Simulation of Self-Renewing Systems

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1. AUTOPOIETIC ORGANIZATION

Autopoietic systems are self-renewing, self-repairing, and unity-maintaining autonomous organizations of components capable of interactive linkages. Examples are cells, organs, organisms, and groups of organisms. *Autopoiesis*, or self-creation, characterizes all living organisms and their organizations, ranging from the macromolecular, unicellular and multicellular organisms to differentiated, self-perpetuating animal and human groupings.

Autopoietic organization can be defined as a network of interrelated component-producing *processes* such that the components, through their interaction, generate recursively the *same* network of processes which produced them and thus realize the network of processes as an identifiable unity in the space in which the components exist. The product of an autopoietic system is necessarily always the system itself, its organization being continuously realized under permanent turnover of matter and energy.

Allopoietic organization, in contrast, can be defined as a network of interrelated component-producing processes such that it does not produce the components and processes which realize it as a unity. The product of an allopoietic system is different from the system itself. Thus, the actual realization of such systems is determined by processes which do not enter into their organization. They are nonautonomous, since their realization and longevity as unities are not related to their operation. Among the examples here figure spatially determined structures like crystals, formal hierarchies, and concentration camps. The process of production of the components that realize the allopoietic organization as a unity does not enter into its definition as a unity.

The simplest autopoietic organization is a *cell* of a biological organism, not because there could not be other autopoietic or allopoietic systems within the cell, but because it clearly displays the *minimal* organization, for *any* set of components, necessary for autopoiesis. There is a *catalytic nucleus* capable of interactions with environmental substrate so that the membrane-forming components are produced. A *membrane* then defines and separates this network of interactions from its environment and an autonomous unity is thus realized. A cell is a continuous and recursive production of components which, through a membrane, define the cell itself.

Erich Jantsch and Conrad H. Waddington (eds.), *Evolution and Consciousness: Human Systems in Transition.*

Although there are myriad distinct subcellular structures within cells—atoms, molecules, macromolecular polymers, mitochondria, chloroplasts, and so forth—the properties of the components do not determine the cell's properties as an autopoietic system. The properties of a cell are the properties of relations and interactions produced by, and producing, its components.

2. AUTOPOIETIC MODELING

Autopoietic modeling has generically evolved from cellular automata theory (see e.g., von Neumann, 1966; Codd, 1968; and Gardner, 1971). Recently, Wainwright (1974) has reviewed the Game of Life, an interesting tessellation model governed by only two simple rules.

In 1974, three Chilean scientists (Varela et al., 1974) published a seminal article describing for the first time a truly autopoietic model, representing a new direction as well as a new hope in contemporary biology. The article is equally important to simulation modeling of social systems, organizational theories, and management sciences.

In accordance with the basic organization of a cell, the simplest model of autopoietic organization must consist of an environment of substrate, catalysts capable of producing more complex elements (i.e., links), which are capable, in turn, of their own bonding, concatenating into a membrane around the catalyst. Including holes, there are thus five different states possible in each position of the grid, because each position can be occupied by one of the five basic components only, which are assigned the following graphical symbols:

	hole
o	substrate
▯	link
-▯- -⊟-	bonded link (singly or fully)
★	catalyst

~~In the cell model of Varela~~ et al. (1974), three basic transformations are accounted for:

1. *Composition:* 2○+ ★ ⟶ ▯ + ★
   A catalyst and two units of substrate produce a link, while the catalyst is left unchanged. A hole is the byproduct of this operation.
2. *Disintegration:* ▯ ⟶ 2○; -▮ ⟶ 2○; -⊟- ⟶ 2○
   A link, free or bonded, disintegrates into two units of substrate, filling available holes.
3. *Bonding:* ▮-⊟- ··· -▮+ ▯ ⟶ ▮-⊟- ··· -⊟-▮
   A free link can be bonded with a chain of bonded links; two chains of bonded links can be bonded into one; two free links can be bonded to start a chain formation.

The actual rules guiding the movement of all components and specifying the conditions for the three basic transformations are quite involved and are formally treated elsewhere (Zeleny and Pierre, 1975). However, it should be mentioned here that, besides the basic system-building components just enumerated the simple model includes two other main constituents:

(a) A simulation of chance, based on a random number generator functioning in conjunction with a special set of rules, including a random walk over two- or three-dimensional space in the tessellation grid (i.e., randomly determining the direction of movement or, alternatively, the next configuration to be established by movements).
(b) Recursive transformation and interaction rules or "algebra," allowing spontaneous encounters and linking of elements as well as subsequent disintegration of the created linkages.

