parsons and Luhmann represent substantial moves towards a dematerialization of social systems. According to both Parsons and Luhmann, social systems are non-material systems, they are relational systems over a material basis. Neither of them denies that an underlying material basis is needed. The real nature of a social system, however, is not conveyed by its material basis. There is no way to understand what distinguishes social systems from other kinds of systems by studying the biological entities that happen to bear them or the physical environment in which they happen to be embedded. This is not to deny that some information may derive from biology or physics. The thesis instead claims that what is specifically social of social systems does not derive from other types of systems, biological or physical. In other words, social systems are higher-order systems organized in such a way that their reproduction is governed by the reproduction of properly social units and not by the reproduction of the units that characterize their underlying material bases. The reproduction of a social system requires authentically social units of reproduction. To repeat, this does not imply that social systems are entirely independent from their underlying material basis. They need a supporting material basis. However, the important result is that, once such a basis has somehow been given, the reproduction of the higher system does follow its own relational laws. Without this theoretical move, sociology cannot be constituted as a science. In the end, it is fair to acknowledge that neither Parsons nor Luhmann were able to spell out the details of this major ontological problem, for which the theory of levels of reality is needed ((Poli, 2001), (Poli, 2007)). Occasionally, Luhmann himself speaks as if he were aware of such a theory, as when he notes that “by proceeding in the way he did, Parsons avoided every sort of reduction to levels of reality that do not consist in actions, such as material substrates or ideas” (Luhmann, 1982, p. 49). The evidence, however, is scant, and runs counter to Luhmann’s constant dismissal of what he calls the old ontological viewpoint. According to Luhmann, an ontological approach is based on a hierarchization of levels. Correct intuitions mix here with basic mistakes. That some ontological hierarchy is needed is not denied by Luhmann: a social system needs to be borne by some other kind of reality – surely by some biological kind of reality and perhaps even by some physical kind of reality. On the other hand, an ontological perspective does not have to claim that social systems must reproduce within themselves the same hierarchy that connects them to their bearers. As soon as the problem is reformulated in this way, its absurdity becomes apparent. Otherwise stated, there is no principled reason why a contemporary ontological framework could not accept both ontological hierarchies – such as the bearer/borne hierarchy between the material and the social levels of reality – and functional differentiation within a level of reality – such as the differentiation of the social level into its functional subsystems. I am perfectly aware that few contemporary proposals are sufficiently flexible to accept so articulated a framework (which may become even more articulated when the psychological level of reality is included). On the other hand, the ontological framework that I have been developing during the past fifteen years does so ((Poli, 2001) (Poli, 2006a) (Poli, 2007)).

I distinguish three main strata of reality (material, psychological and social) in such a way that (1) each of them is characterized by a different group of ontological categories; (2) they are connected by relations of existential dependence organized in a manner such that (i) the material stratum is the bearer of both the psychological and the social strata of reality, (ii) the psychological and the social strata jointly co-evolve from their material bearer, and (iii) they depend reciprocally on each other (all this is explicitly Luhmannian); (3) each stratum of reality presents its own internal organization. Interestingly, the material stratum presents a mainly hierarchical internal organization (well represented by the physics—chemistry—biology series), while the social stratum—as we know it today—is based on an internal organization of a functional nature, and the psychological stratum presents a still different internal organization,
somewhat intermediate between the hierarchical and functional organization of the other two strata of reality.

A general ontological framework such as the one just sketched can clarify some difficult problems. To provide an exemplification, while I fully endorse the thesis that “in the relationship of emergence there is not more or less reality, not diminishing reality” (Luhmann, 1995a, p. 111), I have doubts concerning the correctness of the immediately following sentence, “but rather variably selective connectivity. This is a matter of re-establishing transparency despite opaque complexity, and that can only be attained as new levels of system formation emerge.” Leaving aside Luhmann’s understanding of complexity (on which see Section 8 below), what Luhmann says makes sense only from the point of view of social systems, that is, from the point of view of the strategies that a social system can implement to understand and eventually exploit its external environment (i.e. the levels of reality working as material bearers of the social system). On the other hand, the claim comes close to nonsense as far as the ontological connection between the social level and its material bearer is concerned.

Be that as it may, and with all the limitations we can ascribe to their theories, Parsons and Luhmann nevertheless had the merit—beyond their explicit intentions—of raising the problem of the ontological autonomy of the social level from its material basis.

Communication

The units of meaning used by a social system for its reproduction are communications (Luhmann, 1986, p. 174). From (Bühler, 1934) Luhmann derives the idea that communications are three-sided phenomena based on information, utterance and understanding. Information is the selection of what has to be communicated, utterance is the how of the communication, understanding refers to what the receiver grasps from the previous two aspects of a communication. As Baeccker says, “not the speaker but the listener decides on the meaning of a message” (Baeccker, 2001, p. 66). None of the three components on its own is a communication. Only the three components together form a communication, which implies that a communication can never be attributed to any one individual (Seidl, 2005, p. 29). Communications – as Luhmann defines them – are from the very beginning social acts, for the simple reason that an act of communication requires both a speaker and a listener. Communications come in series, one after the other, and form systems of communication.

In Luhmann’s words: “we can speak of a ‘social system’ whenever the actions of several persons are meaningfully interrelated and are thus, in their very interconnectedness, marked off from an environment. As soon as any communication whatsoever takes place among individuals, social systems emerge” (Luhmann, 1982, p. 70).

Communications generate further communications, and from these a social system emerges. When all communications end, when all the communications are rejected, the connected social system vanishes. The social system at large is the collection of all the ongoing communications. This is an autopoietic system that maintains (reproduces) itself through the reproduction of units, namely communications.

Having established that communications are the basic units of reproduction of social systems, the next step is to distinguish specific, different types of communications. Different types of communications form different social subsystems within the overall, inclusive social system as a whole. Here Luhmann distinguishes two main cases. Face-to-face communications are the units for interactions, and decisions are those communications that operate as the units for organizations.
To avoid misunderstandings between the social system as the inclusive whole containing all the ongoing communications and subsystems based on particular types of communication, the expression ‘societal system’ will refer only to the system of all the communications, while the expression ‘social system’ will be used generically and will be understood as denoting three different types of systems, namely interactions, organizations, and societal systems. “This triadic distinction corresponds to the most important centers of gravity in current sociological research: the theory of face-to-face behavior or symbolically mediated interaction, the theory of organizations, and (admittedly only feebly developed) approaches to a theory of society” (Luhmann, 1982, p. 71).

Each type of social system has its own specific features. Interactions require the effective presence of the interacting agents, which should perceive each other. Only the agents that are present belong to the system of interactions. Interactions, furthermore, develop by focusing on one issue at a time. Participants may change focus, but they are nevertheless constrained to organize subjects of communication into a temporal series.

The requirements of actual presence and thematic focus are strong constraints and they impose severe limitations on capacities for interaction. More complex issues require other systems of communication. Actual presence is the obvious requirement to be dropped. Communication should be also possible with those that are not face-to-face present. Organizations and societal systems can do this.

Organizations are those systems based on membership conditions. Joining and leaving organizations are conditioned procedures. Societal systems, finally, are more than the mere sum of communications. Aggregates of communications do not have the structure required for them to be systems. According to Luhmann, societal systems are social systems, which implies that they are autopoietic systems and need appropriate forms of reproduction.

An important difference between interactions and organizations, on the one hand, and societal systems on the other is that interactions and organizations can always start and stop, begin and end, while societal systems—society—cannot stop. Society is the underlying, ongoing general social system within which all the other types of social system find their place.

This raises difficult problems, both substantive and methodological. While interactions and organizations can be studied against the background of societal systems, what is the background against which one can study societal systems themselves?

Before this problem is addressed, something more must be said about the internal organization of societies.

Functional Subsystems

Modern social systems are different from previous kinds of social system because they are functionally organized into subsystems (economy, policy, law, science, art, etc).

All systems—according to Luhmann—must possess the capacity to distinguish relevant from irrelevant communications. Apart from this basic capacity, functional subsystems are characterized by specific codes: legal subsystems organize communication along the legal/illegal opposition, political subsystems along the power/non-power opposition, scientific subsystem along the true/untrue opposition, etc.

Each subsystem sees the other subsystems as components of its environment. Subsystems are not supposed to ‘understand’ each other, i.e. to share the same constitutive codes, the same basic distinctions. Subsystems read whatever is deemed relevant of the whole social system iuxta propria principia, from their own viewpoint.
Interaction between subsystems and face-to-face interactions share the same basic format of what Parsons called ‘double contingency’. I quote: “each actor is both acting agent and object both to himself and to others” and “as acting agent, he orients to himself and to others and, as object, has meaning to himself and to others, in all of the primary modes or aspects” (Parsons 1968, p. 436). From the point of view of functional subsystems, say A and B, double contingency means that (1) A understands B from the point of view of its own code and B understands A from the point of view of its own code; (2) A knows that B reads the actions of A from the point of view of the code of B and B knows that A reads the actions of B from the point of view of the code of A; (3) A takes its decisions knowing what is relevant to both A and B, and B takes its decisions knowing what is relevant to both A and B; (4) B is meaningful to A and A is meaningful to B.

The first two components spell out the former part of the above quotation from Parsons; the last two components spell out a fragment of its latter part (I have not detailed the various components of the clause “all of the primary modes or aspects”, which refers to Parsons’ idea of action as a system of relations and not as an event).

Apart from major subsystems—such as the political and legal ones—the second part of Parsons quote—the one specified by (3) and (4)—loses some of its force as soon as the subsystems are multiplied. When several different functional subsystems work in parallel, each of them tends to lose contact with the codes and internal relevancies of the other subsystems. One can describe the phenomenon by noting that functional subsystems, once constituted, tend to develop and maintain their own identities and working conditions independently of the other subsystems. This natural dynamic evolution of functional subsystems towards progressive independence and autonomization helps explain several aspects of the current social situation.

**Autopoietic Social Systems**

Autopoietic social systems regulate the exchange with their environment. From the point of view of the theory of autopoietic systems, the environment is not itself a system. The environment does not send ‘signals’ or ‘inputs’ to the system; system and environment do not share a common code. What the environment can do is perturb the system. The environment may eventually “trigger internal processes, but cannot determine those processes” (Seidl, 2005, p. 23). The processes triggered by the environment follow their own internal dynamic laws and communicate only with other processes internal to the system. All communications take place within the system; there is no communicative exchange between the system and its environment.

The relation linking a system to its environment is called structural coupling. Different systems may be related to each other in the form of a structural coupling whereby one of the systems becomes the environment of the other system. Eventually both systems can become each other’s environment.

Whenever different systems are structurally coupled, the exchanges that occur between them take the form of perturbations. In this sense, the brain perturbs the mind (nerve impulses are not thoughts), social systems perturb psychological systems, and vice versa (communications are not thoughts), functionally different social subsystems perturb one another.

As we have said, autopoietic systems do not communicate with their environment. What they can do is exploit the system/environment relation and reproduce the same distinction within the system. This re-entry of the system/environment distinction within the system is the source of the system’s structure. According to Luhmann, the possibility itself for a system
to apply to itself the distinction between the system and its environment requires that the system be capable of observing itself.

The observational re-entry that generates the structure of the system constitutes the second level (or cycle) of autopoietic reproduction.

The capacity of self-observation can alternatively be described as the capacity to produce a description of oneself, or as the ability to follow a norm. An operational implementation of the last version could take the form of a regulatory mechanism able to restore the functioning of the system whenever it goes wrong.

The claim that autopoietic social systems observe themselves raises a major problem. In the case of interactions and organizations, we can detect their unfolding. In both cases, acts of communication and decisions follow one another and form usually identifiable series of acts. We can understand interactions and organizations because they unfold against the background of the social system that includes them. Furthermore, both interactions and organization are patently able to observe themselves, either through the actors’ capacity to observe themselves and the ongoing communication or through the organization’s sense of identity and decision style. On the other hand, when the object of analysis is given by the social system as a whole, we have neither a background against which to place the social system nor suitable acts, observational data or identity conditions to exploit. Whatever it is that lets social systems maintain their working conditions, it is not directly visible. Luhmann may possibly be right in claiming that self-observation, or something similar, is needed. On the other hand, the question is this: How can this claim be proved? How can we prove something that is not visibly detectable?

What we see and can study are both the micro-systems provided by interactions and organizations and the macro-systems represented by the various functional subsystems. None of these, however, is anything like an entire social system.

These problems make explicit why theories of social systems are so scarce. Luhmann is possibly the scholar who has gone furthest along the route to an encompassing theory of social systems. I do not think it is unfair, however, to maintain that he has got no further than halfway.

It is worth noting that the lack of a general theory of its reference object does not afflict sociology alone. Biology is in the same situation. Notwithstanding all the astonishing results that support contemporary biology, it does not have a theory of organisms. And cognitive science likewise: Whatever exciting results mark its development, those working in the field do not have a shared theory about consciousness. The interesting fact is that biologists, cognitive scientists and sociologists are all collecting vast amounts of data and discovering many new truths literally without knowing what they are working on.

This situation requires attention. Something deep seems at work here. I am not bold enough to claim that I have the solution and can explain what is going on in these different situations. For the time being, what I suggest is that serious consideration should be made of relational biology and in particular the ideas of the late Robert Rosen, who was a mathematical biologist with a systemic orientation. In this sense, he worked within the same framework as adopted by Maturana, Varela, Parsons and Luhmann.

Rosen’s (M,R)-systems

The starting point of Rosen’s theory was relational biology, as developed by (Rashevsky, 1954). The main idea behind relational biology is that organisms are something more than their material basis. As Rashevsky was wont to say, in order to understand organisms one
should “throw away the matter and keep the underlying organization”. Matter, the physical
basis of organisms, is simply immaterial to their nature as organisms. While neither Maturana
nor Varela make reference to Rashevsky, autopoietic systems can be seen as possibly the
simplest descriptive way to articulate relational biology. On the other hand, Robert Rosen's
(M,R)-systems (Rosen, 1958) are the simplest mathematical models mimicking autopoietic
systems. In this regard, it is worth noting that Rosen’s proposal antedates Maturana’s by more
than twenty years.

Some of the subtleties of (M,R)-systems are spelled out by (Rosen, 1972). For an intro-
duction, see (Louie, 2008) and (Nadin, 2010a). Deeper analyses have been conducted by
(Louie & Kercel, 2007) (still accessible) and (Louie, 2006) (hard). The most systematic
treatment of Rosen’s systems is provided by (Louie, 2009). General discussion of Rosen’s
ideas is provided by the collections (Baianu, 2006), (Mikulecky, 2007) and the special issue
(What is Life?, 2008).

Omitting all the mathematical details (which, however, are far from being irrelevant), the
main outcome arising from Rosen’s systems is that they provide a natural way to distinguish
at least two main types of higher-order complexity. The guiding idea is that the main differ-
ence between mechanisms and organisms is that organisms, but not mechanisms, are closed
to efficient causation. The claim of closure to efficient causation means that the processes are
mutually entailed within a system more complex than a mechanism; they form hierarchical
loops (also known as ‘impredicatives’ – on the logical coherence of impredicatives see (Dev-
lin, 1991, p. 155-159). The obvious next step is to distinguish between systems in which at
least some of their internal processes are mutually entailed, on the one hand, and those sys-
tems in which all their internal processes are mutually entailed, on the other.

To spell out these and related differences, I first distinguish between (1) systems based on
some internal algorithmic machinery (simple and complex systems, including chaotic sys-
tems) and (2) systems based on internal dynamics comprising hierarchical loops. For obvious
reasons, the latter systems cannot be based on algorithmic functions. I shall baptize them
‘higher-order or super-complex systems’. In their turn, higher-order complex systems come in
two forms, according to whether only some or all their internal functions are mutually en-
tailed.

The distinction between complex and super-complex systems come close to von Foster’s
distinction between trivial and non-trivial machines (von Foster, 1984) cited by Luhmann
himself, e.g. in his (Luhmann, 1997, p. 362).

To avoid misunderstandings, I use ‘complexity’ in whichever is the mainstream sense of
the term, and I distinguish ‘complexity’ from ‘higher-order complexity’ according to whether
maximal models of the former but not those of the latter are algorithmically implementable.
Less cryptically, complex phenomena are fully codifiable by models based on some algo-
rithmic machinery, while the claim is advanced that no models based on algorithmic machin-
eries are in principle able to completely capture super or higher-order complex phenomena
(for the mathematical details see (Louie, 2009)). The present use of complexity (and higher-
order complexity) is patently different from the concept of complexity used by Luhmann, who
based it on the difference between system and environment (see e.g. (Luhmann, 1995a),
Chap. 5, Part II). From the point of view of Luhmann’s understanding of complexity, the title
of this paper makes no sense—an explicit way to call attention to the fact that a different in-
terpretation of complexity is at work. While the use of the same term for different meanings is
unfortunate, the differences are so marked that no confusion is likely to arise.
On the other hand, while the two theories of Luhmann and Rosen define complexity in remarkably different ways, they both share a major conclusion, namely that ‘complex’ systems irredicibly admit to different descriptions. From a Rosennean viewpoint, this conclusion is entailed by the lack of a maximal model for these systems (the validity of a maximal model implies that the model entirely captures the system—only machines (‘trivial machines’ as von Foster terms them) have maximal models). Luhmann’s viewpoint is more convoluted, and occasionally makes reference to Logfren’s idea of ‘hypercomplexity’, as in (Luhmann, 1995b, p. 176)

Higher-order systems are not systems that are slightly more complex than ordinary complex systems. Complexity and super-complexity are entirely different types of complexity. As Rosen himself says, “Just as ‘infinite’ is not just ‘big’ finite, impredicatives are not just big (complicated) predicatives”. In both cases there is no threshold to cross, in terms of how many repetitions of a rote operation such as ‘add one’ are required to carry one from one realm to the other, nor yet back again” (Rosen, 2000, p. 44).

Living systems are such that all their internal functions are mutually entailed. This also means that hierarchical loops do not have leading centers: any member of a hierarchical loop is implied by other members of the loop.

This description of living systems fits well with Luhmann’s analysis of social systems. To repeat, all the subsystems of a social system are mutually related in such a way that modern social systems do not have any leading subsystem.

The distinction introduced above between two kinds of higher-order complexity raises the problem of which of them is more appropriate to society (and mind, one is tempted to add). Taking for granted that the complexity of social system is certainly not the complexity of mechanisms, it remains to be seen whether society presents the full complexity of a living system or the intermediate complexity characterized by loops linking only some of the system’s internal functions. The answer, however, appears straightforward: society as the overall system encompassing both all types of communication and all its functionally distinguished social subsystems cannot but include all its relational processes and their hierarchical loop. Sub-loops present themselves as natural candidates for specialized tasks, such as those performed by functional subsystems.