Each link is allowed to have only two bonds: it can be either singly bonded, -▮ , or fully bonded, -⊟- . Additional bonds are not allowed, to avoid branching of chains. Such unbranched chains can ultimately form a membrane around the catalyst, creating an enclosure which is not penetrable by either ★ or ▯ . These components are thus effectively "trapped" and forced to function for the benefit of the autopoietic unity. Substrates ○ can pass freely through the membrane to facilitate production of ▯ by the catalyst. Any disintegrated links, causing ruptures in the membrane, are thus effectively repaired by this continuous production. The unity of the system is dynamically reestablished.

Multiple catalysts can function in the same tessellation grid of substrate. As the catalysts move closer together or as their number increases, a dynamic balance among interacting membranous unities—a *multicellular autopoietic system*—can be established. Similarly, we can control available amounts of substrate inflows by simply contracting or expanding the corresponding tessellation grid. The rates of membrane formation and disintegration can also be regulated by a simple adjustment of particular rules and parameters. The system can be "forced" to disintegrate totally or to freeze into stable allopoietic structure. Systems incapable of even forming a membrane can be induced into their futile existence. Systems whose membranes never rupture; systems with spacious, large, or narrow membranes; substrate-seeking "amoeba-like" cells, floating through the space; and hundreds of other varieties can be observed by simply adjusting a few rules.

Extraordinarly intricate phenomena can be observed to be *spontaneously generated* by this simple set of rules. In our first simulation studies with a model, coded in APL for the IBM-360 system at Columbia University (see Figure 7.1), the autopoietic "birth-death" process ultimately attains a dynamical steady state, characterized by a self-renewing "membrane." A cathode-ray tube graphical image then allows for continuous observation and analysis of its "life." Inducing a proper deviation from such a steady state can cause disintegration of the "membrane" and ceasing of all vital functions. Similarly, "explosive" conditions, leading to "cancerous" growth, can be induced.

In Figure 7.1, it may be observed that after reaching dynamic stability (somewhere around TIME 25, i.e., just before the first closure of the membrane), the autopoietic cell keeps renewing itself through a series of oscillations between rupture and closure. Its very existence as an autopoietic system is based on this rhythmical opening and closing. We observe that the underlying rules have created a "natural rhythm" of the open system (see, e.g., Klapp, 1975). All living systems, including societies, function through a complex of more or less intricate biorhythms. We might preferably talk of *pulsating systems*, since neither permanently closed nor permanently open systems are autopoietic; they are not "alive."

3. THE AIM: PARAPHRASING DYNAMICAL ASPECTS OF A SYSTEM

The conventional method of reduction approaches complex systems by breaking them up into smaller components. If these are still too complex, they are broken up into even smaller components, until the resulting components are so tiny that at least one of them can be understood. There are roughly 10^{20} molecules in a single living cell. In the cell's nucleus alone, more than one hundred distinct chemical reactions have been identified; yet the properties of components in isolation add little, if anything, to our understanding of the workings of a cell.

Cancer is a problem of this extraordinarily complex universe, the cell. It is due to the disruption or alteration of the autopoietic network

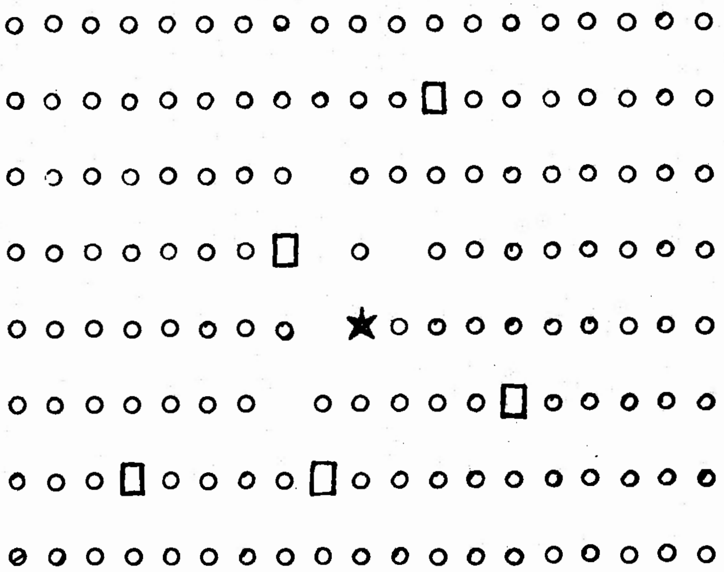

FIGURE 7.1. Simulation of an autopoietic cell system. (The symbols are explained in the text.) (a) TIME 5. The process is initiated by putting a catalyst in the environment of substrate; first free links are produced.