The analyses so far presented suggest a general conclusion, namely that none of the encompassing general systems in which we may be interested (organism, mind, society) appear to be understandable by exploiting customary scientific methodologies. None of them can be fully captured by analyzing the parts of which they are made. For all of them something like a logic of the whole is at work. Admittedly, these are cases where most of us are at a loss.

Luhmann had the merit of recognizing the problem and many of its subtleties. Rosen, however, did something more: he provided both (1) a deeper and clearer conceptual analysis of the intrinsic complexity of these systems and (2) a mathematical codification (which we have entirely skipped) for better delving into the intricacies of the arising, and often so awkward, problems.

To further test the fruitfulness of the framework I have sketched, I now discuss a couple of further issues, namely the problem of anticipation or of those systems endowed with the capacity to make anticipations, and the role of anticipations in the case of conflicts.

**Anticipation**

What is anticipation? The short answer is: Anticipation is future-based information acting in the present situation. The simplest way to understand anticipation is to think about the pro-
jects, plans and aims that persons may have. Occasionally some of these may even operate in an implicit way, i.e. below the threshold of consciousness. Social systems as well may comprise implicit forms of anticipation hidden in their internal loops.

The somewhat longer answer states that anticipation has two aspects: (1) the system has an idea or model of its future development, and (2) it uses the information related to that idea or model to take its decisions in the present. If, according to the values accepted by the system, the model projects a positive evolution of the system, the system tries to realize the projected development; on the other hand, if the model projects a negative evolution of the system, the system may try to modify its trajectory (Poli, 2010a).

Many more details need to be added to this first outline if a reasonable picture is to be developed. For instance, the system may know that it is heading towards a negative outcome, but it may feel unable to change its behavior, or it may reject the very idea of changing behavior. Or the anticipatory model may be wrong and may take for positive outcomes ones that in reality are negative, or the other way round.

The first groundbreaking systematic study of anticipation has been (Rosen, 1985). After years of neglect, interest in his ideas is regaining momentum. For a survey, see (Poli, 2010b) and the annotated bibliography (Nadin, 2010b). I shall focus only on the simplest aspects of anticipation, leaving further developments for other occasions.

Anticipation comes in different guises. The main distinction is between explicit and implicit types of anticipation. Explicit types of anticipation can be used synonymously with prediction and/or expectation, while implicit types of anticipation are properties of the system intrinsic to its functioning. In this regard, we may ask whether we are “consciously creating anticipations on basis of which we plan and make decisions, or are anticipations and decisions making made for us?” (Riegler, 2003, p. 11).

Secondly to be considered is the distinction between anticipation as a simple looking into the future and anticipation as the capacity to take account of the consequences of that looking, i.e. its impact on current behavior. This second distinction may appear to be trivial, yet many conflicts spring from a kind of blindness to the consequences of the actions performed.

The most efficient way to learn how to foresee each other’s reasons and actions is to devise forms of institutionalization of agents’ expectations. Institutionalization lowers uncertainty, and less uncertainty augments confidence. “Instead of getting overwhelmed by the details of a new situation, humans seek to replace them with familiar activity and behavioral patterns that show a high degree of predictability to putatively gain control again, to be able to anticipate the outcome” (Riegler, 2003, p. 12).

The problem with institutionalization, however, is that it generates forms of blindness towards whatever does not match its internal codes. Institutionalized behavior may not be able to detect what futurists call ‘weak signals’, namely early and usually minor behavioral differences that may eventually grow and become new behavioral patterns.

Furthermore, consideration should be made of the distinction between anticipation as a descriptive feature exhibited by some systems and the conditions that the system should possess in order to make anticipation possible (on the difference between anticipation as a descriptive feature and the conditions that make anticipation possible see (Poli, 2010b).

Moreover, no description is able entirely to capture an anticipatory system. Side effects are structural features of anticipatory systems. By default, when the system carries out a particular activity, it uses only some of its internal resources (technically speaking, only some of its degrees of freedom; or only some of its functional subsystems are entitled to assume such
activity). Side effects are due to the tension between the fact that the system’s dynamics characterize it as a whole (the equations of the system’s motion link all the variables defining the system) whilst the system’s functional activities require only some of its variables. The variables not involved in any particular functional activity are therefore free to interact with other systems in a non-functional way, and even in a dysfunctional one (see the reconstruction in (Poli, 2010a).

A major consequence is that activities will in general have effects on a system other than those which are planned. However, there are often typical ways in which a system can go wrong. It may therefore be possible to develop diagnostic tools and devise appropriate responses.

The Functional Structure of Anticipation

The simplest scheme of an anticipatory system is shown by Figure 1 below, where an anticipatory system is composed of three parts: a normal (i.e. not anticipatory) system S, a model M of S, and a steering device D able to steer S according to the outcomes of M.

The only internal condition is that the model should be able to run faster than the system itself. In this way the model can precalculate the evolution of the system S. Apparently, Luhmann’s reference to “the utilization of time differences” has some connections with the situation under discussion (see (Luhmann, 1997, p. 364).

Provided that the entire system has the capacity to distinguish positive from negative states, when the model detects that the system is running towards a negative state, it may order the steering device to modify the system’s trajectory. If instead the system is running towards a positive state, the model tells the steering device to maintain the system’s dynamic trajectory. This description of an anticipatory system is simple, but it is nevertheless helpful because it enables us to distinguish some of the typical ways in which an anticipatory system may fail. For instance, it may fail because the model is inadequate and needs updating, or it may fail because the steering device is unable to steer the system (Rosen 1974; Poli, 2010a,b).

Figure 1. The internal configuration of an anticipatory system

Anticipation can be understood at two different levels of abstraction. The simplest approach is to ask which types of controllers make anticipation possible. On considering the problem of the regulatory structure that a system may have, Rosen was able to distinguish different types of controller. In order of complexity, the various cases are the following:

1. System with feedback controllers.
2. System with feed-forward controllers.
3. System with feedback controllers with memory.
4. System with feedforward controllers with memory.

Feedback controllers ‘perceive’ the system’s environment. The most important characteristic of feedback controllers is that they are special-purpose systems: for them, only highly selected aspects of the environment are relevant. Given some selected value, feedback controllers steer the system in order to force it to maintain that value. This is achieved by error signals indicating the difference between some fixed value and the actual value of the selected environmental variable. Within limits, the controllers in this family neutralize environmental variations and are able to keep the system stable. Their main limitation is due to the delay between environmental change and system adjustment: if the changes in the environment happen too rapidly (the exact meaning of ‘too rapidly’ depends on the type and sensitivity of the controller) the controller ends up by tracking fluctuations and rapidly loses its capacity to steer the system.

Unlike feedback controllers, feedforward ones ‘perceive’ the controlled system, not the environment. The simplest way to imagine a feedforward controller is to think of a model of the system as in Figure 1 above. In other words, a material system with a feedforward controller is a system containing a material model of itself. In order to behave as a feedforward controller, the model should run at a velocity faster than the velocity of the system. In this way the model anticipates the possible future state of the system.

The third class of controllers comprises feedback controllers with memory. If a feedback controller is able to leave a trace of the system’s experience, this memory trace can be used to tune the system’s behavior better. A system with this capacity is obviously able to learn from its past experience.

The next class of controllers consists of feedforward controllers with memory. As in the previous case, systems of this type can learn from their past experience. Rosen notes that systems of this type – “ironically”, he says – must use feedback controllers of type 1 for their operations. In fact, they must be able to work on deviations from predicted states (i.e., they need error signals, exactly like type 1 controllers).

One may also consider the idea of general-purpose controllers. All the controllers discussed so far can be described as working on single types of ‘perceptions’ or variables. The obvious next step is to let systems behave in as articulated a way as possible (i.e., exploit as many variables as possible). The only constraints are given by the unavoidable need to use feedback controllers to modify the internal models of systems with this latter type of controllers (Rosen 1974; Poli, 2010a).

On a higher level of abstraction, one forgets all the details concerning the nature of the controllers and considers only the functional connections internal to the system. What emerges in this case is that an anticipatory system presents hierarchical loops among the underlying system S, the model M and the steering device D. This implies that all the relevant information is generated internally to the system. The environment may eventually act on the system as a trigger for actions, not as a source of information (Luhmann, 1995a). Hierarchical loops (or impredicativities as they are called in logic) mean that the system generates its own meanings internally. An anticipatory system is a system able to generate its own behavioral codes, and the formal side of this capacity is provided by hierarchical loops.

Those systems that are capable of observing their own behavior can use this information to generate new structure. This is done by adding self-observations to the hierarchical S-M-D
cycle. The observational re-entry that generates structure constitutes the second level (or cycle) of autopoietic reproduction of an anticipatory system (Poli, 2009).

**Do Anticipations Change?**

A system’s schemata determine how it looks at the environment. They are therefore anticipatory. Schemata construct anticipations of what to expect, and thus enable the system to actually perceive the expected information. Construction imposes anticipations and poses the question of how to construct.

Most anticipations work as acquired habits either through evolution (as in biological anticipation) or learning (as in most cases of psychological and social anticipation). Evolution-based anticipations are difficult to change, for obvious reasons. However, as difficult as they are to change, they may evolve, and this raises the question as to whether we can eventually bend evolution in some or other direction.

According to the theory of anticipation, behavior is almost always goal-oriented rather than being stimulus-driven. Anticipation runs contrary to the claim that psychic processes in general are determined by stimuli (i.e. it is at odds with both Behaviorism and most of current Cognitive Psychology) (for some data see (Poli, 2010b)).

If behavior is indeed goal-oriented, this implies that changes in behavior are filtered by the system’s identity (seen as the second entry in the system’s autopoietic cycles). The reason for this is straightforward. Anticipation is based on feedforward controllers, i.e. on controllers that detect and control the system itself. Changes in the system’s working (i.e. in its identity) are therefore projected by feedforward controllers into new anticipations. From this basic dynamic of the system it follows that the most productive strategy to change the anticipations that a system may have is to modify the system’s dynamic identity.

Anticipation works at many different levels (and sublevels). The least we can assume is that there are biological anticipations, psychological anticipations and social anticipations. As far as conflicts are concerned, the most relevant types of anticipation are obviously the psychological and social ones.

From what we have seen, it is evident that most anticipations work silently: they constrain the system’s behavior without the system being aware of them. Given the connection between anticipation and identity sketched above, this implies that the system knows only some fragments of its own identity.

The main problem with such an extensive family of anticipations is that the different types of anticipation may work together and synthetically produce the system’s general anticipatory patterns, or they may conflict and eventually cancel each other out. Very little is known about these processes, and I am forced to leave their analysis for another occasion.

**Conflicts**

The connection between anticipation and conflicts has been well known since the early days of conflict studies. In fact, the difference between defensive and aggressive conflicts is often articulated in terms of anticipations, as shown by the way in which the basic types of conflicts are usually defined:

- Defensive conflict = when the initiating contendant tries to avoid an anticipated loss.
- Aggressive conflict = when the initiating contendant tries to acquire an anticipated gain.
Furthermore, it is often assumed that power is a scarce resource, i.e. that “what he loses, I gain”. If power is indeed a scarce resource, the obvious consequence is that contenders will try anything to acquire more of it.

To date, conflict studies have taken it for granted that the idea of anticipation is sufficiently clear and does not require further analysis. We have seen, however, that anticipation is far from being properly understood and presents unsuspected complexities. Indeed, the theory of anticipation has many surprises in store. Conflicts, as based on anticipations, embody people’s habits, dispositions, tendencies, and attitudes – and none of these are well understood, to say the least. Much more is involved, however, for systems which are able to anticipate behave in a much more sophisticated way than systems without such a capacity.

If it is true that anticipations essentially depend on hierarchical loops, no complete algorithmic model of anticipatory systems will ever be developed. What we may eventually be able to develop are sets of partial models addressing different aspects of a given anticipatory system.

While some of these models may represent observables and the procedures for dealing with them (e.g. conflict management procedures), other models should try to represent the system’s latents. Since anticipations may be at work behind manifest behavior, we should find ways to map reality not as something entirely manifest but as a field of dispositions and powers, i.e. as a field of possibilities or latents.

The most general way to make latents visible is to change the system’s boundaries. The simplest strategy is to embed the system within a larger context or system. In fact, most systems change their dynamic patterns when embedded within larger systems. Inducing new dynamic patterns via embeddings within larger systems is usually less difficult than trying to change the system’s dynamics in a direct way.

When embedding into larger systems proves not to be a viable strategy, the opposite strategy of segmenting the original system into smaller systems can be tried.

For those cases in which none of the usual strategies work, one may try to induce (controlled) dynamic dissonances into the system. This is a potentially dangerous option, because it may definitively ruin the system. However, there may be cases in which the induction of dissonances is the only option available. The presence of internal dissonances forces the system to reconsider its dynamic identity and eventually change its guiding patterns, e.g. by reconfiguring what it considers to be good and bad.

**Systems of Higher-order Complexity**

Although widely incomplete, the theory of higher-order complexity paves the way for a new, deeply innovative, vision. Even if most details of this new vision are only starting to become dimly visible, some of its categorical requirements are nevertheless surfacing. In this section, I shall offer for discussion the idea that higher-order complexity requires at least four different categorical frameworks, namely those provided by the theories of levels of reality, chronotopoids, (generalized) interactions, and anticipation.

Put briefly:

- The theory of levels of reality provides the basic ontological framework for articulating the relations of dependence and autonomy between entities. See (Poli, 2001) for a first introduction to the theory.

- In its turn, the theory of levels paves the way for the claim that there may be different families of times and spaces, each with its own structure. The claim is that there are numerous
types of real times and spaces endowed with structures that may differ greatly from each other. The qualifier ‘real’ is mandatory, since the problem is not the trivial one that different abstract theories of space and time can eventually be and have been constructed. I shall treat the general problem of space and time as a problem of chronotopoids (understood jointly, or separated into chronoids and topoids). The guiding intuition is that each stratum of reality comes equipped with its own family of chronotopoids (see Poli, 2007) for further details.

- The theory of levels of reality also provides the natural framework in which to develop a full-fledged theory of causal dependences (interactions). As in the case of chronotopoids, the theory of levels of reality supports the hypothesis that any level has its own form of causality/interaction (or family of forms of causality/interaction). Material, psychological and social forms of causality/interaction may therefore be distinguished (and compared) in a principled way. Besides the usual kinds of basic causality between phenomena of the same nature, the theory of levels enables us to distinguish upward and downward forms of causality/interaction (from the lower level to the upper one and vice versa).

- An anticipatory system is a system such that the choice of the action to perform depends on the system’s anticipations of the evolution of itself and/or the environment in which it is situated; reactive systems, on the contrary, are such that subsequent states depend entirely on preceding states. Whatever organisms, minds and societies may be, I take it for granted that they cannot be understood as purely reactive systems.

A couple of short addenda on anticipation are worth considering. First, given that anticipation requires only that the system contains a hierarchical loop including at least some of the system’s functions, also non-living systems can be anticipatory. Second, organisms, minds and society require the capacity to coordinate the rhythm of the overall system with those of its parts. These general systems are all multi-strata systems composed of different types of components interacting at different functional levels and at different levels of organization. While most details of these highly complex systems are still unknown, the possibility should be considered that the anticipatory capacities of the system as a whole may diverge from those of its subsystems.

**Latents and Other Philosophical Conundrums**

The cursory reference to latents in Section 12 above requires brief explanation. The only aspect that I need to touch upon is that reality comprises not only what is actually given but also dispositions, habits, tendencies, and the forces generating them. These are collectively called latents.

Even if latents may not be actually detectable in any given situation, they may nevertheless be there. Latents may become actual if proper triggering conditions are in place, or they may be lost in the process. The simplest case of latents is given by dispositions, which can be described under the label “what would happen if” (what would happen if sugar were added to a liquid, or if the country went to war). Occasionally, latents can be perceived even when they are not exercised. They form a kind of halo around persons and situations. Individual and group decisions can actually be based on the perception of latents. The lack of a general theory of latents, however, makes it difficult both to organize systematically the psychological and social data already available and to guide research towards a better understanding of the less known aspects of the systemic perception of latents. Be that as it may, a major difference between the behavior of people and the behavior of institutions is that the latter seem remarkably less able to perceive latents. This raises an interesting side to the problem of institutionalization, namely the passage from more flexible, generic structures to more constrained...
and more specialized ones. I am forced, however, to leave discussion of this issue to another occasion.

The most relevant latents of interest here are provided by the hierarchical loops governing the general encompassing types of system—organism, mind and society. As we have seen, all them seem to be governed by normally undetectable hierarchical loops, which implies that they depend on the working presence of suitable latents.

Some other comments on philosophical matters are needed. One of the main problems with Luhmann—but not with Rosen—is his rather idiosyncratic understanding of ontology. Apparently, Luhmann believes that ontology starts from a pre-given set of elements, and it studies the combination of those elements. As he repeatedly says, the unity of the system’s elements is not something that is ontologically given (e.g. (Luhmann, 1995a) and elsewhere). I for one have no problem in accepting his claim. I think it is also important to note that, whilst some ontologists have indeed defended atomistic ontologies, almost all the great figures in ontology have defended much more sophisticated ontological frameworks. Indeed, the idea itself of focusing the analysis of the ontological import of the theory on the status of the system’s elements alone is patently too restrictive. The real issue, in fact, is not the ontological status of elements but the ontologival status of the systems themselves, and in particular the ontological status of autopoietic systems. Provided that the theories partially discussed in this paper are correct, the conclusion is straightforward: biological, psychological and social realities have the nature of autopoietic systems (eventually of generalized autopoietic systems). This is a major ontological claim, which gives us important insights into at least one of the major differences between physical and chemical systems, on the one hand, and biological, psychological and social systems on the other. Luhmann occasionally shows that he has some understanding of the problems that lie behind all these questions, for instance when he asserts that “autopoietic systems … do not create a material world of their own. They presuppose others levels of reality” (Luhmann, 1986). Even if this quotation is not entirely correct, because biological entities are material entities, it nevertheless moves in the right direction, namely the thesis that autopoietic systems are relational systems which can be realized by material systems. To repeat Rashevsky’s vivid dictum in a slightly modified version: in order to understand autopoietic systems, “throw away the matter and keep the underlying organization”. Clarifying the ontological nature of autopoieisis is one of the problems on the agenda of contemporary ontologists.

The second problem to be mentioned is that there is no reason to identify the system’s composing elements with its units of reproduction. Many interesting wholes present both a material and a functional kinds of composition.

The third problem is the connection between latents (see (Poli, 2006b), (Poli, 2009)) and autopoietic systems. The shortest answer is that, from the point of view of elements (again!), many aspects of the systems of which they are parts are latent: systems constrain the behaviour of the elements without obviously being part of them. The fact that (at least some) elements may have been generated by the system makes the system’s latency even more interesting. It has been recently suggested that one of the consequences of the downward causation exerted by the system on its elements is non-locality: “The causation is seemingly everywhere in the process and not localizable at any specific place”. A further consequence is the “inability to tease the causal links apart” (Kercel, 2004, p. 15), a consequence explicitly discussed by (Rosen, 1985).

Lastly, what is the complexity of self-reference? Needless to say, self-referential systems cannot be entirely based on rote, algorithmic frameworks. Even if any of their states can obviously be simulated, self-referential systems, almost by definition, escape the possibilities of
rote iteration. This argument only shows that the complexity of a self-referential system extends well beyond mainstream complexity theory. For this reason, the idea of systems of higher-order complexity has been introduced. As we have seen, these types of systems come in at least two forms: self-referential (or impredicative) systems, and living systems. Anticipation is but one of the many intriguing features of self-referential systems. Living systems are those self-referential systems in which all internal functional relations are entangled within one overall hierarchical loop. The really surprising outcome is that self-referentiality does not necessarily require life. Also non-living systems can be self-referential systems. However surprising, this conclusion is nevertheless most welcome because it shows that reality still has many surprises in store.

From Luhmann to Rosen and Back

Only the most general aspects of Luhmann and Rosen’s theories have been considered by this paper. Even at such an ethereal level of abstraction, however, it is apparent that their theories are closer to each other than one might think.

I shall restrict my remarks only to the following two aspects. Luhmann states that “auto-poiesis, as a concept, has no empirical explanatory value. Its potential lies rather in the fact that forces other concepts into adaptation” ((Luhmann, “Organisation und Entscheidung”, 2000), quoted by (Seidl & Becker, 2005, p. 11). As a matter of fact, Luhmann’s claim is overstated: almost all innovative frameworks require what may be a long period of maturation before they are ready for application. Be that as it may, both Luhmann and Rosen’s theories have been used to model real, empirical situations. From the point of view of Rosen, Luhmann’s lack of “empirical, explanatory value” assumes the form of the realization of (M,R)-systems. As Louie writes, “functional organization cuts across physical structures, and a physical structure is simultaneously involved in a variety of functional activities” (Louie, 2006, p. 36). Hence there is no obvious translation (‘realization’) of an (M,R)-system into a biological individual. (M,R)-systems provide a conceptually very abstract framework in which to understand life. The realization of life into actual organisms requires many more details extending beyond (M,R)-systems. The same applies to Luhmann’s social system theory, which addresses only the most basic, the deepest, aspect of social systems. Many more details are needed in order to understand this or that concrete system. I for one fail to see why all this should be a problem.

The second problem that I shall discuss concerns the question of the structure of an autopoietic system. I mentioned above that structure is related to the second autopoietic cycle of an autopoietic social system. From the point of view of Luhmann’s theory, the first autopoietic cycle realizes the constitution of the system, while the second cycle generates the system’s identity. Interestingly, Rosen also stresses that the minimal (M,R)-system is based on two relations, namely metabolism and repair. Metabolism is the basic activity that constitutes the system, repair is modification of the system’s dynamics according to some norm. Whenever the system’s dynamics (its metabolism) go awry, the repair component intervenes in order to reestablish order.

Thirdly, according to Rosen’s distinction between self-referential and living systems, Luhmann’s theory of social systems pertains to the latter class: it is the theory of a particular class of living systems. Within the said classification, the reference to self-reference is a necessary but not sufficient condition for characterizing social systems.

If we resume the four types of controllers presented in section 10 above, we can discover a further interesting subtlety. Let me first repeat the short description of the four controllers:

1. System with feedback controllers.
2. System with feed-forward controllers.
3. System with feedback controllers with memory.
4. System with feedforward controllers with memory.

One of the underlying difficulties with Luhmann’s theories is that he uses only type 1 (and occasionally type 3) controllers in his reflections. Luhmann apparently has no idea of controllers of type 2 and 4. Even if Luhmann describes social structures as expectations (Luhmann, 1995a), he apparently has no composite theory of anticipation. Rosen’s theory may then help to articulate Luhmann’s proposal by explicitly including feedforward structures in his framework.

Finally, an overview of the foregoing discussion may help. Luhmann’s work can be broadly divided in two main phases. The first phase was mainly focused on the task of generalizing and giving a better grounding to Parsons’ theory of social systems. The development of the theory of autopoietic systems in the 1980s triggered Luhmann’s second phase. The categorical framework provided by autopoiesis gave Luhmann the tools with which to further generalize and deepen his previous efforts. The theory of social systems developed by Luhmann thus represents a generalization of autopoietic theory through its application to social phenomena. This paper has drawn attention to the fact that the theory of autopoietic systems can be reconstructed as a specific fragment of the more general theory of (M,R)-systems developed by Rosen. Luhmann’s generalization of autopoiesis still falls within the capacities of (M,R)-systems. The hypothesis has then been suggested that an explicit consideration of Rosen’s theory provides room for a further generalization of Luhmann’s theoretical framework. The intriguing phenomenon of anticipation and the problem of conflicts have been proposed as possible testing grounds to verify the fruitfulness of the generalization suggested.

References

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The cybernetics of evolutionary processes 
and of self organizing systems

by
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Introduction to Gordon Pask’s “The Cybernetics of evolutionary processes and of self-organising systems”

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The paper, “The Cybernetics of evolutionary processes and of self-organising systems”, was presented at the 3rd International Congress on Cybernetics Namur, Belgium, 1961, and published in 1965 as part of the proceedings. The paper is about 15,000 words, which is very substantial for a conference paper. This was typical of Pask. Many of his major works are to be found in the proceedings of conferences. Such proceedings can be quite difficult to obtain. The paper sets out in some detail Pask’s thought as it had matured to that point. As the title suggests, the theorising is thoroughly grounded in cybernetics and Pask spends some time setting out his understanding of key concepts in cybernetics, including, what is a system, black box theory, what is a self-organising system, what are evolutionary systems. He presents an abstract model for an evolutionary system and goes on to apply it to the domain of what he refers to as ‘cognitive machines’ and ‘cognitive systems’. “A cognitive machine is the environment, usually an internal environment such as a network or a brain, wherein cognitive systems are induced to evolve,” (Pask ibid, p. 64). Notice, the distinction between cognitive machines and cognitive systems is an analytic distinction which permits Pask to discuss cognition and, in due course, consciousness as phenomena, irrespective of their embodiment. A cognitive system is a linguistic or, equivalently, self-referential symbolic system. This key analytic distinction of Pask’s evolved in later papers into the distinction between ‘mechanical individuals’ and ‘psychological individuals’, central concepts in his ‘conversation theory’, first set out in the early 1970’s. With respect to this distinction, cognitive machines adapt. They may learn in the limited sense of being subject to the laws of behaviour as set out by Skinner (1967) and others governing (using Skinner's terms) ‘respondent’ and ‘operant’ conditioning. In contrast, for a cognitive system learning is a form of evolution and adaptation but this time it is the ‘symbolic evolution’ of concepts.

To appreciate what is innovative in Pask’s approach, it is worth recalling that in the same period that Pask was writing (the early 1960s) ‘cognitive science’ and ‘the information processing approach’ in cognitive psychology were coming into being. Both critically depend on the analogy between computer hardware and software and brain and mind. What Pask is alive to and what marks his approach out as different is that he wishes to include interaction between ‘hardware’ and ‘software’ to encompass the idea that changes in brain structure affect thinking and that thinking changes brain structure. In contrast, in the world of the digital computer, by definition, hardware and software do not interact. They are just isomorphic...
ways of looking at the same thing: the transformation of inputs to outputs following strict rules. Pask also emphasises that cognitive systems are self-referential; the symbolic forms may refer to themselves and to the system as a whole. Again, these are not properties to be found in computer software, where such self-referential forms are ruled out as likely to lead to paradox and ambiguity.

Compared to many of Pask’s writings, the paper is presented in relatively non-technical language. Pask also takes his time developing his arguments. This makes the paper quite accessible for someone not familiar with cybernetics. It is worth working through the paper if only to see what Pask has to say in the final sections about the nature of consciousness and what it means to be human. On the way, amongst other topics of interest, you will find an early reference to the interaction between a human and an adaptive system as a form of conversation. You will also find a prescient description of the circularity of the biological processes that Humberto Maturana some twenty years later refers to as ‘autopoiesis’ (Maturana and Varela, 1980) and that Pask himself in later years refers to as ‘organisational closure’ (Pask, 1975). “Survival of the physical material that constitutes the element is a prerequisite of the stability of the organisation that maintains the element ….. conversely, survival depends on stability (of the organisation) ..” (Section 2.1.1).

Enjoy!

References

The cybernetics of evolutionary processes and of self organizing systems

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I would like to thank the research sponsors who lend substance to these ideas by giving us the chance to apply them in our work, in particular, to Burroughs Research Corporation (cognition project), Solartron and Wright Air Development Division (through contract AF 61, 052, 402, on group teaching systems) and, latterly, the Air Force Office of Scientific Research (through contract AF 61, 052, 640, on a cybernetic model).

1.1. — Introductory comment.

Cybernetics is an art, a technology, a science and a philosophy. Neither the art of effecting control nor the technique of applying this art is my speciality. But I intend to speak as a scientist and later as a philosopher about these other aspects of our discipline.

Cybernetics is the science of systems. Today we shall consider a couple of special but important categories of systems, namely, those that are self organizing and those that evolve.

First let us be certain what a system is. Perhaps you will excuse a lengthy and rather elementary discussion on this point because my contentions can readily be mis-construed, and to avoid this we must be quite certain of the meaning given to a word that is so often and so carelessly bandied around, as the word "system".

1.2. — Definition of a system.

The paradigm of a system is Ashby's [1] concept of a black box: The idea is closely related to Shannon's statistical information theory, with which, indeed, it grew up. Within the compass of Shannon's theory, a black box is an information source. Within a more general context, the contents of a black box may be anything you please. The black box may, figuratively, be a radio set with
components inside, or it may be this room with you and I inside it. Of course, we do not mean that the walls of the radio set or this room literally bound the box, for the intended closure is informational. The whole construction is meant to emphasize that certain relevant attributes have been decided, and that the set of these determines a state description, for the values of these attributes, at a given instant, are an assertion of the state of the black box at that instant.

In one plausible state description we might consider all the people in this room and where they are sitting, who is talking, and the temperature of the room. We neglect, as irrelevant in this state description, the concentration of tobacco smoke, and the intensity of the illumination. So a state is specified by your positions, the temperature, and the fact that I talk continually. But it is essential to remember that for every attribute of the physical assembly that is deemed relevant, there are an indefinite number of equally acceptable attributes that are deemed irrelevant.

Ashby comes to the crux of the matter by insisting that we talk of systems, not of things.

The attributes may be independent binary properties that are or are not present, such as I am, or am not, talking. If they were all like this the state could be expressed as a binary number, and for \( n \) attributes there would be \( 2^n \) states. But there may be constraints, for example, the fact that not more than one of you can sit on a chair at once, is a constraint and the fact that the temperature cannot rise from \( 22^\circ \text{C} \) to \( 24^\circ \text{C} \) without going through \( 23^\circ \text{C} \), is also a constraint. Consequently only certain arrangements of you need be considered, and temperature ceases to be a binary attribute of the form “temperature is or is not \( 22^\circ \text{C} \)”, “temperature is or is not \( 23^\circ \text{C} \)”, and becomes simply “temperature”, which assumes a lot of different values.

We suppose there are measuring instruments that convert attributes of the real world into abstract symbols, often selected from the set of numbers. Typical measuring instruments are voice keys, and thermometers. An attribute is defined by the construction of the instrument that measures it. Equally, however, these instruments may be our own senses and in this case the specification of an instrument is called a “percept”. Now, whether we do the job with our own senses, or whether we allow an instrument manufacturer to do it for us, we end up with an “abstract representation” or merely “an abstraction” of the real world, which consists of a set of possible numbers, defining states in a state description determined.
by the choice of attributes, and conveniently envisaged as the read-
ings obtained from a set of meters or dials on the outside of the black box. The meters or dials are labelled as "variables" with which the attributes have been identified by the process of abstraction. Thus, as before, the values of the variables define a state of the black box.

The totality of possible assertions about the variables and their relations to one another is called "a universe of discourse". Statements that are understandable within this universe of discourse are made in terms of an observational language. Some conceivable statements will be excluded by any constraints that are agreed to exist by a group of observers who communicate with each other in this observational language. That temperature is a continuous variable, is taken as logically true in the universe of discourse we have thought about so far, and consequently an assertion like, "the temperature went from 22° C instantaneously to 24° C", is logically false. Similarly, "more than one of you is sitting on the same chair" is logically false. There are only some logically possible assertions.

A system is a universe of discourse together with its identification to the attributes in a state description of the real world. States of the system are sets of values of these identified variables.

Notice that any assertion about the fact that the variables are identified with the real world, of the room, or you and I, is prohibited in the systems observational language. Such assertions could only be expressed in a metalanguage used for discussion about the system as such and its relation to other systems.

1.3. — Dynamic systems and behaviour.

We shall be wholly concerned with dynamic systems. In the present case this means that the room containing you and I is freely supplied with energy, mostly derived from metabolizing our breakfast, so that we produce a lot of autonomous activity as a result of which the system describing us changes state and provides whoever constructed it (call him the "observer" or the "experi-
menter") with a stream of evidence about the attributes with which his system is identified. This stream of evidence is a behaviour of the system. A behaviour delineates those events that actually do occur (as distinct from those that are logically possible). At this point, we come up against a basic uncertainty in measurement, a so-called metrical uncertainty which gives cogency to the idea of the
black box. There is a definite limit as to how often or how accurately the values of the variables can be specified. In terms of a black box, the meter readings or dials indicate uncertain evidence regarding the values of the attributes, which they are supposed to measure. The system defines the limits and the location of an observer's certainty.

Recall that in informational thinking, the black box is an information source. Similarly an observer becomes a receiver aware of the possible states of a transmitter connected to the source. The universe of discourse is a specification of just these states and the constraints upon their transition. The abstraction specifies the coding that determines the form of channel, namely the connection of the transmitter and its relation to the receiver. A transmitted message constitutes evidence. A sequence of received messages constitute a behaviour. If we pose a source of "noise" acting into the channel, this "noise" represents the observer's metrical uncertainty: Like any other model of this kind it is not a picture of things as seen by the observer himself, but a picture as seen by someone looking on from outside at the process of observation. In other words, this model of observation exists in a metalanguage. With this in mind, the image in Diagram 1 is concise and convenient.

![Diagram 1](image)

Now, an observer would like to describe a coherent behaviour in terms of his observational language, so that he can make predictions about the state of the system. The possible predictive hypotheses depend upon the universe of discourse chosen by this observer, or, equivalently, upon the constraints implicit in Diagram 1. Predictions are hypotheses of which the observer has become more or less certain because of the evidence he has received, but because of his necessary uncertainty there is no more than a definite probability that a predicted occurrence will be realised.

The simplest procedure an observer can adopt for collecting his evidence is cumulative induction. He watches what occurs, records how often it occurs, and represents this counting of events in terms...
of a probability, of occurrence, or joint, or successive, or conditional occurrence. Now he assumes that events which have occurred often will be likely to occur again. But this never yields certainty. For something can occur that has not previously occurred. Indeed, cumulative induction is rather inefficient and its great advantage is that it can always be used, even if nothing is known about the constraints that determine the behaviour of a black box. Whenever something is known, so that there are a limited number of logically possible hypotheses, the experimental procedure of science is much more informative. Using it, the experimenter poses an hypothesis and uses evidence in an attempt to disprove it for whereas indefinite repetition cannot entirely confirm any hypotheses, one negative observation can disprove a sufficiently strong hypothesis.

The system is greatly enhanced by adding a further channel as in Diagram 2, using which an observer is able to change the conditions in the "black box" or the corresponding "parameters" of his system. In this case observations are made conditional upon different parameter values. The experimenter, of Diagram 2, being in a position to control the parameters, or at least to control their probable values, is able to perform experiments upon the system, rather than watching and waiting for events to occur and the falsifying procedure becomes realistic. A parameter in the system corresponds with some action upon the real world that is correlated with a coherent change in attribute values. Thus the action of opening the window corresponds to a parameter of the system we have been examining, so far.

![Diagram 2.]

A system is a structural framework largely determined by an observer and the observer cannot guarantee before he begins his experiments, that it will exhibit coherent behaviour. If it does not, it is uninformative and the observer must try another. But there is an indefinitely large set of possible systems and no real observer can
search through the whole set unaided. In practice, his search, if it is realistic at all, must be guided by previous experience (which is only useful in an ordered world) or by convention (which is only tenable in an ordered world).

But suppose the system is coherent, it can be variously characterized. In particular, we are interested in statistical measures like the variety of its behaviour and in measures of the organization it exhibits. If the system is coherent, it will be possible to compute a measure of organization as a redundancy, which is:

\[ \text{Redundancy} = \eta = 1 - \frac{\text{Variety}}{\text{Maximum Variety}} = 1 - \frac{\xi}{\mu} \]

and having computed a redundancy to ask what one would mean by a self-organizing system.

1.4. — A self organizing system.

The most rigorous discussion of a self organizing system is due to Beer [3]. But for this purpose, we shall adopt a very elegant definition advanced by von Foerster [31] which is consonant with Beer's argument. Von Foerster points out that a system is a self organizing system if and only if the rate of change of redundancy is positive valued:

\[ \frac{d\eta}{dt} > 0 \]

Further, von Foerster argues that this system can be self organizing either because the variety of the behaviour is reduced or the maximum possible variety is increased.

If \( \mu = \text{Constant} \), then \( o > \frac{d\xi}{dt} \).

If \( \xi = \text{Constant} \), then \( \frac{d\mu}{dt} > 0 \).

Suppose that \( \mu \) the maximum variety is constant, as it would be in a conditional probability machine, like one of Dr. Uttley's devices or a finite adaptive network. Statistical constraints are built up in the network when its input is manipulated and the redundancy of its behaviour increases. This is a self organizing system which exists over a definite interval, but ultimately when all the constraints are built up, \( o = \frac{d\xi}{dt} \). Suppose, on the other hand, that the variety, \( \xi \) is
made constant, and the maximum variety is increased by adding elements, for example, by uniform growth, as in a crystal, or in the development of a mushroom, where after a primordium has appeared, the mushroom grows uniformly. This is also a self organizing system; but unless we are prepared to countenance an indefinite extension, it is liable to a different kind of limitation.