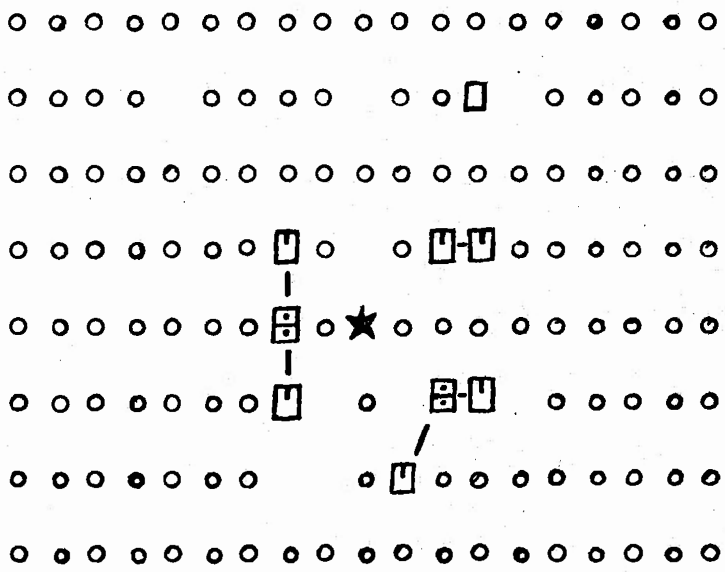

FIGURE 7.1b. TIME 10. Catalytic production continues and some initial bonding occurs. Observe that all matter is conserved: the number of holes is always equal to the number of all links (free **and bonded**).

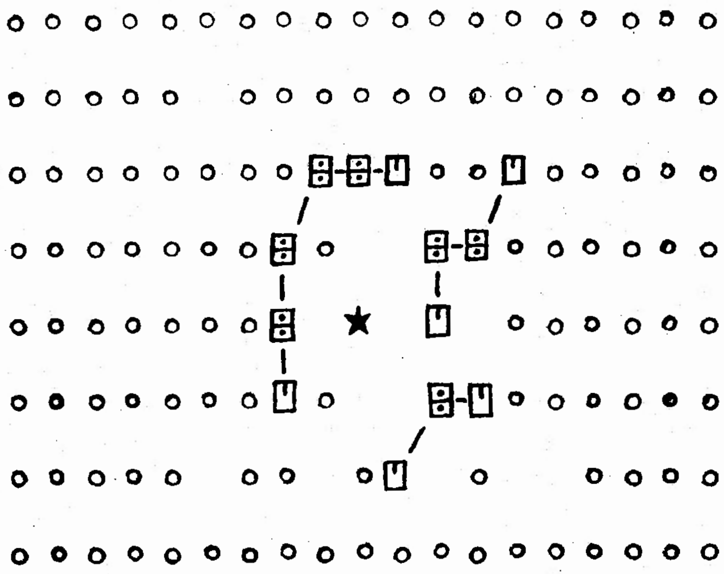

FIGURE 7.1c. TIME 15. Larger chains of bonded links are being formed. These concatenations already tend to be positioned around the catalyst.

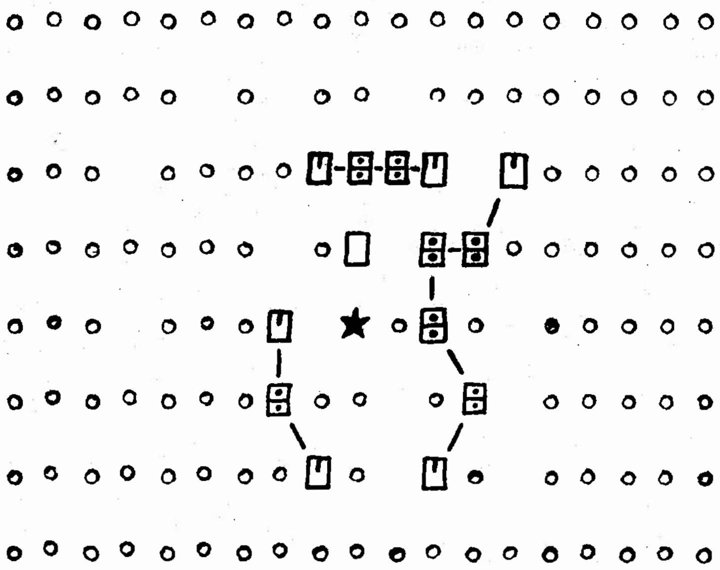

FIGURE 7.1d. TIME 20. Even though some links disintegrate in the process, we can observe an overall increase in the amount of organized components.