In the commonest and most interesting cases, there is considerable interaction between these modes of organisation and development and the process as a whole is called "differentiated growth". A structure develops, in the simplest case by additive growth alone. Then, within the limits of this structure the degree of organization will increase, after the manner of the constraints in an adaptive network. The point is that we cannot, in these conditions, say what is becoming organized for whatever it is (the structure) is, itself, evolving. Looking a little further back (at the system we considered a moment ago), the primordium is a structure which evolves from an increased organization amongst the elements of a completely different structure, namely, a mesh of hyphae. The apparent discontinuity between hyphae and the primordium is, of course, typical of biological development. Comparable differences appear between cellular level and tissue level organization and between individual and group organization.

1.5. — The strict impossibility of a self organizing system.

We defined a system as an identified universe of discourse. We defined a self organizing system as a system such that

\[ \frac{d\eta}{dt} > 0 \]

Remarking that its continued existence depended upon a change in the value of \( \mu \). But, whereas \( \xi \), the variety, is a function of the behaviour of a system \( \mu \) depends upon the state description, and the specification of the system itself. Further, \( \mu \) cannot change without change in the system. Thus, a strictly interpreted self organizing system is either trivially restricted (\( \mu \) remains invariant, \( \xi \) changes) or it is a logical impossibility (for change in \( \mu \) changes the system we are talking about). All the same the idea of a self organizing system is intuitively reasonable and seems to ideally describe the observational framework in which we are accustomed to image events like the development of organisms. So, rather than discarding the notion, it is worth elaborating the underlying informational
construct to permit its rigorous definition. Minimally, we must replace the idea of selective information by the more comprehensive theory of "scientific information" advanced by Gabor and Mac Kay [16]. Whereas in Shannon's concept, a source, transmitter and channel, must be decided before the measure "selective information" is introduced and the whole notion depends upon a satisfactory specification of these structural entities, the Gabor and MacKay's theory is also concerned with the act of choosing a structure which is tantamount to choosing what can be asserted in addition to what does occur. In our nomenclature the structural aspect of the theory is concerned with the universe of discourse and its identification, or, in other words, with the metalinguistic specification of a system, whereas its metrical aspect is concerned with the acquisition of evidence given these structural constraints (if a system is defined the theories are isomorphic). An observer is liable to a structural uncertainty (about the form of hypothesis to test or enquiry to make) in addition to the metrical uncertainty which we considered previously.

1.6. — Structural uncertainty.

Thus it is useful to distinguish between a) the case in which an observer has no significant structural uncertainty and the black box analogy is completely applicable and b) the case in which structural uncertainty is important [22], [23], [33]. In either case, it will be possible to construct a system. But whereas in case a) due to the assured relevance of the identified attributes, the system will be informative, the system of case b) is only informative by dint of good fortune, experience, or perhaps intuition.

Typically, a) is characteristic of the classical sciences where there are well established methods of measurement (the construction of a thermometer or a voltmeter is public knowledge) and where measurements are comparable (a thermometer and a voltmeter although different instruments can be compared within the boundaries of classical science). Further, all tenable hypotheses appear in a common frame of reference and data gleaned with respect to one hypothesis tends to validate or deny all others. In short, any system is a subsystem of a gigantic system that defines the entire discipline. The limit of case a) is reached when a designer observes his own automaton. There is no structural uncertainty for the function of each part is known.
In contrast, b) occurs in the behavioural sciences where there is no common frame of reference and knowledge is only locally consistent. Often the experimenter does not know, before he performs his experiment, what kind of enquiry will be relevant and will yield a coherent behaviour. Thus, a child psychologist is bound to give his subject a great deal of liberty. He can "motivate" the subject and he can "direct" his attention, but, in the last resort these are chancy procedures and the experimenter's system (if it is to be informative) must be identified with whatever does occupy the subject's attention. Building blocks at one moment, toy motor cars, at the next. Sometimes, of course, the experimenter does know what kinds of enquiry will be needed, but, in this case, the different enquiries tend to be incomparable (and thus they cannot necessarily be identified with variables in the same system). Investigating the development of embryo it is necessary to perform experiments which refer to incomparable entities such as organization at a cellular level and the organization of a tissue and the embryologist is likely to obtain incoherent results if he adheres to only one approach.

1.7. — Application of the phrase "A self organizing system".

Now for case a) the phrase "A self organizing system" is unnecessary and (as we have seen) the idea it conveys is inconsistent and apt to be confusing. For, if there is no structural uncertainty, an observer who obtains incoherent results must either conclude that the world is incoherent (and thus behaves like a chance machine) or that his method is inadequate. If the latter is true, there exist procedures for improving the method which entail making more accurate or more prolonged observation, and which amount to changes of coding of the information from a given black box.

Consider a world in which behaviour is manifest by the appearance of a pair of differently coloured (red and orange) signal lamps which are placed close to each other on a panel and labelled as X and Y. Suppose that the most accurate state description we need to consider is identified with the condition of these signal lamps according to the mapping rule state \( a = X(R) \), state \( b = X(C) \), state \( c = Y(R) \) and state \( d = Y(O) \). When considered in this detail an observer is presented with a system (I) having a determinate behaviour such as:
In the state description, let \( \Lambda = [a \text{ or } b] \), \( \Lambda = [ \lambda \text{ or } e] \), and let \( D = [a \text{ or } e] \) and \( C = [b \text{ or } d] \). An observer who views the panel through a red glass filter (thus changing his identification for the colours become indistinct) considers a system (II) with a behaviour:

\[
\begin{array}{c}
\text{(II)} \\
0.5 \\
\text{A} \\
0.5 \\
0.5 \\
\end{array}
\]

whilst an observer who views it through blurring spectacles (so that the position is indistinct) will obtain a system (III) with a behaviour that preserves the essential feature of a cyclic transformation in (I), but which requires no greater observational channel capacity than system (II) which obscured this characteristic.

\[
\begin{array}{c}
\text{(III)} \\
0.5 \\
\text{O} \\
0.5 \\
0.5 \\
\end{array}
\]

Finally, let \( A(A) \) mean "state \( A \) after state \( A \)", and let \( A(B) \) mean "state \( A \) after state \( B \)", so that an observer, viewing the world through a red glass filter (but able to recall previous states) discerns a determinate behaviour (IV) which is isomorphic to the determinate behaviour of (I) given the correspondence: \( A(A) \rightarrow b \), \( A(B) \rightarrow a \), \( B(A) \rightarrow c \), \( B(B) \rightarrow d \), namely:

\[
\begin{array}{c}
\text{(IV)} \\
\end{array}
\]
Now, an observer viewing the world through a filter discovers a behaviour as in (II), apparently determined by a chance machine. He can make no predictions about the state of his system. The procedures he can use to improve his ability in this respect are:

1. — increase the accuracy of observation by removing the filter to obtain (I),

2. — prolong the observation and recall previous states to obtain (IV), or finally, change the state description without altering the channel capacity by exchanging the filter for the blurring spectacles to derive (III).

If this is a case a) system, the coloured filter and the blurring spectacles are assumed to be comparable impediments defining the deficiencies of comparable procedures of measurement. In particular, the experimenter is able to explain what he is doing when he changes the coloured filter or the blurring spectacles in much the same way that he can explain the mechanism of sensory instruments and it is because of this that the procedure is admissible.

For case b) there are several possibilities. Notice, in the first place, that an apparently haphazard world cannot be brought to heel by the neat "coding" procedures we have just described and the observer is bound to search for a form which on the one hand seems regular (which is one of his percepts) and in terms of which the behaviour of the world is coherently representable. He has to construct a completely different black box. We remarked in 1.3. that this search (for a system) could not be unlimited. There are indefinitely many attributes of the world, but either the observer or the observed entity will have decayed before the list is exhausted.

Failure to discover some kind of apparent regularity means that the observer is confronted with events of which he is unaware either because he cannot conceive them, or because they cannot be expressed, for communication, in the language of his group.

We might, with caution, call the abortive system that our observer is trying to construct, a "haphazard system" (which is quite distinct from "chance machine" behaviour within a well defined system of possible outcomes), since experience of it could vary from "nothing" to fleeting, elusive, glimpses of regularity. (This sort of world cannot, so far as I know, be "found" but it is non trivial since its conditions can be approximated, over a limited interval, by a special arrangement. Take a display presenting varied and possibly regular occurrences. Consider an indication, that an observer, viewing the display, detects any kind of regularity.
Let \( X \) be the occurrence on a given occasion. If the observer detects regularity, decrease the probability of \( X \) upon succeeding occasions, either manually or by the action of an automatic device.

At the other extreme, the observer finds a system in which an interesting body of behaviour is always coherent. Thus Lettvin and Matturana [15] discovered a rather elaborate experimental system in which the neural activity as well as the overt response of a frog to visual stimulation became coherent (the crux of their discovery was the set of logically elaborate retinal configurations that act as stimuli which are, "simple" to the frog). Once the system is found, case b) becomes case a).

Finally, the world may be such that an observer who is anxious to find coherence must construct a self-organizing system which now appears as a sequence of systems related by agreement on the part of a group of observers but (because they are commonly incomparable), unrelated in any other way.

Consider the topic of intellect and its developments in the child. Each of Piaget’s [24] “stages” in the development presents a coherent behaviour (the descriptive invariants of this behaviour characterize the “stage”). But each is observable in quite a different experimental system, and, in order to give a coherent account of maturation (either of brain processes or intellectual behaviour) an observer is bound to construct a sequence of systems. Strictly these are incomparable and cannot be regarded as subsystems of a common whole. But these systems are related and called a self-organizing system because the child is something which the observer regards as a consistent entity for reasons that are nothing to do with his experimental data.

1.8. — The salient characteristics of “a self-organizing system”.

1. — The phrase is used relative to the existing state of knowledge. Previously incomparable attributes and systems become comparable as knowledge increases and mere correlation between events gives place to a substantial predictive rule. Given any particular case, we do not deny that it will become representable strictly in terms of a “black box”, nor that all observables will ultimately have this form (though if they did, “scientific enquiry” would amount to statistical prediction). The idea of a self-organizing system belongs to the present and imperfect search for coherence.

2. — A self-organizing system is specified relative to a given observer
or a group of observers with a common logic. We stressed in 1.3, that any system is defined relative to some observer, but this fact can be overlooked when, as in case 1 the relation is determined by scientific convention.

3. — It is a sequence of otherwise incomparable systems, exhibiting coherent behaviour, rendered comparable by agreement and resort to such additional data as "the behaviour is engendered by that man", or "by the development of that species".

4. — It is specified relative to a topic that interests the observer or relative to an objective to be achieved. The occurrence of self organizing systems in the behavioural sciences is partly due to our ignorance in this field, but partly due to the kind of enquiry (regarding issues like "development" or "maturation") that is significant in this field.

5. — We have already remarked that an unguided search for a system would be impossible and, in practice, the scientist is directed by metainformation. Often this assumes the form suggested in 3. Other forms entail inferences of "similarity", for example the observer infers that another man will "learn" (and his behaviour may be represented as a self organizing system because of this) on the grounds that this other man is made as he is made and of the same material (which has absolutely no bearing upon the observational language statements about information processing). Again the observer may infer that "it" where "it" perhaps is an automaton, is similar to himself in the sense that it will construct the same kind of concepts. Finally, we may cite as a commonly used bit of metainformation, our belief in the regularity and continuity of the environment.

2.1. — Evolutionary systems.

When we are concerned with the evolution of a species or the evolutionary process which is the mechanical correlate of the behaviour called "learning", our attention is directed towards the necessarily time dependent character of a self organizing system. By definition we are talking about a time sequence of systems that becomes a single self organizing system by virtue of the topic we have in mind and it is convenient to call such sequences "evolutionary systems".

Once there existed a rough-and-ready distinction between the physical and the biological science — the physical scientist sat in his laboratory and constructed artifacts or experimental situations
which he devised at will and studied — the biological scientist went out and brought into the laboratory animals and vegetables which had been generated by evolutionary processes beyond his jurisdiction. Now when, as cyberneticians, we are chiefly concerned with organization this distinction disappears. We can perfectly well construct evolutionary processes within the laboratory that will generate any number of organizations from which we select a few that happen to be interesting. It is true that in certain essential particulars, the evolutionary process remains beyond our jurisdiction so that, even if it takes place in a computer, we are bound to learn about it by studying its products. The process itself is incompletely determined and our abstraction of the process is a typical "evolutionary system".

One objective is to discover correspondences between this evolutionary system and similar abstractions from the evolutionary processes of nature in an attempt to set out principles common to any kind of evolution. Consequently, the cybernetician may identify a collection of elements in his evolutionary system with the object called a population in the natural system insofar as the "collection" and the "population" exhibit the same behaviour. Also he will alter the evolutionary rules in his process (which in turn effects the development in his system), and try to increase the number of possible identifications. Finally, we are anxious to investigate modes of evolution that do not appear (or are not recognizable) in the real world because of its topology or because of energetic constraints. Rashevsky's [26] work in this field is well known and chiefly related to the evolution of species. Richard Feldman [13] has recently developed a process for the evolution of structures in networks that has an obvious correlate in the maturation and learning activity of a brain. I could do justice to neither in a brief summary, and refer you to the original papers. For the moment, I shall present an outline of a model of my own which, though less elegant than either Rashevsky or Feldman's model, is especially tailored to demonstrate the points I wish to make.

2.2. Background for abstract models.

Any model for evolution must involve the environment in which evolution occurs as well as that which evolves. If we are thinking of organisms that evolve, or species of organism, the environment will be a physical structure in which there is food to consume and form to perceive and the companionship of other organisms. If we are think-
ing of brain activities that evolve, the environment will be sequences of messages in various languages and various modalities. These environments, or, for that matter, many others, can be represented as abstract constraints. One feature of the present model is that its abstract constraints can be identified with a variety of different environments or the attributes of different evolving entities. But these interpretations will appear more or less plausible (to the extent that some may become impractical and others become imperative) at different stages in the evolutionary process. (We might predict as much, since the evolutionary system is a self organizing system.)

As a consequence we have a structural uncertainty regarding what it is that does evolve — the organism, an aggregate of organisms — or the process of development of each individual. Let us specify a few prerequisites for evolution of the kind we are trying to model.

1. — In the real world, evolution occurs when there are a number of distinct elements each of which can survive in certain conditions of the environment and cannot survive in others. The issue of whether or not a particular element does survive in conditions that permit its survival depends upon its behaviour, and in any interesting process the behaviour of the elements must be such that they tend to remain in existence. Survival of the physical material that constitutes the element is a prerequisite of the stability of the organization that maintains the element, commonly by resynthesis of structural components from raw material (or "food") in the environment. Thus, conversely, survival depends upon stability. Cells are typical elements in the biological environment (though we could cite the reaction centres of some autocatalytic reactions or regions of activity in a network of artificial neurones as perfectly legitimate evolving elements in different environments). Thinking of cells, the survival of the energy transforming mechanism is a prerequisite for maintaining the nucleic acids, that chiefly determine the cellular organization.

2. — We remarked that survival is conditional. The simplest conditionality occurs if "food" is available in short supply. "Food", of course, can be read as "money" or "electric current" or any other conservable commodity without altering the essential condition that if it is restricted there will be competition between the elements for whatever is available.

3. — Either the elements must be capable of reproduction on their own account, given success in the "food competition" or there must be a locally specified state of the environment such that one element is created when the local "food concentration" is high. Since it is possible to show that these alternatives reduce to the
same thing, it will be more convenient, at the moment, to think of a reproductive mechanism.

4. — This mechanism may take many different forms and act at many different levels, for characteristically, it evolves. So it would, perhaps, be more accurate to assert a principle of reproduction as our requirement. The point that needs emphasis is that "reproduction" is not intended to mean "replication", in the sense of creating accurate images of the ancestor. The process of reproduction (at whatever level it is realized) is imperfect and the resulting offspring include variants upon the original.

5. — Thus it is customary to consider an active source of variation as a prerequisite of evolution. In biology, the source of variation acting upon the genetic reproductive mechanism, is genetic mutation.

6. — We remarked that "food" or some other conservable commodity must be "restricted" in the environment. Even this much (the metric over the states of the environment) implies a structured environment. Let us add to this a further structural requirement, namely, that some of the variants shall be at an advantage in the competition for survival.

7. — To elaborate the idea, we must be more specific about this "advantage" and it seems reasonable to introduce a principle that certainly applies throughout biology and which I believe to have universal application. It is that the environment is such that it favours an increased degree of organization in any process abstracted as a self organizing system. This principle implies that there is "advantage" associated with co-operation. Co-operation involves forming coalitions wherein the participants communicate. In this sense the participants in the coalition form a subsystem or organization and relations between subsystems add structure to the system as a whole. In biology the process is evidenced by the development of multicellular organisms rendered stable by distance receptors and nervous systems and societies rendered stable by languages and channels of interpersonal communication.

8. — Given these conditions inflow of "food" into the "environment" will initiate a process of evolution, wherein elements, once created, tend to form increasingly organized aggregates and successful variants tend to be selected and reproduced.

2.3. — A specific evolutionary model.

The environment is a lattice of the kind shown in Diagram 3. In a more detailed discussion, I have considered various topologies
(toroidal, infinite plane, and so on) but for the moment we shall restrict the discussion to an infinite plane. Each node in Diagram 3 is a point at which "food" becomes available and where one of the evolving elements or (as it is convenient to call them) *automata*, can sit and feed. The connections in the lattice are pathways along which automata can move from one node to another.

![Diagram 3.](image)

The structure imposed upon the environment is 1) the set of pathways or nodal connections and 2) the rule for delivery of food which though open to rigorous expression, is more conveniently visualised as in Diagram 4 a, where each node is associated with a food bucket filled through a constricted aperture. When an automaton rests at a node it eats food from the bucket faster than this commodity is replaced through the aperture. The electrical current equivalent is also shown in Diagram 4 b. It is essential to realize that the food supply and the network are distinct and that the food neighbourhoods that may be introduced by making cross connections are commonly not the same as the nodal neighbourhoods that determine relations between the automata.

**Rule 1.** The simulation proceeds in discrete stages, \( t = 1, 2, \ldots \) at which automata move.

**Rule 2.** If the amount of food, \( u_i \), in the \( i \)th bucket exceeds a level \( a \) an automaton is created at the \( i \)th node. This automaton may be of "type A" or "type B" according to whether it is the 1, 3, \( \ldots \) odd \( a \), or the 0, 2, \( \ldots \) even \( a \) to be created. In a refined version of the model, creation of an automaton at the \( i \)th node would be a function of \( u_i \) (determining the probability of this occurrence) and a chance variable. The refinement is motivated by analogy with the creation of bubble nuclei in a superheated liquid where the local temperature (by analogy with \( u_i \)) determines the probability of a
bubble developing, but the appearance of a particular bubble also depends upon nuclei being available. If these are uniformly distributed the model is not greatly changed by this refinement.

Rule 3: Automaton creation has a cost $\beta$ which is removed from the $i$th bucket.

Diagram 4 a.

Rule 4: Once produced, an automaton, say the $n$th automaton, must eat food from the node bucket where it rests, at a rate proportional to the amount of food in the bucket. In eating, it accumulates a reserve denoted as $\theta_n$ in an internal bucket. Thus if it rests on the $i$th node, it eats proportionally to $u_i$.

Rule 5: Creation of an automation implies that food has been converted into structural material which has a tendency to decay.

Diagram 4 b.
Rule 6: Automata move in discrete jumps, including the possibility of jumping to the same location. The cost of maintaining the structural material of an automaton such as A or B is $\gamma$ per move and $a > \beta + \gamma$.

Rule 7: If $O > \theta_n$, the $n$th automaton disappears.

\[ \begin{array}{ccc}
\begin{array}{cccc}
& * & * & * \\
A & o & A & \end{array} & \begin{array}{c}
* \\
B & o & B \\
\end{array} & \begin{array}{cccc}
& & & * \\
A & o & B & \end{array}
\end{array} \]

Diagram 4 c.

Rule 8: Automata A can move one up or one down and into the same node. Automata B can move one right or one left or into the same node. An automaton can inspect any location into which it can move and determine the food available at this location.

Rule 9: Automata are designed to survive. Consequently their behaviour is determined by a $\theta$ maximizing decision rule. Consider node $a$ where an automaton rests at $t$ and the pair of nodes to which it may move at $t + \Delta t$, denoted $b$ and $c$. Let $\Delta u$ be the minimum difference in local food concentration that an automaton is able to detect. Now, at $t$, the automaton inspects the food available at $a$, $b$, or $c$ and moves at $t + \Delta t$, where there is most food. Many situations are unambiguous. Whenever

- $u_b - \Delta u > (u_a$ or $u_c)$ the automaton moves to $b$.
- $u_c - \Delta u > (u_a$ or $u_b)$ the automaton moves to $c$.
- $u_a - \Delta u > (u_b$ or $u_c)$, it remains motionless.

But if $u_b = u_c$, the situation poses an undecidable problem and in this case the automaton must, again, be motionless.
Rule 10: The rate of food inflow is less than \( \gamma \), the rate at which \( \theta \) must be metabolized to maintain the components of the automaton. Consequently, the automaton cannot survive if it remains indefinitely at one node, and in particular, if it does so because the problem posed by its environment is undecidable.

Rule 11: An undecidable problem is resolved by creating an automaton for which the environment problem may be solvable. If it is not solvable then the new automaton will be unable to survive, so that on the whole an account of evolution refers to the successful variants.

A new automaton is created by combining original automata. Combination occurs when a) a pair of automata, say \( x \) and \( y \), reside at the same node coincidently, b) at least one of the pair is presented with an undecidable environmental problem. The combination of these automata is written \( x \circ y \).

The possible combinations of A, and B, are \( A \circ A \), \( B \circ B \), \( A \circ B \) and their capabilities are indicated in Diagram 4 c. The cost of maintaining the fabric of a combined automaton is \( \sigma \). If \( \sigma > 2 \gamma \) the cost per unit of material is greater in the combination and if \( 2\gamma > \sigma \) the reverse is the case. With a few obvious modifications the rule of combination applies at any level of development, for example, to yield structures like \( A \circ A \circ A \) or \( A \circ B \circ B \) of Diagram 4 c which have elaborate behaviours.

Rule 12: The rate at which an automaton moves depends upon its value of \( \theta \).

Since we are considering discrete stages this rule implies an order in which, as part of the simulation, the various adjustments are made to the values of \( \theta \) and the location of the automata. These adjustments are made starting with the automaton having the highest \( \theta \) and taking the whole set of automata in the order of their \( \theta \) values.

It may appear that this is a matter of convenience but the model is deceptive in this respect. For, very early in the process of evolution, the outcome depends to a large extent, upon which automata are dealt with before the others.

2.4. — Some results.

In our leisure hours, Alex Andrews and I have considered the possibility of programming this model on a computer, but although Alex Andrews has made a draft programme, we have not, as yet, obtained any data. Consequently I shall describe some broad results obtained from a crude paper and pencil simulation. Due to
the tedium of this work some mistakes are possible and whilst the important conclusions are based upon results that appear to be repeatable, they should be regarded as tentative until the simulation has been realized on a computer (1).

As the food inflow builds up a food concentration at the nodes, automata are created, move about, and combine with one another. Whilst the food distribution remains on average, uniform, there is on average, an advantage in the combination $A \circ B$ but, in regions that are populated by a particular species of automaton, say $A \circ A$, this may not be the case (commonly $A \circ A$ or $B \circ B$ would have a better chance of survival than $A \circ B$), because the feeding pattern of the prevalent species induces a characteristic pattern upon the food distribution over the nodes in this part of the environment. The mean population size depends initially upon the rate of food inflow (and this remains the case if $\sigma = 2\gamma$). However, in the arrangement that has been used, $2\gamma > \sigma$ and the mean population size can increase either by increase in the food inflow rate or by the development of combined and more efficient species of automata, with the food inflow rate invariant.

We have already cited the interaction between the automata and their environment, due to the fact that a given behaviour induces a characteristic pattern of food depletion. Now the behaviour of any automaton is a function of its own state and the state of its environment. But where this interaction is very strong, due to the concerted activity of many similar automata, the state of the environment is increasingly determined by the behaviour of this population, and as a result, a) it becomes difficult to speak of any automata in isolation and in practice, b) the automata form groups wherein the individuals play specialized roles.

At a somewhat earlier stage, it seems reasonable to regard the activity of the automata as co-operative, since pairs of automata behave in a fashion that increases their joint chance of survival (the behaviour would be impossible for the individuals alone). The action of the isolated automata that constitute the pair is correlated. The food concentration sensory mechanism has begun to serve a different function (which it reasonably can in these conditions) namely that of a communication mechanism whereby one automaton senses the presence of the other in terms of food depletion. The

(1) Since this paper was written, these results have been confirmed by research sponsored by the Air Force Office of Scientific Research through the European Office Aerospace Research USAF with contract AF 61, 052, 649.
"memory" capacity needed to rationalize this statement resides in the inertial characteristics of the environment.

The experimenter recognizes a group of automata and increases food inflow at the nodes occupied by automata in group.

Diagram 5.

Now, automata, as such, cannot sense a group of automata. But groups can have a characteristic behaviour unlike the behaviour of their components and we, looking on omnisciently, can recognize a group. Suppose, then, that we decide that a group manifesting a certain behaviour shall be at some advantage in evolution. Being omniscient, we are in a position to modify the environment so that this is the case. The simplest procedure is shown in Diagram 5, where the experimenter in the role of nature, determines that the favoured group shall receive a greater food inflow than the rest. He pursues the group about the environment, feeding it. Notice that the procedure of Diagram 5 is a special case of selection due to the constraints in the environment. The actions of the experimenter constitute a sequence of constraints that might have existed in nature to favour this group.

A well-fed group becomes increasingly dense. More automata are created within it. Since they are created in a very specialized environment their development, by combination, is largely determined
and, on average, is compatible with this environment. Notice that insofar as the group is regarded as an individual entity this process is a mechanism of group reproduction which has evolved. The existing mechanisms of automaton creation and automaton combination are constrained to act in this fashion just as high level selection of lower level selectors is responsible for the amplification discussed by Ashby [2].

When the density of automata becomes high enough there is a very interesting discontinuity in the structure, reminiscent of crystallization. Although the group moves about as a whole (modifying the environment where it resides), any individual has a behaviour that is invariant relative to its neighbours. Some individuals, for example, behave as units in a transmission line, composed of a chain of automata, such that motion of one induces food depletion that induces a completely determined motion of the next automaton. Transmission lines have a critical role in the stability of the group since they act like a nervous system that determines a direction of movement for the group as a function of the food available in other parts of the environment (sensed by the relatively unrestricted activity of the outermost automata) and the food available internally (or, more cogently, the internal state).

An impartial observer would be bound to regard the group (not the individual automaton) as an organism, to talk about the behaviour of this group organism, and say that it, rather than its components, made decisions. Although it is occasionally possible to locate a subset of the component automata that remain in a particular critical relation to the others, so that their state determines the group behaviour, this measure of differentiation is uncommon. Ordinarily, there is no place where decisions are made. Rather, "decision making" is a distributed characteristic of the group. In McCulloch's words [19], the group has a "redundancy of potential command". Also, to cite McCulloch again, the components of the group have a "redundancy of mechanism" for, whilst it is true that differentiation leads to a division of labour, the process is partly reversible. Each component retains the potentiality of acting like an automaton, though it may never exercise this potentiality. Various kinds of disturbance invoke the latent capabilities of the components, and the job of maintaining group stability can be done in many different ways.

The group, being a stable entity, is in a certain sense, aiming to survive. It makes "decisions" with this objective. We may thus ask what is maximized by the group "decision rule" by analogy
with the $\theta$ maximizing function of the "decision rules" of the individual automata. Obviously a prerequisite of any group "decision rule" is maintenance of the components. The $\theta$ values of the individual automata must be sufficient. But it is certainly untrue to suppose that mere quantity of food is the most important factor. Indeed for a group the distribution of food (in a part of the environment that the group may visit) is much more significant.

But the distribution (as sensed by the outermost automata) need not necessarily indicate the quantity of food which can ultimately be collected by the component automata. For a group is able to compete with or co-operate with or engulf other groups of automata, possibly having a different organization. A food distribution indicates the existence of another group. Now our group may be instable because it lacks, say, the species $A \circ A \circ B$ and it would be a possible but very esoteric exercise to represent this "need" for $A \circ A \circ B$ automata as a "need" for a certain distribution of food in the environment. The required automata might be created internally, given a rich enough environment. But equally, they could be obtained from parts of the environment where they existed in any case, or by a symbiotic relation with some other group having a suitable organization, or by engulfing some other group containing automata of a more elaborate kind, such as $(A \circ A \circ B) \circ (A \circ B)$. In the latter case, we assume that $(A \circ A \circ B) \circ (A \circ B)$ automata are unviable in the conditions that prevail within our group. Thus if our group engulfs the group in which they exist, these elaborate creations will come apart, leaving their $A \circ A \circ B$ (which we know to be stable in the conditions of our group) in order to satisfy our groups need. Of course, our group may not succeed in this competition. It may be engulfed. At any rate, it seems legitimate to remark that the reasonably interpreted objectives of the evolutionary system change in kind, as well as degree, when the system evolves.

Finally, an observer would experience difficulty in stating the boundaries of whatever he regarded as undergoing evolution. He is at liberty, of course, to dogedly consider individual automata. But if he does so, their behaviour will be increasingly determined by group relations and (unless he admits to this and considers the whole group) his predictions will become less and less accurate. On the other hand, if he adopts a changeable image, examines sequences of structurally different systems which constitute a self organizing system, the group of automata he will consider capable of making decisions and manifesting a behaviour not only moves in the environment, but expands. We have tacitly admitted a couple of
expansions. First, there is the literal increase in size of the group, increase in density of automata and often increase in volume, as well. Next there is a linguistic expansion.

An observer who talks about "group decisions" is making statements in a metalanguage relative to the observational language in which he previously discussed "automaton decisions". In precisely the same way the message conveyed, at the level of groups, by a food distribution is a metalinguistic statement relative to the message conveyed, at the level of automata, by local food depletion. In other words there is a linguistic expansion that entails the construction of those metalanguages that are needed to maintain the stability of the evolving system. The process can be otherwise described, as the development of relational logics in a domain of abstract objects or as the development of communication modalities in a domain of physical entities with which the abstract objects are identified. The phrasing is a matter of choice. But the choice of a linguistic description is legitimate insofar as that which evolves is credited with the ability to decide.

3.1. — Interpretation.

The process can be interpreted as a self organizing system at many different levels. Thus one observer may regard individual automata as unitary entities whilst another observer may take groups of automata as unitary entities. In either case the states of the process can be metricized. Ordinarily, the abstract objects in this process will be identified at the same level of discourse with physical objects and the model will be used to make predictions about the real world. As it is formulated, this process describes a mode of evolution which is too general to be conveniently identified with the main course of biological evolution (the formulation is deliberate since we wished to indicate that evolution is not uniquely characteristic of biological organizations). It reflects some peculiar biological products rather well, (the colonial amoebae are a case in point), but it would be necessary to introduce constraints favouring a spatially compact reproductive mechanism in order to generate the mechanism of specialized and sexual reproduction which, as Tyler Bonner points out, is a consequence of this constraint.

3.2. — Principles.

The evolutionary process gives rise to mechanisms that satisfy the conditions for stability of the evolving organizations in a given
environment. The dictum that each set of conditions must be satisfied is a principle of evolution in the sense that mechanisms readily interpretable as mediating a common function become apparent regardless of the level at which the process is identified. The constraints that determine how these principles are manifest will be called "evolutionary rules".

There is, for example, the principle of reproduction. If groups of automata in the model are identified at a cellular level, we indicated how a mechanism of reproduction evolves. If the automata are identified at a cellular level and distances in the network are identified with similarities (rather than spatial displacements), a "group" becomes a "tissue" and the same reproductive mechanism mirrors the induction and habituation process whereby the form of a tissue is maintained throughout its development. But this (in cybernetic terms), is a reproduction of form. Further the comment is useful, since form could be preserved otherwise, by rigid constraints, or by exact replication from a pattern, which would entail the evolution of completely different mechanisms.

3.3. — The paradox of identification and the status of the models.

Given a physical object, it can be identified with an indefinite number of systems and conversely, an indefinite number of rational state descriptions correspond to an arbitrary system. This paradoxical situation is commonly but unsatisfactorily resolved by recourse to our normal way of speaking. We can readily construct an identified state description of a table such that the resulting system will "learn" or be "conscious". But since we do not normally speak about tables "learning" or being "conscious" the proposed system is rejected on these grounds.

This dogmatic approach is essential. Nevertheless it is dangerous. For what one generation of scientists regard as unable to learn is often viewed as able to learn by the next and precisely the same comment applies to distinctions such as able or not able to reproduce alive or inanimate, intelligent or devoid of intellect, which rest at the foundation of each evolutionary principle. The conventions of identification which are built up may seriously hinder the advance of science although they are needed for the conduct of everyday experimental work. Nowadays, for example, we are bedevilled by conventions that lead us to look for such things as "memory", "personality" and decision making in a particular place or a
particular process and the evidence of models is needed to demonstrate that although we can occasionally locate the vaults of memory or the seat of decision making, this discovery is exceptional.

The point about a model (one of the evolutionary models of the kind we have considered) is that state descriptions of it are restricted (and consequently possible identifications between it and a self organizing system are restricted). Initially there is always a unique state description. In the case we have considered it might be the food distribution stated at $t = 0$ for

"A plane lattice with $M$ nodes"

or

"The lattice on an infinite plane".

If "M" is large or the plane infinite, it would soon become impracticable or impossible to use a unique, omniscient, state description. But certain rules still apply, for example, definitions of the forms of automaton, and in principle, it is always possible to work back through the sequence of transformations and reach the state description which is unique.

[Diagram of a system with labeled parts:
- Tap turned to modify inflow rate as a function of event
- Sensing event that $n$-th automaton is at $i$-th node]

Diagram 6.
Further, because of this we can comment upon the status of a model with reference to a principle it exhibits. Consider the principle entailed by the assertion that some organizations, especially man, control the environment in which they develop. The present model is able to demonstrate the discontinuity in evolution that occurs when this statement becomes true.

But the status of the model, with reference to this principle, is vastly improved if, as in Diagram 6, we introduce the possibility of effecting permanent changes in the rules that govern the “environment”, in Diagram 6, by altering the width of the local food inlets, depending upon how much has been eaten in this locality.

The change induced by the behaviour of one generation of automata is neither reversed by disuse nor by the action of the next generation.

3.4. — Review of the evolutionary principles we have considered.

The inbuilt characteristics of variation, reproduction, competition and co-operation, become mediated by mechanisms which arise as the products of the evolutionary process, and to a large extent, supersede the original mechanisms. But the originals are potentially available and a single mechanism rarely serves a single function. Thus there is redundancy of mechanism. The distinction between an organism and its environment is obscured due to the expansion of the organism when it gains control of its surroundings and because of the concomitant increase in coupling between the organism and the environment, we cannot say, unambiguously, what evolves. Further, it is legitimate to assert, as Tyler Bonner does, in the case of biological evolution [8], that whenever a species evolves so also does a miniature process of evolution (or sequence of interactions between the organism and constraints induced by the organism in its immediate environment) which we call the development of a member of this species. On each score, indeterminacy of spatial and indeterminacy of temporal extension, there is a redundancy of potential command. Viewed as data processing or computing arrangements the different evolutionary forms, or their replicas in the miniature sequence of ontogeny, are characterized by an hierarchically ordered sequence of languages. Further the different orders of organism coexist, for evolution is a provident business that uses outdated parts to build up-to-date forms, rather than starting afresh with each variant. Stability requires that the co-existent forms can
interact or, in terms of data processing, that the different orders of language characterizing these different forms, are translatable.

Discontinuities, engendering differences of kind rather than degree are apparent to any observer who adopts a given reference frame. Of these we have mentioned: a) the point at which the group organism, if consistently reinforced, increases in density and acquires an internal communication structure, b) the point at which the evolving organism can exert sufficient control over its surroundings to largely determine the environmental constraints that catalyse the differentiation of the species. At this stage, the evolution of the species becomes autocatalytic, c) the point at which the objective for which individuals of a species are competing changes from “food” to “members” of a different species, d) the point at which organisms of a species, already able to register their activity by a permanent impression upon their environment, become capable of conveying experience from one generation to another generation. This is one of the most important events in the process of evolution, for differentiation and adaptation by selection is replaced by a far more efficient method.

4.1. — Practical utility.

Has this kind of abstraction, or indeed, has any theory of a self organizing system, a practical use? The reply is in the affirmative. It was given, most comprehensively, when Stafford Beer [4] spoke from this platform at the last meeting of this Association. You will recall that he conceived industrial organization as biological. Any other form of organization would be or, in view of technical progress would become, crassly instable. Speaking on the same theme, Georges Boulanger [9], our president, envisaged industrial controllers, like brains rather than automata, able to plan what job to do (not merely how a prescribed job should be done).