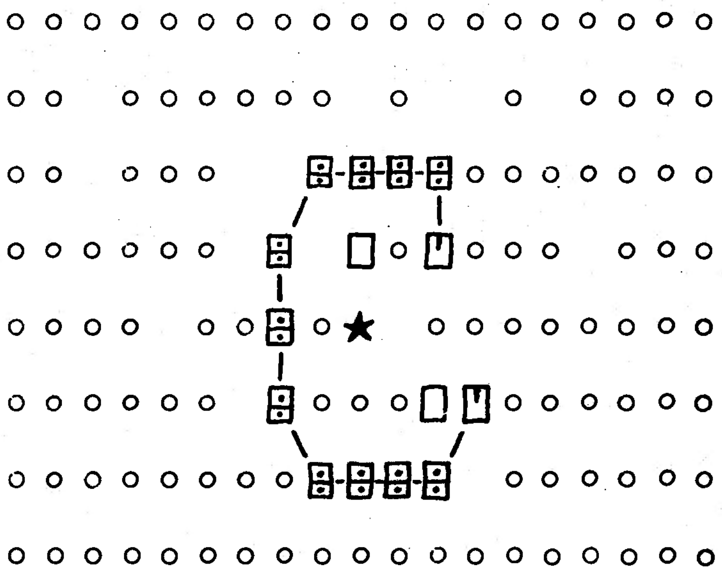

FIGURE 7.1e. TIME 25. The ratio of links to substrate, which is now almost one eighth, indicates that the "life-sustaining conditions" have been approached. Next we look at the succeeding iteration (rather than screening only every fifth one as before).

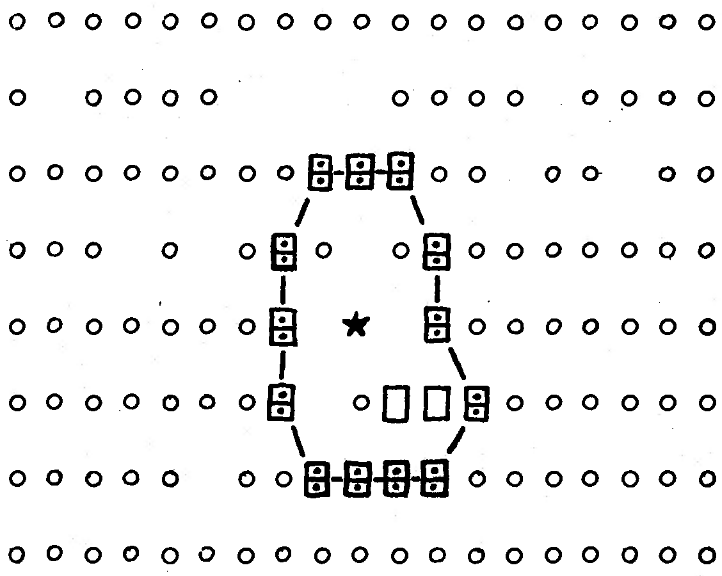

FIGURE 7.1f. TIME 26. A membrane has enclosed itself around the catalyst and a clearly defined unity of a certain size and shape can be observed. We now look at every second iteration.

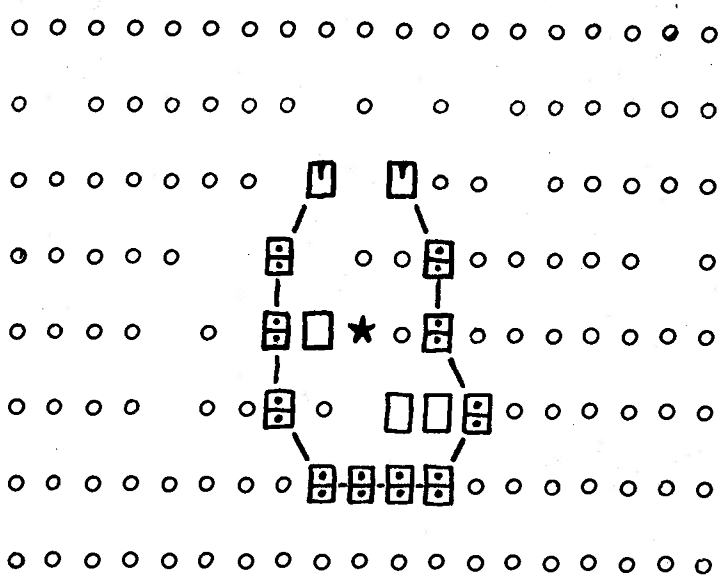

FIGURE 7.1g. TIME 28. The membrane has been ruptured. Although the essential forms and functions are still being perpetuated, the unity must repair itself in order to be truly autopoietic.