The crux of the matter is that man has reached a critical stage in his own evolution. Technical advances offer him unlimited power to control his environment. In order to stabilize a system which (because of this) is subject to rapid changes in state, men and their social aggregates must be closely coupled. But the price we have rightly and necessarily paid for an advanced technology is division of labour and this, on the face of it, seems to prohibit close coupling. For the existence of the physical means of communication is not enough to ensure that communication will take place. The real limit lies in lack of compatibility on the one hand between men
themselves (when it is a question of mutual understanding, and
being intelligible) and on the other hand, between man and the
automata (or automaton-like organizations) that form an increas-
ingly dominant feature of an increasingly man-made environment.

Specialized men speak different languages. They do not share a
universe of discourse. Specialized machines are only slightly more
distant, in a semantic sense, than some of our own species. One often
hears that there is a need for wisdom and for breadth of mind, and if
these words augur or describe the ability to translate between di-
verse tongues and the flexibility to attempt different kinds of trans-
lation, then we must surely agree with this hoary sentiment. But it
is a cyberneticians job to inject the wisdom, to make certain that
translation and understanding actually occur. As Beer pointed out,
the ideal organization is biological and since we are thinking of man
it is man-like.

Take man as a model. Much of human behaviour is determined at
a reflex level, by biological automata, some of it is thalamic, some at
the other extreme, is cortical. But there is no discontinuity. Al-
though the field of consciousness (which I take to mean, at least, the
universe of discourse we have in common with our immediate neigh-
bours) normally refers to a facet of cortical activity alone, it can be
otherwise (when physically embarrassed, for example, or in stressful
conditions). On these occasions we do consider our breathing, we do
become aware of our heart rate. Obviously translation is possible
when it is necessary, between the normally disjoint languages that
characterize different levels in our nervous system. Now the ideal
environment would preserve this much continuity. It would extend
our internal organization into a single self organizing system, which,
in a sense, must be an image of ourselves.

The problem of constructing this kind of environment is enormous.
Except in some special cases, building it is out of the question. The
best we can do is encourage the system to evolve.

4.2. — Particular applications.

The theory is also applicable to detailed projects. In our labora-
tory, we have been concerned with the interaction between men,
participating in “decision making” groups. Our hunch, which is
discussed in a separate paper, is that the kind of optimum decision
making that is credited to the joint action of a group and is deemed
superior to a mere consensus of individual choice, is a product of
redundancy of potential command that can only occur if the group is a self organizing system. To realize such a system the communication structure, which in most experiments is invariant, must be made labile and continually changed as a function of the decision making activity of the several participants.

We are also concerned with the interaction between man and various adaptive automata used for teaching skills and for aptitude testing. In this case, we are anxious to distinguish between the common form of man/machine interaction (where the characteristics of the machine are unaffected by the man’s behaviour) and the present arrangement in which these characteristics are adaptively modified. Given this modification, man and automaton become closely coupled and the logic of the joint system (which is a self organizing system) is isomorphic with the logic of a conversation in which concepts evolve. This work, also, is described in a separate paper.

Finally, we are interested in cognitive automata able to learn about their environment. Since this project is at a very early stage, there are few tangible results and I shall use some preliminary thoughts on the subject to illustrate the way in which ideas of evolution or of self organization come into a research programme.

4.3. — Evolution of cognitive machines.

Current thinking about cognitive machines is divided over the issue of specification. On the one hand, it is possible to construct automata that imitate the perceptual filters of various animals. For the visual modality, J. Z. Young has described “octopus vision” whilst Lettvin and Matturana have displayed the attribute filters of the frog and revealed a mapping of fibres from the retina to the colliculus that bears out the earlier predictions, made in terms of a network of artificial neurones, by McCulloch and Pitts [20]. Nor is it necessary to imitate a particular animal, for the mathematics of perceptual filters has been worked out with nicety chiefly by von Foerster’s department at the University of Illinois [32]. Although the frog does not appear to learn any percepts (and its filters are invariant) this is not a necessary feature of the approach (certain parameters of an attribute filter can be changed by adaptation without losing the point of the filter model). A very well known but special case is Uttley’s [30] conditional “probability machine” where the categorizing network is invariant but
the contents of state probability registers or, equivalently, the
impedance of the network connections are variable.

On the other hand, there is a school of thought that advocates a
completely unconstrained network in which some kind of perceptual
filter is built up by selective reinforcement of signal pathways or
connections in a network. The reinforcement is administered by an
arbiter who views the moment-to-moment performance of a device
such as Rosenblatt’s “perceptron” [27]. One difficulty is that
no realistic machine can be unconstrained. The perceptron has
initial and possible connectivities determined in an arbitrary
fashion “by chance”. But these, in any particular case, specify
a definite structure. It is argued that over many cases the form of
structure will be irrelevant to certain statistical parameters of the
networks behaviour.

Alexi Ivanhenko [27] has examined the problem from the point
of view of his combined system theory and it seems as though
his work will do much to reconcile the structured and the “un-
structured” schools of thought.

The far from original point of view we have adopted has no
connection with servo theory. It can be interpreted as a compromise
between the extremes or alternatively, as a completely different
approach.

4.4.— An approach involving maturation.

Cognitive machines, able to learn as much as you please, are
highly constrained yet (barring omniscience) they are unconstruc-
table. Let the automaton be a system evolving in a network. If we
call the whole sequence of development a “cognitive machine”
its behaviour is virtually determinate and constitutes a self organi-
zing system (when viewed by an observer in a suitable sequence of
state descriptions). But, as we noticed previously this observer does
not adopt the attitude of a constructor. He does not determine the
state description as a constructor would determine his. Instead, he
reaches a compromise in order to make sense of the behaviour. If,
on the other hand, we call the final product a “cognitive machine”,
it has a virtually chaotic behaviour and we are in the position of
J. Z. Young with octopus or Lettvin and Matturana with their frog.
We must look at the behaviour of the final product and discern a
state description to fit it. In the case of the frog, a fitting state
description turned out to be a bizarre set of attributes, ideally
suited to a world of flies and shadows (indicating predators). Our
cognitive automata will have a very different world, no doubt, and they will not always be as tractable and structured as the frog. But we shall no more make sense of even their simplest behaviour by classical analysis (our preference) than the earlier workers made sense of frog vision by shining discrete points of light on the frog retina.

One mechanical basis for the evolution of a cognitive automaton is a region of activity in a network of adaptably connected artificial neurones. Such networks have been described and simulated by R. L. Beurle [5] and, in a simplified version by Farley and Clark [12]. Whilst R. L. Beurle was chiefly concerned with a model for cortical activity and determined the initial constraints from physiological and anatomical data (he made the artificial neurone with characteristics similar to real neurones and specified the possible connections according to the statistical connectivity of a real cortex), we may take a broader view, unrestricted by the parameters of any actual brain. But, in other respects our network will resemble Beurle's. Thus, like Beurle's network, there will be a restriction upon the number of active "neurones" per unit area (consequently, action will be competitive). Further, the activity of any one neurone will depend upon the correlated activity of several others, inducing co-operation. The changes in "synaptic" impedance which determine the effect of activity at a distance upon the state of a given neurone will depend upon the history of coincident activity and the previous values of a reinforcing variable.

Let the individual neurones become indefinitely small. The network becomes a transmission medium in which waves of activity are
propagated. Adaptation at the synapses alters the impedance of this medium to different forms of wave. Coincidence of waves may, in certain conditions, give rise to a novel wave unrelated to the form of its ancestors, but normally the waves are replicated. Finally, we require that the network is autonomously active, and that in the absence of external constraints (or inputs) the variety of the oscillation within it is maximized. Inputs from the external environment induce waves of activity as suggested in Diagram 7 a, and (in some conditions, when there is a correspondence between the input wave and the existing oscillatory mode) these will dominate the autonomous activity. Outputs are obtained, as in Diagram 7 b, by transforming a wave front into a signal, using a special component or a wave attenuating region built up from a block of the artificial neurones.

The continuous case has been developed with great elegance by Weiner [34] who originated the crucial idea that memory and, indeed, much of learning is representable as the constrained reproduction of organizations such as stable modes of activity. We shall confine our attention to a special case commenting that it is included by Weiner’s work.

Recall that there is an isomorphism between the evolutionary model we discussed previously and this kind of artifact. An automaton or group of automata acting like an organism corresponds to a “mode of activity”, or, loosely speaking, an “active region” in the network.
This correspondence was first pointed out by J. W. S. Pringle [25] who aimed to show that learning in the mammalian brain was a kind of evolution. His paper demonstrates an identification between cycles of typifying activity and behavioural invariants characterizing types or species of organism, and should be consulted. For the moment, it will be sufficient to remark that the features of evolution we noticed in the case of our automata make their appearance also in the case of active regions (some recent work by Ashby indicates that this is no quirk due to our choice of the parameters but that the evolutionary process is characteristic of any large dynamic system with many metastable states). However, some care is needed when interpreting the phrase "active region" (in particular when talking about reproduction). For an "active region" is neither activity at a given location in the network alone nor the plastic changes which are a consequence of this activity alone. It is due to the interaction of these only partially separable entities.

The active region moves around in a network but its activity, or certain facets of its activity, remain invariant. Thus it can be recognized or, conversely, since a pattern of events remains invariant although the underlying activity is differently embodied, this pattern is reproduced.

Thus there is a satisfactory analogy between a biological species and a pattern, and between a biological organization and one active region. When we say reproduction occurs, we mean that a form of behaviour, characterizing a species, is replicated. The process of replication which is the ontogeny of the organism, is characteristic of an organism of this species, and we have seen how the evolutionary process gives rise to this mode of development. Similarly, the history of the species, its phylogeny, is a comparable story told at a different level of discourse.

The evolutionary system is an abstraction of the process identified with states of the network in such a way that relevant events remain distinct and insofar as a coherent behaviour of the system can only be obtained by telling stories at different levels of discourse, it is a self organizing system because an observer who tells a coherent story must adopt a sequence of different state descriptions. That it is a self organizing system rather than a haphazard system is guaranteed by the condition that the stories are comparable.

D. M. MacKay [17], who first considered this field, remarked upon the importance of hierarchical structure in any cognitive network. His artifact was a device of the kind we have described. Suppose, for simplicity, that it receives no input apart from the
reinforcement variable though the argument is unaffected if the input dimensionality is increased. In this case, the artefact agitates its environment by making trial actions. It is tempting to conceive the device as dissatisfied with a changeless environment. The autonomy condition ensures that it must attend to something. Failing any change in the reinforcement variable, it tries out fresh modes of internal activity which induce fresh sequences of trials.

Assuming that some of its trial actions are reinforced there will be a tendency for structuring to occur. The active regions that select the reinforced trial action becomes stabilized and reproduce. Thus, it is legitimate to consider stable sequences of actions which can be selected as a whole. The active regions that induce the stable sequences of actions interact with other active regions that are incapable of selecting actions as such but select, instead, from the set of action sequences. Consequently, some of these are reinforced and become stabilized and reproduced. As MacKay points out, a process of this kind yields a selective hierarchy in which the organizations at different levels, selecting trial actions and sequences of actions, and so on, are characterized by distinct languages. Thus, to talk about (or to make selections in terms of) an action sequence, is to make utterances (or selections) in a metalanguage with reference to utterances or selective procedures that concern the individual actions. We have cited this characteristic, also, in the case of the evolution of automata.

The hierarchy is an informational concept and it can assume many different physical realizations. Invoking the principle of redundancy of mechanism, we might predict that hierarchical structure would be multiply represented. One realization, for example, is a literal structure of levels, like an adaptive controller, in which a high order controller determines the parameters of a lower order controller. Another realization is a separation of levels by phase displacement of messages (the kind of organization proposed by Crane for his "neuristor networks" [11]). Again, the separation may appear at the level of components which are selectively sensitive to different aspects of the same physical signal (one component might respond to the average frequency of impulses whilst another, developed by evolutionary modification, might respond to phase difference or interval between impulses).

In any case there is no doubt that any machine which purports to learn about a structured world (or to recognize aspects of its structure) must possess an informational hierarchy (if it did not, the adaptive process would be too slow to be realistic). Further the
structure of the hierarchy must be related to the structure of this world and since building an hierarchy is tantamount to the process that occurs when an unstructured machine adapts to the world, it is argued that the hierarchy, or its main outline at least, must be built into any realistic machine, either mechanically, by a predetermined connectivity between the elements, or informationally, by a heuristic programme.

Newell, Shaw and Simon, and Marvin Minsky have pursued the heuristic approach, Oliver Selfridge is more concerned with the mechanical approach and mathematically they are largely equivalent. Minsky and Selfridge have indicated the basic mathematical requirements in a recent paper [21].

One practical attempt to meet these requirements is Oliver Selfridge’s recognition programme “pandemonium” [28]. The programme determines a set of computational routines called “demons” that recognize specific attributes of their environment. The lower level “demons” in an hierarchy send recognition signals to demons higher in the hierarchy that form “percepts”. In turn, data regarding “percepts” is collected and a state of the environment is defined. Each component is selectively reinforced according to the agreement between the designated state and whatever designation an omniscient arbiter, also aware of the environment, has in mind. Depending upon their value in obtaining reinforcement, demons at a lower level are preserved or rejected by higher order demons. If a “demon” is rejected at least some of its component subroutines are used in constructing a further routine or “demon” to replace it. Since the process is selective and provident of variation, it is evolutionary.

Now a device like “pandemonium” is certainly “structured” and is capable of development within this structure. But it seems to me that this is not the only way of introducing structure and it is not necessarily the best way. It is particularly efficient if we aim to evolve something that imitates a certain transformation of input data, like a passive network that selects one output for each combination of inputs. Now a frog brain, say, is a machine that resembles a passive network, although it probably evolved from some brain that was not. But a frog brain does very little learning whilst the cognitive machines that are of the most interest, learn a great deal. Thus, without denying the propriety of this approach, the word “cognitive” seems to be used minimally or even trivially in connection with pattern recognizers, for if we take the evolutionary viewpoint seriously (as it is indicated, for example, in the paper by
J. W. S. Pringle] a cognitive system functions because it evolves. It would be absurd to consider it apart from its evolution or (because of the continual interaction between the system and its environment) to separate it from the maturation and adaptation of the brain or other network in which it evolves.

Since we aim to achieve this broader connotation of the word, we shall adopt a definition consonant with the initial contention of 4.4. A cognitive machine is the environment, usually an internal environment such as a network or a brain, wherein cognitive systems are induced to evolve. Design of a cognitive machine thus entails specification of the internal environment together with rules of evolution that constrain the development of active regions.

The definition is loaded with philosophical overtones. For the moment, let us put these aside and avoid any detailed consideration of the function of a cognitive system in order to concentrate upon the practically important issue of determining the evolutionary rules.

1. — The “cognitive system” is a self-organizing system. To make sense of its behaviour we must adopt a sequence of different state descriptions. Equally, seeking to constrain its evolution, we must use constraining operations that are pertinent within the current state description.

There is an immediate departure from the existing structural and heuristic techniques since these constraining operations are commonly valid only within one state description. Yet the more flexible procedure is familiar enough. It is well known that different kinds of influence have different potencies according to when, in evolution or development, they occur. Sometimes the precise moment of a constraining operation is critical (imprinting of data in birds) and commonly the pertinent form of a constraining operation is changeful (the entirely different training techniques we use at varying stages in the maturation of a child’s brain). At a more intimate level, chemical, mechanical, and neural influences are differentially effective constraining operations.

2. — The cognitive system regulates its own development and our interference must, so far as possible, be consonant with this regulation.

Thus, the cognitive system, evolving in a brain, determines the behaviour of an organism. As the system develops, the organism becomes capable of actions that elicit increasingly elaborate situations in the external environment. Now these situations determine constraints, and the constraints induced at any stage are cogent.

We do not pretend to know what constraining procedures should be adopted in the case of an arbitrary cognitive machine, however...
suggestive analogies with the brain may be. But this is where evolutionary models, like the population of automata, become useful.

For it is not too difficult to visualize procedures that alter the course of evolution of a species of automata. These procedures, altering the structure, the food available and the basic evolutionary rules for combining automata, can be transformed into often less obvious equivalent operations upon a network.

5.1. — Speculative and philosophical comments.

In conclusion, let us indulge in some moderately speculative comments about cognition itself, about consciousness and its relation to cognition, about the location of consciousness, and finally, about the extent of and the location of memory.

5.2. — The character of cognition.

My hunch is that cognition, in its non trivial sense, is associated with a special kind of redundancy of potential command. In the situations that McCulloch envisaged when he coined this phrase, there are a number of decisive elements so coupled that resonance
conscious this decision is a somewhat personal matter, for your attitude towards the machine, which will be completely different if you regard it as a conscious machine, does not arise as the result of a logical conclusion you have arrived at upon the evidence from any well defined set of experiments. Broadly speaking, you require evidence of similarity between you and the machine and whilst the tests you make are perfectly explicit, your criterion of similarity is personal [22]. My view is that we should say of “X”, that “X is a cognitive system” as a prerequisite of saying “X is conscious” (1).

This does not imply that any cognitive system is conscious (indeed as above, statements about systems and statements about consciousness are distinct), nor does it delimit a category of conscious objects (you may call a chair “conscious” insofar as you can construct a set of state descriptions in which the chair is a cognitive system). On the other hand, it does allow us to restrict the operational statements we make about consciousness to those which could reasonably be made about cognitive systems. So, for example, it is unreasonable to talk about the location of consciousness because, operationally, it is impossible to locate a cognitive system.

My view, in this matter, stems from the fact that a cognitive system is able to make self referential and interpretative statements, and is the least organization with this capability.

The phrase “self referential statement” has its usual connotation. Burke [10], considering the evolution of von Neuman automata, argues that the system as a whole must make self referential statements, which interpret the activity of its constituent subsystems, in order to evolve. His requirement is equivalent to the condition of 3.4 that the metalanguages, characterizing different layers in the hierarchy of a stable evolutionary system, must be translatable. “Interpretative statements” are comments upon the relation between the cognitive system and objects in its universe of discourse (2).

Returning to the point that our decision to call “X” conscious rests upon evidence of similarity, it seems to me that whatever criterion of similarity is adopted, the tests of its satisfaction entail “X

(1) Cognitive systems that are not similar to us must be commoner than those that are similar. They may be more or less stupid than we are. Those that are not less stupid have a promising application in controlling bizarre environments in which we should be unable to detect any regularity.

(2) With reference to our previous comments about attention, a cognitive system is the least system able to construct a universe of discourse.
referential statements” or “interpretative statements” (on the part of “X”) about objects in a universe of discourse that is common to X and the tester (the tester will need assurance that X appreciates these objects in much the same way that he does). Consequently, in order that a criterion of similarity be tested, X must be a cognitive system.

Further, when a cognitive system evolves (implying that the physical assembly with which it is identified increases in size or structure) the possible “profundity” of interpretative statement must also increase (this is only another way of indicating that higher order metalanguages must be constructed to achieve stability). The more evolved the system, the more wisdom is needed to keep it viable.

The word “profundity” can be made precise in the special case of interpretative statements used to specify a system. In order to count a collection of statements as “the specification of a system”, we must, I believe, credit the source of these statements with consciousness. So we are considering the special case of a cognitive system, agreed to be conscious, specifying a system which is a mutually intelligible image of some assembly open to joint inspection. In particular the specified system may be identified with that collection of physical parts that we have identified with the cognitive system which is producing the specification, and, if so, this cognitive system is uttering self-referential statements.

Now, in these conditions, the greatest possible profundity of interpretative statement is measured by the degree of organization (a redundancy) associated with the most elaborately structured system that can be specified.

5.4. — The spatial extension of the evolving cognitive system.

Since there is no absolute dictum about coupling between a pair of systems, there are no absolute boundaries which define the spatial extension of a cognitive system.

Where, for example, does a man have his limits. Even if we have agreed to speak informationally (rather than speaking in terms of anatomy or of energy) these limits are tenuous and changeful. Is his brain a closely coupled system “the man” as separate from his receptors or effecter mechanisms? Or should we consider his influence upon organizations in the environment which may, of course, include “other men”? We need not dwell upon the issue
(since it was discussed in 3.4) except to comment that the limits depend upon us and upon our choice of system and our objective in constructing it. But, however arbitrary, these limits do exist.

Now, from 5.3, we can also ask: What are the limits of the system that a cognitive system specifies as an image of itself? In particular: What are these limits if the system is stable and is evolving? In this case, the reply must be that the cognitive system has an unlimited spatial extension. For the more extensive it is the wiser it must be, and the wiser it is, the more states of the environment will be involved, and, commonly, the greater its spatial extension (the greater the region of potential control). You may or may not find this circularity illuminating. It means that the environment needed to sustain the stable evolution of a self-organizing system (in particular a cognitive system) is, as we argued in 4.2 a similar self-organizing system.

The case of an unstable system is trivial, because it is unobservable. The case in which the system does not evolve is the special cognitive system called a “perceptual filter” or “recognition device”. Its spatial extension depends upon the form of receptor whilst the set of states of the environment, involved in the system, are those required to specify the percepts of the system.

5.5. — The temporal extension of the evolving cognitive system.

Let us take it that there is no problem of memory capacity, for any brain like assembly is made up of components such as neurones that can and must exhibit many kinds of hysterisis. True, there is a tendancy to single out one sort of state description, for example, to regard neurones as almost binary registers, and to compute a memory capacity in terms of the limited forms of hysterisis that the resulting system can exhibit. But manifestly this is no more than a convenience and a convention. Neurones have chemically distinct states and mechanically distinct states. The membrane in the region of a synapse is highly structured and could determine memory at a molecular level. Maybe other bodies than neurones are significantly involved in memory [5].

The point is, one cannot do anything to a brain, stimulate it or change its chemical environment, without inducing persistent changes of state. This would be true of any large system, with many equilibria, as Ashby points out. But the brain is more like a set of these large systems each defined in “binary impulse” terms, or in
“chemical state” terms or in terms of active cycles, and these systems are closely coupled. So that if, for example, neurones are set into cyclic activity (which amounts to “memory” of the stimulating event) plastic changes occur at the synapses and molecular changes occur at the membranes and these also constitute “memory” of the event).

The problem of memory is thus a coding problem, for information is registered and processed in many different, closely coupled, and coincidentally utilized representations. Brains are physically capable of retaining an index of any occurrence. But the indexed data may or may not be decodable.

I wish to make only a single point in this connection, namely, that the temporal extension of cognitive systems evolving in hierarchically structured brain like networks (with components as messy and versatile as we suggested) is unlimited. To illustrate the point, consider an active region at layer 1 (higher, in a hierarchy of metalanguages, or historically more advanced than layer 2), so that a layer 1 active region can interpret the active regions of layer 2, in the sense of constructing a system to represent their states. Notice that constructing a system is precisely the decoding procedure needed to extract some arbitrary memorized event.

Now we may interpret the active regions in layer 1 and in layer 2, at, say, the level of impulse transmission and abstract them in this sense, as little cognitive systems. We admit, of course, that plastic changes also occur, but regard these as irrelevant to the activity. (If they had seemed relevant, we could have examined them in detail). So in this picture, a layer 2 cognitive system computes data and hands it on to layer 1 and some memory resides in each layer.

Now a layer 1 cognitive system, defined in terms of impulses, can only make statements about impulses in layer 1 and the same comment applies to layer 2 cognitive systems in layer 2; but a layer 1 cognitive system can build its own system to represent layer 2 activity. It is free to select a different representation (say, in terms of plastic changes at the synapses) to the one we happened to choose. Indeed, higher level systems can interpret lower level activity in a variety of different ways (each of which amounts to a coding procedure). Since the process is cumulative and since the evolving cognitive system can construct hierarchical levels it can, in principle, decode from any state of the brain. But there are indefinitely many state descriptions and thus of states. So the temporal extension of the system is unlimited.
Equally, memory may involve the environment. Given a minimal
coupling to a minimally adaptive kind of environment it is still true
that any change of state in a cognitive system exerts some effect
upon the state of the environment and it is always possible that a
system capable of appreciating the significance of this change will
evolve. In more adaptive surroundings bits of the environment
may be used like bits of a brain. We have seen this occur in our
abstract model and there is no sparcity of cases in biology. The bird
builds a nest. The nest provides a feedback stimulus that evokes
the behaviour of egg laying and the hormonal changes needed to
lay eggs. The eggs provide the feedback stimulus for sitting. Because
the bird sits the eggs will hatch and provide a further stimulus.
So functionally the bird does engulf its environment. But if the
organism that embodies our cognitive system is part of a larger self
organizing system, which a stable system must be, its memory is
distributed and unlimited and resides in language and in systems
of evolving concepts.

It seems to me that a human being must be described as a cog-
nitive system. With Heinz von Foerster I insist, as a matter of
faith if you like, that there is a relation between any human being
and any other and anything he would call his environment, such
that the systems he may build are structured. For, if so, there is
something to perceive. Finally, again as a matter of faith, I have the
healthy materialism to believe that systems are identified with a
physical world which, unlike a metaphysical or merely intellectual
world, is open to an indefinite number of interpretations.

These seemingly innocent requirements lead a cybernetician to
some odd conclusions about the immense permanence and immuta-
Bility of form in such a self organizing system.

1. — With Huxley and others I must conclude that “me”, my
“consciousness” is not localized. It cannot, for example, be found
in my head. Ideally, if not necessarily, the vehicle of this conscious-
ness, a cognitive system, has an unlimited spatial and temporal
extension. It is doubtful if one can say “my cognitive system”.
There is an intriguing sense in which “my” consciousness may
develop because the system ramifies.

2. — Because memory is hewn in the stuff of a physical world
identified with indefinitely many systems, nothing thought or
felt or done can ever be forgotten by the system in which we live
and of which we are part. That it should not evolve is incon-
ceivable.
References

[18] MacKay, D.M., Many papers, of which the most recent was presented at the 1961 Conference of the British Society for Philosophy of Science.
Reference is also made to relevant points developed more fully in An approach to cybernetics, by Gordon Pask (Hutchinson, 1961), and the author's contribution to the Urbana Symposium on the principles of self organization, where the evolutionary model is exhibited in greater detail.
Technical Paper

Conceptualising, Mapping, and Measuring Social Forces

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Abstract: A map of the socio-cybernetic forces controlling the operation of the “educational” system is first used to highlight some things that can be learned from the preparation of such a diagram and especially to ask how social forces like those represented can be harnessed to achieve the manifest goals of the system more effectively. It is then used to raise more fundamental questions, which it is hoped participants will help to answer, about how “social forces” are to be conceptualised and measured. The huge benefits that would accrue from being able to quantify social forces are illustrated in an Appendix. Ironically, that same appendix again implicitly highlights the fact that attempts to initiate social action on the basis of good information (such as that provided in that very appendix) will continue to have largely counterintuitive and counter-productive effects unless the network of social forces controlling the outcomes is understood and taken into account via a more appropriate socio-cybernetic system for the management of society.

Some 20 years ago, following 30 years’ studying why the educational system in general fails to deliver on its manifest educational goals and, instead, performs mainly sociological functions (see footnote below and Raven, 1994), we found ourselves, following Morgan (1986) (whose diagrammatic representations of the networks of forces or feedback loops controlling the operation of three social systems are reproduced in Appendix 1 below), trying to map what we later came to think of as the network of social forces which undermine the system*.

* It cannot be too strongly emphasised that this paper has been written to provoke discussion of some fundamental issues in systems thinking - and in socio-cybernetics in particular. We have introduced our work on the educational system in a purely illustrative capacity. Any discussion here of possible solutions to the manifold problems of the educational system would, so far as the objectives of this paper are concerned, be diversionary. Nevertheless, in order to reduce confusion and misunderstanding, it should be underlined that, when we refer to the “goals of education”, we do not have in mind the goal of conveying and assessing knowledge. In the research which preceded the research discussed here we had shown, first, that the most widely endorsed goals of the system included nurturing such qualities as the confidence and initiative required to introduce change and identifying, developing, and recognising the huge variety of talents that different people possess … that is to say, nurturing and credentialing diversity. Second that these opinions are essentially correct: these are the qualities people require at work and in society. And, third, that, in reality, schools generally do the opposite. They stifle initiative and adventurous enquiry, instead devoting the vast proportion of time to inculcating and assessing tiny smatterings of knowledge that is out of date when it
The result is shown in Figure 1.

What the Figure shows is that:

A. There is no single “explanation of the problem. Multiple, mutually reinforcing and recursive, processes are at work. The dominance of the activities with which schools are preoccupied arises from:

(i) A series of sociological imperatives (e.g., that schools assist in legitimising the rationing of privilege); what happens in schools is not determined by the wishes of parents, teachers, pupils, employers, ministers of education or anyone else but by what is assessed in the sociological process of allocating position and status.

(ii) Inappropriate beliefs about the nature of the changes that are needed in education itself, the management of the educational system, and the management of society;

(iii) Society’s failure to initiate research which would yield useful insights into such things as (a) the nature of competence and how it is to be fostered and (b) how to manage the educational system to nurture high-level generic competencies;

(iv) The absence of (a) systematically generated variety in, and choice between, educational programmes which have demonstrably different consequences and (b) Information on the consequences of each of these alternatives;

(v) Failure to introduce “parallel organisation activity” to produce innovation within schools, and

(vi) Inadequate dissemination of the results of research into the nature, development, and assessment of generic high-level competencies, and, especially, the implications of the values basis of competence.

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That widely shared beliefs about how public sector activities should be managed seriously undermine the operation of the system. These beliefs include the notion that it is the job of elected officials (described by John Stuart Mill and Adam Smith as “committees of ignoramuses”) to tell public servants … including teachers … what to do and to monitor achievement of the goals or targets thus prescribed using heavy-handed, command-and-control oriented, techniques.

The narrow educational process that is implemented has a series of knock-on effects which finally contribute to its own perpetuation. The competencies and beliefs that are nurtured and inculcated in schools reinforce a social order which offers major benefits to “able” people who do what is required of them without questioning that order; it creates endless work which gives meaning to people’s lives (but does not enhance the general quality of life); it creates wealth at the expense of the biosphere, future generations, and the third world; and it protects its citizens from a knowledge of the basis of their wealth. The educational system helps to teach a host of incorrect beliefs which collectively result in nothing being what it is popularly or authoritatively said to be (for example, the educational system itself claims to be about promoting the growth of competence when it in fact mainly operates to engage vast numbers of people in “teaching” and “learning” activities of little educational merit but which ensure that those who are most able and willing to challenge the fraudulent nature of the system are routed to social positions from which they can have little influence while those who are least able to do anything except secure their
own advantage are promoted into influential positions in society). This double-talk makes it extremely difficult to conduct any rational discussion of the changes needed in society. The sociological imperative that schools help to legitimise the rationing of privilege helps to create a demand for, and encourages acceptance of, narrow, invisible, and mislabelled assessments. Those predisposed to acquire these “qualifications” are not inclined to see the need for, or to commission, genuine enquiry-oriented research or notice other talents in their fellows. Teachers who become aware of the hidden competencies of their “less able” students experience acute distress. The lack of understanding of the nature of competence leads to a failure to underline the need for a variety of value-based educational programmes and thus to the perpetuation of narrow educational activity.

D. That the main motives for change are widespread awareness that there is something seriously wrong with the educational system, and, more specifically, that it fails miserably in its manifest task of identifying, nurturing, recognising, and utilising most people's motives and talents. The most commonly proposed solutions to this problem, based as they are on other misunderstandings, are, however, inappropriate. Another motive for change stems from increasing recognition that we have created a non-sustainable society and that basic change in the way society is run is essential.

E. That there are a number of points at which it should be possible to intervene in the feedback loops to create an upward spiral. These might involve:

(i) Promoting wider recognition that one cannot get value for human effort in modern society unless we introduce better means of monitoring and evaluating the long-term effects of what we are doing and better ways of giving effect to information on such effects. This points to the need to change the way we run society, to the need to introduce more, and more appropriate, social research and evaluation activity, and to find ways of holding public servants and politicians accountable for seeking out and acting on information in an innovative way in the long-term public interest;

(ii) Introducing the “parallel organisation” activities that are required to promote innovation within schools;

(iii) Establishing a greater variety of distinctively different, value-based, educational programmes and providing information on the short and long-term, personal and social, consequences of each;

(iv) Creating public debate about the forms of supervision – the nature of the democracy – needed to ensure that public servants seek out and act on information in an innovative way in the public interest and,

(iv) Disseminating what is already known about the nature, development, and assessment of competence and its implications.

Standing further back from the Figure what we see is that:

1. It is impossible to achieve significant benefits by changing any one part of the system … such as curriculum or examinations or teacher training on its own … without simultaneously making other changes – otherwise the effects of the change will either be negated by the reactions of the rest of the system or produce counterintuitive, and usually counterproductive, changes elsewhere. On the other hand, it is equally clear that command-and-control-based system-wide change based on uninformed opinion will achieve little.

2. Pervasive, systems-oriented, changes are required to move forward. But these changes, although collectively system-wide, cannot be centrally mandated because there are too
many new things to be done.

3. Since what happens is not determined by the wishes of any particular group of people but by the sociological functions the system performs for society – i.e. by the system itself - the widespread tendency to single out and blame parents, pupils, teachers, public servants, or politicians is entirely inappropriate. Their behaviour is determined by the system. One needs to take these social forces seriously and ask how they can be harnessed in an analogous way to that in which marine engineers harness the potentially destructive forces of the wind: They will not go away!

4. It is vital to generalise the observation made in (3): We need to fundamentally re-frame the way we think about the causation of behaviour in a way which parallels one of the transformations Newton introduced into physics. Before Newton, if objects moved or changed direction, it was because of their internal properties: they were animated. After Newton it was mainly because they were acted upon by a network of invisible external forces which could nevertheless be mapped, measured and harnessed. Observation (3) implies that we need a similar transformation in the way we think about the causes of human behaviour.

5. The network of forces depicted (a) has the effect of driving attempts to deal with the problems based on single-variable common-sense interventions ever more narrowly, and ineffectively, around the triangle at the top left of the Figure, and (b) diverts attention from the developments, indicated in the bottom part of the figure, that are so essential to move forward.

6. The causes of the symptoms (and thus the appropriate place to start reform) are far removed from those symptoms.

7. The system does not merely reproduce itself – it leads to the production of ever more elaborate versions of itself; it is self-elaborating; autopoietic.

Although we did not, at the time, describe what we next tried to do in these terms, we then set about asking how these social forces could be harnessed to push the system in the direction in which most people wanted it to go instead of crashing it against the rocks. This is analogous to thinking out how to map and harness the forces acting on sailing boats in order to be able to sail into the wind*. Other analogies include amplifying and damping down electrical currents derived from sensors in a control system for a missile.

The result is shown in Figure 2.

We were very proud of this Figure. It generated important new insights into how to create a pervasive climate of experimentation, innovation, and learning via comprehensive (holistic) evaluation, public debate, and feedback … exactly the opposite of the arrangements embedded in centralised command-and-control thinking.

Despite the importance of all of these insights, we have belatedly realised that the socio-cybernetic governance system we designed (i.e. that summarised in Figure 2) was not analogous to what would have emerged from an attempt to use an understanding of the forces acting on sailing boats to invent ways of harnessing those forces to push the boat where its captain and crew wanted it to go. Instead, we had, in effect, suggested replacing the existing equipment (i.e. sails etc.) by a marine engine.

* To repeat: A brief discussion of the way in which physical forces can be mapped and harnessed will be found in Appendix 2.
So now a more fundamental problem is bothering us: How are we to conceptualise, map, and measure social forces in a manner which is indeed analogous to doing these things for the physical forces acting on a sailing boat?

Note that, to undertake this task for a sailing boat, Newton first had to articulate the concept of “force” itself … before that there had just been the wind, the waves, and the gods. He had to show that whatever this invisible “thing” was, it was something which was common to understanding some aspects of the behaviour of winds, waves, falling apples, and the movement of the planets. To do this he had to show that these invisible forces were measurable. (Making the invisible visible has been a constant component in scientific advance.) And then he had to show how the various separate forces acting on a sailing boat could be mapped, measured, and integrated. He could then leave the task of re-designing sailing boats to harness those forces to someone else: ships’ designers.
Figure 2

New Societal Managements Arrangements
In the foregoing discussion of Figure 1, we have made continuous use of the term “force”. We must now take up the question of the nature, or status, of these “forces”. At the most basic level, Figure 1 is analogous to a map of the interacting gravitational forces controlling the orbits of the planets. But the nature of the social forces involved has yet to be elucidated. What is clear is that the links in the diagram are not flows of e.g. resources as in the models developed by Forrester (1971) and Meadows et al. (2008)*. Nor are they flows of “information” as in networks of emails. Nor are they flows of e.g., people from one section of the “educational system” to another. The contents of the boxes are not people or stocks of food or components. Only if the links really are forces in some sense analogous to physical forces does it make sense to ask how they can be harnessed (as in the forces acting on a sailing boat) or amplified or damped down (as in electrical energy flowing through a radio). It is worthy of note, however, that, just as one can “feel” the force of gravity acting on an object held at arm’s length or the force of an electric current passing through that same arm, so can one “feel” social pressures. Note, too, that one does not have to fully “understand” the nature of these forces before one can set about measuring and harnessing them.