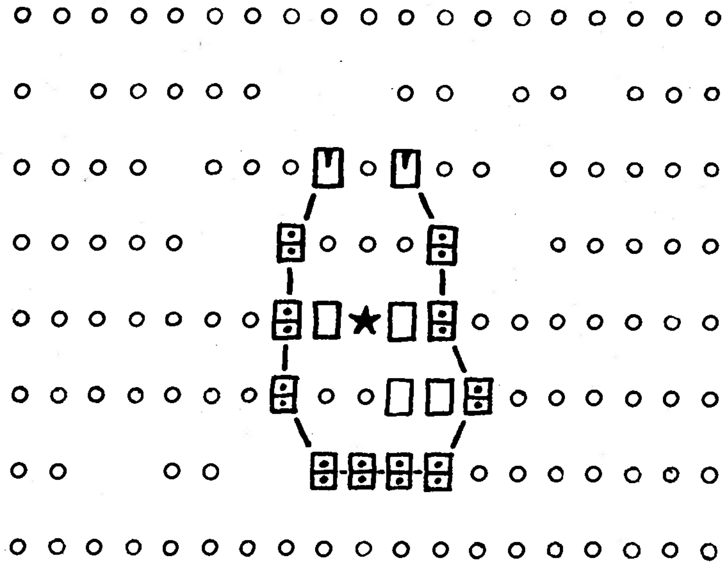

FIGURE 7.1h. TIME 30. Observe the increased number of links and substrate concentrating inside the cell. The chances for an early reinstatement of the whole membrane are good.

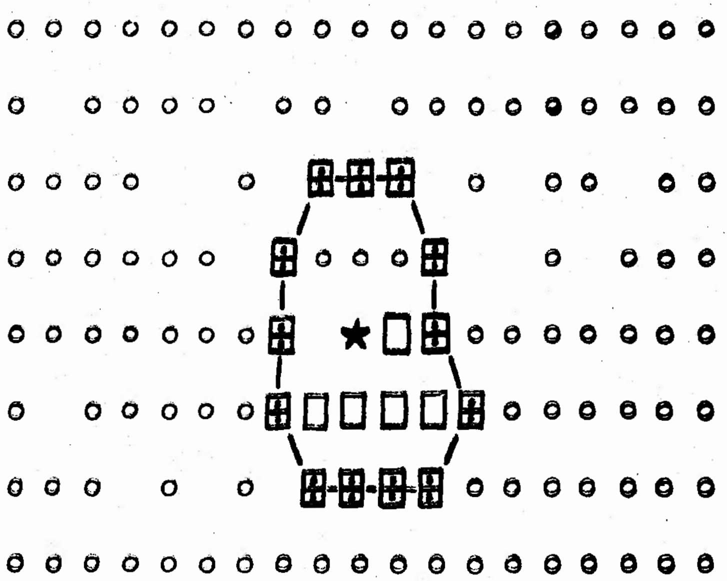

FIGURE 7.1i. TIME 32. The membrane has been repaired and the autopoietic unity restored.

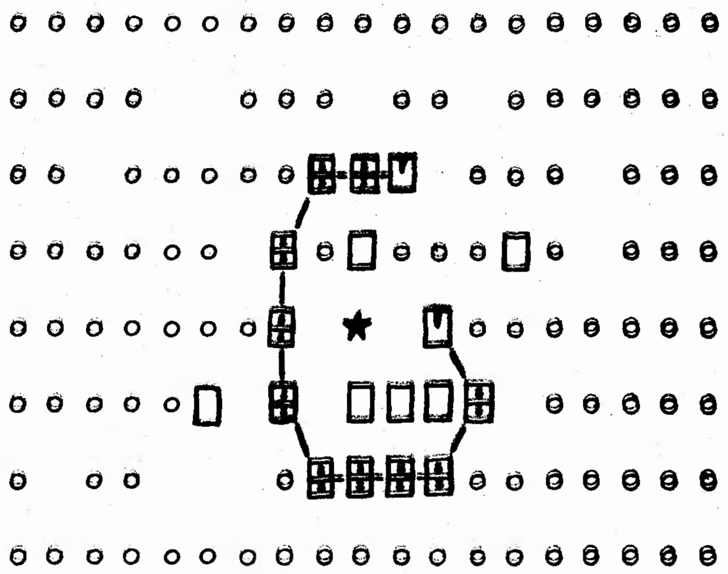

FIGURE 7.1j. TIME 34. We can observe another rupture of the membrane.

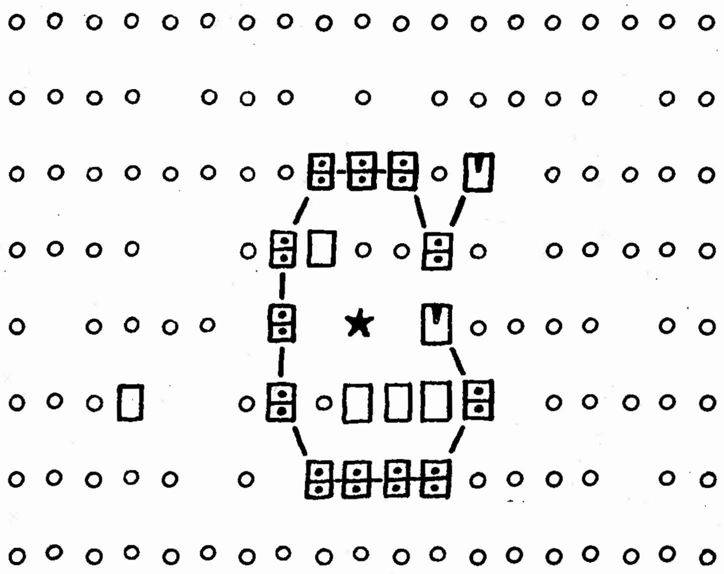

FIGURE 7.1k. TIME 36. The number of links (19) is the highest now and early repair is imminent. The autopoietic unity is going to "survive" until we turn the computer off. Next we look fourteen iterations ahead.

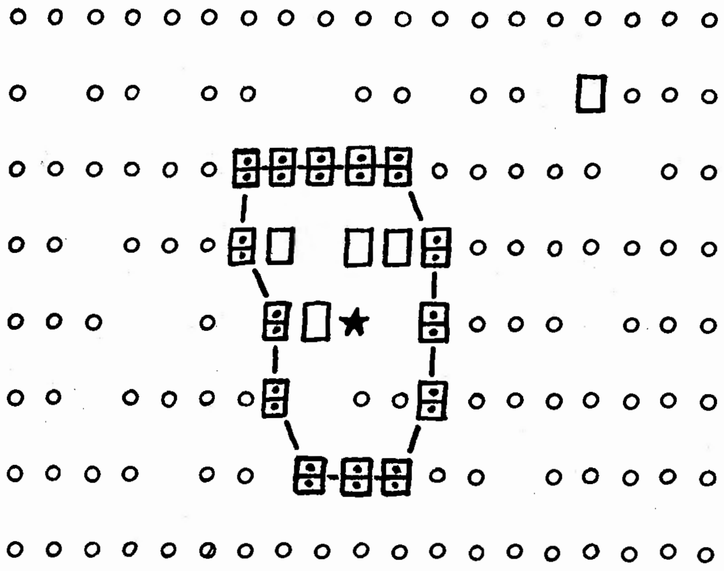

FIGURE 7.1l. TIME 50. The unity is still clearly defined and the whole autopoietic process exhibits global stability of a series of ruptures/repairs. Note the changed contour of the membrane.

of interactions. Yet reductionists hope to gain the crucial understanding of the functions (or dysfunctions) involved by studying its tiniest components: molecules of ribonucleic acid, viruses, chemical reactions at the molecular level, and so forth.

A cell, as an autopoietic system, cannot be understood by studying the properties of the components. Its properties as a whole are determined by the properties of the *interactions* between the components, that is, by its dynamical organization. To try to ascribe a determinant value to any component, or to any of its properties, be it DNA, RNA, or a virus, is a scientific artifice.

In this situation, we face a formidable dilemma: We cannot afford to lose sight of the full complexity of the cell, and on the other hand, it becomes increasingly difficult to cope with this complexity in our inquiry. The number of chemical reactions that must be going on simultaneously in a cell at a given instant of time simply staggers the imagination. If these complex processes could be translated into thousands of corresponding differential equations, a mathematical model of the cell, we would have a tool which could simulate chemical reactions and test suspect aberrations as well as hypothesized control actions. However, even the most sophisticated solution procedures in conjunction with the most powerful computer systems will allow solutions of, at most, only fifty to sixty differential equations—a tiny fraction of the interactions within a cell, indeed.