So these are the questions I would like the audience for this session to help me answer: How are we to think about these social forces? How are we to measure them? How are we to map them?

It may be helpful to note in passing that this is, in a sense, the problem that has hampered the advance of ecology: How to map the multiple interactions between all the plants and animals in a particular ecological niche?

Although the question of how to harness them is really a question for someone else – such as political scientists – experience has shown that attempts to resolve practical questions can sometimes lead to theoretical advance … so we should perhaps not exclude this question.

The huge benefits which would stem from being able to map and measure social forces so as to be able to actually quantify the operation of a social system having multiple interacting and recursive feedback loops are dramatically illustrated in Appendix 4, taken from Forrester (and the Club of Rome), 1971/1995. This documents the extensive, generally counterintuitive, effects that can be seen from a systems analysis of this type to be likely to follow from various types of common-sense-based intervention in the World economic, population, resource, and environmental quality system. It is vital to find out how to document the probable effects of different types of intervention in social systems.

And here is Forrester’s Achilles heel. For, having used his systems thinking to indicate the kinds of things that urgently need to be done, it then becomes necessary to get someone to act on this information. Yet our starting point was, precisely, that it is precisely the network of forces controlling such actions that we need to map and understand if we are to avoid serious counterintuitive and counterproductive outcomes of well-intentioned interventions.

* Some of these are, thanks to the help of Luciano Gallon, reproduced in Appendix 3 below.

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Appendix 1.

Morgan’s Diagrams of the Networks of Social Forces and Feedback Loops

Constituting three Socio-cybernetic (guidance and control) Systems

The easiest way to give the reader a feel for the nature of the work on which we were trying to build when we, some 20 years ago, prepared Figure 1 is by reproducing the diagrams Morgan himself constructed to represent three social systems … or perhaps the socio-cybernetic (guidance and control) processes controlling the operation of those systems. The first of these dealt with the network of mutually supportive and interacting forces and feedback loops that contribute to price inflation. It is reproduced in Figure 3.

Figure 3

*Price inflation as a system of mutual causality*

As Morgan comments “When we understand the problem of price inflation as a system of mutual causality defined by many interacting forces, we are encouraged to think in loops rather than in lines. No single factor is the cause of the problem. Price inflation is enfolded in the nature of the relations that define the total system. Many of the links represented in this diagram are
deviation-amplifying (heavy lines); negative-feedback relations (dotted lines) are more sparse. Positive feedback thus gains the upper hand. The system can be stabilized by strengthening existing negative-feedback loops and by creating others. Many government policies implicitly attempt to have this effect. For example, wage and price controls introduce negative-feedback loops that attempt to moderate the wage-price spiral. Government or media criticism of trade unions as unreasonable, greedy "villains" attempts to weaken the positive-feedback loop between public support and union power in the hope that it will moderate the power of trade unions to negotiate higher wages.

“In understanding this kind of mutual causality, we recognize that it is not possible to exert unilateral control over any set of variables. Interventions are likely to reverberate throughout the whole. It is thus necessary to adjust interventions to achieve the kind of system transformation that one desires.”

The next diagram Morgan presents deals with positive and negative feedback loops in the Power industry (Figure 4).

**Figure 4**

*Positive and Negative Feedback Loops in the Power Industry.*
His final Diagram deals with the Watergate cover up

Figure 5
Cover Up and Exposure in the Watergate Affair.

Morgan makes the following general comments … which are strongly reinforced by observations made in the current paper.

“When we analyze situations as loops rather than lines we invariably arrive at a much richer picture of the system under consideration. There are many levels at which a system can be analyzed, and the choice of perspective will very much depend on the nature of the problem with which one is dealing. As noted earlier, systems always contain wholes within wholes, and one often finds that the problem with which one starts quickly becomes part of a larger problem requiring a broader focus. It is thus often necessary to supplement analysis conducted at one level (e.g. of socioeconomic trends at a macro level) with a richer picture of the dynamics of a set of relations that seem particularly important (e.g., organizational and interorganizational relations among a specific set of institutions). This broadening or deepening of analysis adds to the complexity of the overall picture, but often brings benefits in that it may identify new ways of
solving the problems of specific concern. For when the problem is reframed, new opportunities often come into view.

“In conducting this kind of analysis it may not always be possible to map the loops defining a system with the degree of certainty and completeness that one might desire. In complex systems the degree of differentiation is high, and there are usually numerous intervening processes shaping any given set of actions.”

In the light of comments that have been made on our own work in the 20 years since we embarked upon it, it seems worth yet again underlining three things: First, many of the feedback processes depicted in these diagrams mutually reinforce many of the other feedback processes shown. These multiple lines cannot meaningfully be omitted and reduced to single, simple, lines. There is no single most important cause or explanation of “the problem” - nor remedy for it. Second: One cannot change any one part of the system on its own. Either the change one introduces will be negated by the reactions of the rest of the system or it will result in entirely unanticipated and counterintuitive effects elsewhere. Third: The overall system becomes self-perpetuating, self-elaborating, in a word “autopoietic”. (The significance of autopoietic processes is discussed more fully in other articles on this website, perhaps most fully in Raven, 2009.)

Appendix 2

Mapping and Summing Physical Forces

It has emerged that some readers are not as familiar with the procedures involved in mapping, measuring, and summing physical forces as had been assumed. The following note has therefore been prepared with the help of Luciano Gallon, to whom heartfelt thanks are due.

The most basic illustration we can think of is predicting in which direction, and with what force, a group made up of two boys pulling on ropes attached to a goat’s collar will move – see Figure 6.

![Figure 6](image-url)

*Figure 6*

Two Boys and a Goat

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To progress the analysis, both the direction and strengths the three forces can be represented as in Figure 7, where the lengths of the lines (vectors) shows how strongly each is pulling in the direction shown.

![Figure 7](image)

**Figure 7**

The Struggle between the Boys and the Goat Expressed in Vectors

The direction and strength of the outcome of this struggle can be calculated by dropping perpendiculars onto any two dimensions (or orthogonal axes) inserted into Figure 7 at random (Figure 8). Summing these intersects, or coordinates, (i.e. $A_x + B_x + G_x$ and $A_y + B_y + G_y$) (treating coordinates to the left of the origin on the X axis and below the origin on the Y axis as negative) gives the coordinates ($R_x$ and $R_y$) of the final vector resulting from the struggle ($\mathbf{R}$ in Figure 8). This shows the strength and direction of the outcome. (In this case, the goat wins!)
Calculating the Outcome of the Struggle with the Goat

Mapping and summatating the forces acting on a sailing boat is more complicated, but the process is the same. Even an oversimplified diagram has to include the force of the wind on the sails, the resulting thrust on the mast and, via the ropes attached to the outer corner of the sail, toward the stern of the boat, the effect of the rudder, and, most importantly from the point of view of our discussion here, the force of the sea on the keel (see Figure 9).
Why is the keel so important to us?

Prior to Newton, not only had the concept of “force” – so obvious to us now – not been articulated, the movement of sailing boats was to a much greater extent than later in the lap of the Gods. Boats could only sail with the wind. If their captains wanted to reach a destination upwind, they had to hove-to and pray for a favourable wind.

The first thing Newton did was show that what he hypothesised to be a “force” in this invisible wind could be measured. He did this by first jumping with the wind and measuring how far he could jump and then jumping into the wind and making a similar measurement. The difference between the two gave him the strength of the wind.

(In the context of this discussion it is worth noting that a key thing Franklin did in order to substantiate the concept of “electricity” was to show that its strength could be assessed – “measured” – from the relative strengths of the electric shocks he experienced in his arms.)

Back to Newton and sailing boats.

Among other things, Newton also formulated a number of “laws of motion”.

Among these, was the law that “To every force there is an equal and opposite reaction”.

Now. Where is the equal and opposite reaction to the force of the wind on the sailing boat?

In the sea?

OK. If so, how can it be harnessed?

Answer “By adding a keel to the sailing boat”. And that is precisely what is shown in Figure 6. Harnessing the invisible force in the sea is key to getting the boat to sail into the wind.

It is important to note that none of the above is “common sense” … indeed, from the common sense perspective that preceded Newton, it is just madness … I mean, its just crazy to suggest that there is a force in the sea! The necessary developments could not have been taken unless Newton had articulated the concept of force and shown that it was measurable and behaved in predictable – law-like - ways.

Newton went on to do something else which is even closer to what we are trying to do here – namely to map the forces determining the orbits of the planets and compute their cumulative strengths.

First, he needed the concept of “gravity”. Then he had again to demonstrate that it could be measured. And then that the results were consistent. Indeed they were. Indeed they were. And very surprising: bags of coal and desert spoons if dropped from the top of a tower, reached the ground at the same time. (Actually, this last discovery had been made earlier, but we do not need to concern ourselves with this here.)
And then he had to find a way of integrating all the interacting pulls of every planet on every other.

To perform that task he had to invent calculus.

We do not have to do that.

But my thesis is that we do have to embrace an exactly parallel series of problems if we wish to develop better ways of thinking about the nature, measurement, and harnessing of social forces.

Appendix 3

Predicting Socio-Economic Change from Recursive Interactions between Social and Economic Indices: The Forrester/Club of Rome Models.

In the report they prepared for the Club of Rome, Forrester (1971) and Meadows et al. (1972) mapped the recursive interactions between numerous economic, resource, and environmental quality indices in a range of domains.

A simplified version of the overall model (reproduced from Forrester, 1971) is shown in Figure 10. Some of the details of what lies behind it (extracted from Meadows et al. (2008)) are shown in the diagrams which follow. Meadows et al. (2008) provide links to an interactive version of the model which allows researchers to study the effects of introducing changes of their own choosing.

This material was originally introduced both to provide a comprehensible analogy to illustrate what we have been trying to do and, at the same time, to enable readers to appreciate the distinction between the social forces which cannot be measured with the tools currently available to us and those that it is currently possible to quantify. However, the material in Appendix 4, which shows the scenarios which result from changing certain parameters illustrates the huge – and often counterintuitive – benefits which would stem from studying the operation of systems qua systems instead of continuing to introduce what are essentially single variable interventions based on common sense and very incomplete mental maps of the interactions between variables. The latter usually entirely neglect recursive effects of the kind illustrated in our own and Morgan’s diagrams.

4 I am deeply grateful to Luciano Gallon for drawing my attention to the existence of these models and helping me to download them.

5 A series of projections derived from inserting different assumptions into the model will be found in Appendix 4.
Fig. 10 Simplified World Model used to analyse the effects of changing population and economic growth over the next 50 years. The model includes interrelationships of population, capital investment, natural resources, pollution, and agriculture and background variables which influence, and are influenced, by them.
I have to confess that I am not entirely clear how weights are assigned to indicate the strength of the contributions of the components indicated in the models below as they add up in different scenarios. The way many of the social forces exert their effect remains unclear. The preceding variables clearly influence the subsequent ones. But how do they influence them … and how is the differential strength of their influence calculated to compare with the strength of influence of other variables? Also, although this is not the case in the Forrester model shown in Figure 10, despite the use of curved lines, the directions of influence seem mostly to be one-way, linear. There are very few negative, never mind self-elaborating, self-amplifying, autopoietic, loops.

It is therefore not at all clear to me that the authors have achieved even the initial, subjective, level of measurement of the strength of the wind and electricity achieved by Newton and Franklin respectively - never mind the more sophisticated measures that came later. In the end, therefore, I am not sure that they help us to understand or measure – and thus how to damp down, amplify, or harness – the patterns of influence represented in Figure 1.
Fertility

Life Expectancy

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Appendix 4

Some illustrations of the Counter-Intuitive Effects of Common-Sense-Based Interventions

Derived from: NonRPMarticles: Excerpts from Forrester HEADINGS.doc

As we have seen, Forrester (1971) developed a systems model somewhat akin to those developed by Morgan to document the mutual and recursive feedback loops between population, capital investment, natural resources, pollution and agriculture. Plus many background variables, such as birth and death rates, which contribute to and are affected by them in a recursive manner.

The big difference is that the strengths of the effects are quantified and its major limitation – and it is a very serious one – is that it does not deal with the kinds of social forces depicted in our Education diagram and Morgan’s diagrams.

A more elaborate form of this model was the one used in Meadows’ (1972) submission (entitled The Limits to Growth) to the Club of Rome’s Project on the Predicament of Mankind.

Unlike the normal, and incomplete, mental maps we all carry around in our heads, and are used as a basis for most government planning, not only are many more of the mutual and recursive effects shown, each assumption is explicit and can be subjected to scrutiny and modification.
The assumptions built into the models are derived from common discussions and assertions about the world system.

The main difference from the Morgan/Raven models discussed earlier is that these inputs and outcomes can be quantified using the economic and production methods currently available.

Forrester gives several striking examples of the, generally counterintuitive, effects of changing some of the assumptions fed into the model. Many of these are similar to the 10 scenarios presented in Meadows et al. (2004), which were themselves derived from experimentation with what became an interactive version downloadable from Meadows et al. (2008). This can be used to discover, in real time, what would happen if one were to intervene in any way – or combination of ways – one may choose.

Many of the results of such experiments are dramatic and frightening.

In this way they illustrate the vital importance of studying systems *qua* systems and, in particular, of finding ways of conceptualising and measuring social forces of the kind depicted in our own or Morgan’s diagrams.

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Figure 2 in this Appendix (which would have been Figure 11 if all Figures in the text had been numbered consecutively) shows the trends that would occur in the six main outcomes if things are left pretty much as they are so that industrialization is eventually suppressed by falling natural resources.

It starts with estimates of conditions in 1900.

On the basis of the assumptions fed into the model, quality of life peaked in the 1950s and by 2020 will have fallen far enough to halt further rise in population. Declining resources, and the consequent fall in capital investment, exert further pressure which gradually reduces world population.
Forrester comments that we may not be fortunate enough to gradually run out of natural resources in this way.

Science and technology may find ways to use more plentiful metals and alternative ways of generating energy so that resource depletion does not intervene.

But, if this happens, it only leaves the way open for another growth-resisting pressure to arise.

Figure 3 shows what happens if the resource shortage is avoided.
Here the only change from the assumptions fed into Figure 2 concern the rate of usage of natural resources. In Figure 3, resources are, after 1970, consumed at a rate 75 per cent less than assumed in Figure 2.

In this way the standard of living is sustained with less drain on the expendable and irreplaceable resources.

The outcome is even less attractive than it would have been if things had been left alone!

By not running out of resources, population and capital investment are able to rise until a pollution crisis is created. Pollution then acts directly to reduce birth rate, increase death rate, and depress food production. In this case, population, which peaks in 2030, declines by 83% within 20 years. Forrester notes that this would be a disaster of unprecedented proportions.

Generalising: What we have here is a dramatic illustration of the everyday experience that common-sense based interventions aimed at fixing one problem within a poorly understood system create unexpected problems somewhere else in the system.

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Let us now ask what would happen if one set out to sustain quality-of-life – which, according to this model, begins to decline from 1950.

One option might be to increase the rate of industrialization by raising the rate of capital investment.

Figure 4 shows what happens if the “normal” rate of capital accumulation is increased by 20 per cent in 1970.

Again, a pollution crisis appears.

This time the cause is not more efficient use of natural resources but an upsurge of industrialization that overtaxes the environment before resource depletion has a chance to depress industrialization.

Again, an “obviously desirable” policy has caused troubles worse than these that the policies were originally introduced to correct.
Figure 5 retains the 20 per cent additional capital investment rate after 1970 from Figure 4 and in addition explores the effects of birth rate reduction in the hope of avoiding crisis.

Here the normal birth rate has been cut in half in 1970.

What then happens is that Quality-of-Life surges upward for 30 years for the reasons that are customarily expected.

Although not shown in the figure, food-per-capita grows, material standard of living rises, and crowding does not become as great.

But the more affluent continue to use natural resources and to accumulate capital plant at about the same rate as in Figure 4.

In other words, the 50 per cent reduction in normal birth rate in 1970 was indeed sufficient to start a decline in total population.

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But the rising quality-of-life and the decline in the pressures act start the population curve upward again so that the end result is much the same.

Load on the environment is more closely related to industrialization than to population, so the pollution crisis occurs at about the same time as in Figure 4.

In other words, the 50 per cent reduction in normal birth rate in 1970 was indeed sufficient to start a decline in total population.

But the rising quality of life and reduction in pressures start the population curve upward again.

The bottom line is that the end result is much the same.

Figure 6 combines the reduced resource usage rate and increased capital investment rate of Figures 3 and 4.

![Graph showing combined data](image)

Fig. 6. The 20 per cent increase of capital investment from Figure 4 and the 75 per cent reduction of natural resource usage from Figure 3 are combined.

The result is that population collapse occurs slightly sooner and more severely.
Figure 7 shows what happens if technology finds ways to reduce the pollution generated by industrialization by 50 per cent from that shown in Figure 6.

Pollution rate, other things being the same, is reduced by 50 per cent from that shown in Figure 6.

The result is to postpone the day of reckoning by 20 years and to allow population to rise by another 25% before it collapses.

Thus the “solution” “reducing pollution” has, in effect, caused more people to suffer the eventual consequences.

In this way, Figure 7 again reveals the dangers of partial, “common-sense” based solutions. Actions at one point in a system to relieve one kind of distress produce unexpected results in some other part of the system.

If the interactions are not sufficiently understood, the consequences can be as bad as, or worse, than those that led to the initial action.

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More optimistic scenarios are also available, if requiring more disciplined and concerted public action.

Figure 8 shows how the world system reacts if several policy changes are adopted simultaneously in the year 1970.

Population is stabilized.

Quality-of-life rises about 50%.

Pollution remains at about the 1970 level.
But would such a world be accepted?

It implies an end to population and economic growth.

The rate of capital accumulation has been reduced to 40% below its previous value.

The birth rate has been reduced to 50% of its earlier value.

The rate of pollution generation has been reduced to 50% of its value before 1970.

The rate of food production has been lowered 20% from its previous value.

Reducing the investment rate and emphasis on agriculture are counterintuitive and unlikely to be accepted without extensive system studies and years of argument – perhaps more years than are available.

It may be easier for people to understand and take the steps necessary to reduce pollution and consumption of natural resources.

Among the changes experimentally introduced in Figure 8, achieving a dramatic reduction in worldwide birth rate would be the most improbable.

Even if technical and biological methods become available to help reduce birth rates, the improved condition of the world as a whole that would arise from the changes envisaged in Figure 8 might remove the incentive to sustain the lower birth weight.

References


Forrester, J. W. (1971/73). *World Dynamics*. Waltham, MA: Pegasus Communications. (Second edition has an added chapter on physical vs. social limits.)


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