Foerster (1971) has proposed another avenue by which to bypass this dilemma: "The idea is to abandon the strategy of reformulating the problem into terms that smack of mathematical rigor but lack the contextual richness originally perceived, and to develop the algorithms that transform the descriptions of certain aspects of a system into paraphrases that uncover new semantic relations pertaining to the system as a whole." The rules, transformations, transitions and interactions observed in Conway's Game of Life and in the autopoietic model outlined in the preceding section—they are the paraphrases! The set of computer-based rules governing the organization in its autopoietic state has an enormous potential. It is "bioalgebra," a formal tool for studying living and bioadaptive systems, an autopoietic mathematics that "lives" as does the system it describes.

Instead of studying details of separate chemical reactions, we must concentrate on the interaction of autopoietic components: the set of rules, or program; process generators, transducers monitoring the output of the process generators; autopoietic regulators; repressors; and so forth. Autopoietic models allow us to study their interactions in a holistic and organic way. Cybernetic models are bound to fail here because they attempt to define communication channels, or "wired circuits," of pathways linking these components—an impossible task even if the cell were an electronic or cybernetic system.

Through the autopoietic model we could plot the functions and amounts of main autopoetic components and draw "profiles" of cells under different environmental and organizational conditions. These profiles should allow us to detect the main differences between normal and cancerous cells in terms of their overall interactive patterns. We could then test the balance-restoring actions on the computer many times before trying them on patients. We could treat cancer without being concerned about the chemical-molecular properties of the balancing and restorative agents.

To give an idea of the complexity involved in setting up simple autopoietic models, we might mention that we have found that the autopoietic model of Varela et al. (1974) can be programmed and operated by graduate students in less than a month.

4. APPLICATION TO HUMAN ORGANIZATION

The design of allopoietic institutional structures should not be confused with the study of autopoietic organizations. To specify spatial relations between components, to create a frozen image, a pyramidal hierarchy, has probably little in common with growing an autopoietic organization.

The task of management is to stimulate the *growth of a network of decision processes*, systems, programs, and rules, that is to say, an organization which may be considered effective in attaining institutional objectives. Since one of these objectives is the continuous self-renewal of the autonomous dynamic unity of the organization (i.e., an autopoietic operation), the network of decision processes must produce components capable of recursively generating the same network through their interaction. In this sense, *a manager is the catalyst* rather than the designer of an organization.

Mechanistic concepts of organization and of the design or redisign of its "mechanisms" are the concern of the modern *cybernation* approach, described by Beer (1975, p. 107) as follows: "Thus, we shall gradually be able to devise a more complicated model, redolent with feedback loops, which is of practical value. In doing all this, we pass from the notion of a straightforward feedback mechanism to the notion of multiple loop systems." What we are left with after such strenuous modeling could be just some *allopoietic debris.* No matter how many loops are designed, no matter how complex they are, if they are not self-productions of the organization itself, there is no autopoietic, autonomous, and dynamical system in existence.

In order to have autopoietic systems, the components must exhibit a multitude of interactions through their decision-making capabilities. Human systems differ from all other systems in the enhanced ability of their components to make decisions, to choose among or to create alternatives according to their own objectives. Yet the notions of *goals* and *decision-making* are missing from both cybernetics and theories of organizational behavior. The latter are designed to control and to predict the *behavior* of organizations. They attempt to elicit certain behavioral patterns by imposing the rules or designing a structure from without.

Hayek (1975) characterizes the order of social events as such that, though it is the result of human action, it has not been created by men deliberately arranging the elements in a preconceived pattern. He also talks about ordering forces, spontaneous orders, and "the rules." If we understand the forces that determine such an order, we can use them by creating the conditions under which such an order will form itself. The autopoietic approach has the advantage that it can be used to procure orders that are far more complex than any order we can produce by arranging the individual components in their appropriate places—a method for systems analysis. Hayek (1975, p. 11) actually preconceives a *social autopoiesis* when he writes: "Though the conduct of the individuals which produces the social order is guided in part by deliberately enforced rules, the order is still a spontaneous order, corresponding to an organism rather than to an organization. It does not rest on the activities being fitted together according to a preconceived plan, but on their being adjusted to one another through the confinement of the action of each by certain general rules."

The attained degree of complexity of the structure of modern society exceeds by far that which would be possible to achieve by deliberate organization. It is a paradox of a futurist contending that we must deliberately plan modern society because it has become so complex. Rather it turns out that we can preserve an order of such complexity only if we control it not by the method of "planning" (i.e., by direct orders), but on the contrary, by aiming at the formation of a spontaneous order based on general rules—a strategic *scenario* planning at best.

Modern computer and simulation methodology are powerful tools with which to grow and observe real social organizations in laboratory settings. To use these great advances effectively, however, we have to treat values, objectives, decisions, norms, and other precepts of human conduct as essential attributes of human systems and their management. By reducing human conduct to a succession of overt physical behaviors, modern behaviorists and behavioral science have prevented themselves from coping successfully with so important a social phenomenon as autopoietic organization. They are bound to endless batch-processing of quantities of primitive data.

The idea of *computer simulation of organizations* can produce only trivial results in dealing with allopoietic behavioral systems. Such "behavioral simulation" can only predict or control the behavior of organisms whose actions rigidly follow rules imposed by the designer from without. In contrast, managers as catalysts induce the components to make their own decisions, conduct their own analyses, select their own criteria. A unique autopoietic organization, a network of values, norms, and precepts, is self-created, self-maintained, and self-grown.

Such a growth process of an autopoietic unity evolves its own rules of change. These rules, in turn, determine what kinds of development can occur. The totality of such an autopoietic network of rules constitutes a theory of organizations. Social change results from free choice by independent decision-makers; it is a teleological advance and need not be just the shaped outcome of external environmental pressures. The pioneers of social simulation, Beatrice and Sidney Rome (1971, p. 2), state,

> When people form and become members of an organization, they agree to conduct themselves according to rules or prescripts that *they* establish and maintain. These covenants stipulate what members must, may, can, ought, and should do and not do, according to their roles in the organization, and these enable individuals to act as agents for the corporate whole. As organizations develop, their covenants become successively transformed. Inasmuch as these processes have formal order, a science of social development is possible, that depends not on past regularities, but on future opportunities.

But human systems are not only contrivances for processing information and making decisions. Humans *live* their lives through human systems, shape them through their *individual* aspirations, goals, norms, values, and actions, creating a set of *systems* aspirations, goals, norms, values, and actions, which could be quite different from and independent of the individual ones. Humans are, in turn, continuously being shaped by these self-organized entities, their spatial arrangement evolving through a succession of orderly but temporary structures. Human purposeful action and the autopoietic interaction with their emerging organization are *irreducible to behavior*, as has been so forcefully stated by Jantsch (1975).

5. TOWARD A HUMAN SYSTEMS MANAGEMENT

Human systems management requires a new mode of inquiry into complex and dynamical human systems. Its contours emerge in the context of the following set of observations:

1. Complex and dynamical human systems are to be *managed* rather than analyzed or designed. Human systems management is not systems analysis or design.
2. Human systems management is a process of *catalytic reinforcement* of a dynamic self-organization and bonding of human components. It does not design a managerial hierarchy of command or control.
3. Components of human systems are *humans.* As such, they differ significantly from other components, mechanistic or biological, in their ability to anticipate the future, to formulate their objectives, to plan for their attainment, and to make decisions. These properties are sufficient to make human systems quite distinct from all other systems.
4. The integral complexity of human systems can be lost in the process of its simplifying reinterpretation by the rigor of mathematical mechanics. Human systems can be described and studied through a relatively simple set of linguistic, fuzzy, and semantic rules, governing the self-creation of its complex organization. Human systems management is not operations research, econometrics, or applied mathematics.
5. Interactions between components are not those of electronic circuitry, communication channels, or feedback loop mechanisms. Rather, they are organic and dynamical manifestations of organizational autopoiesis. Human systems management is not cybernetics or the information theory of communications.
6. Dynamical order of human systems organization is maintained through a continuous renewal of certain *nonequilibrium conditions.* Both nonequilibrium and instability are essential for self-organization of higher complexity. Human systems management is not a theory of general equilibrium.
7. The concepts of optimization and optimal control are not meaningful in a general theory of human systems. Human aspirations and objectives are dynamical, multiple, and in conflict, as are those of human organizations. This conflict is the very source of their creative evolutionary unfolding. Human systems management is not optimal control theory or theory of conflict resolution.
8. The inquiry into human systems is *transdisciplinary* by necessity. Human systems encompass the whole hierarchy of natural systems: physical, biological, social, and spiritual. Human systems management is not interdisciplinary or multidisciplinary; it does not attempt to unify scientific disciplines, but transcends them.

In conclusion, we believe that autopoietic modeling, as outlined earlier in this chapter, carries great potential for making a significant contribution to the development of human systems management in this spirit.

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