What Is Autopoiesis?

Milan Zeleny

INTRODUCTION

Readers working their way through this volume will learn about autopoiesis from 15 different expositions, including those of the very creators of the concept: Maturana, Varela, and Uribe. But experience shows that a careful tutorial orientation, before a plunge into the articles themselves, can go a long way toward providing a framework for understanding. One acquires a template, a point of reference. and the subsequent reading and study can take place in a directed, selective, and therefore creative way.

Autopoiesis means literally "self-production." We should be careful about the variety of expressions with similar connotation: self-organization, -renewal, -creation, -generation, -maintenance. -perpetuation, and the like. Similarly, there are also such terms as biopoiesis, heteropoiesis, and allopoiesis characterizing different aspects of the processes of production. The audience may worry why we use the Greek "autopoiesis" instead of the English "self-production." "Self-production" could mean many different things to different people: it could be interpreted in a variety of ways. "Autopoiesis" is not a translation but a label for a particular, clearly defined interpretation of "self-production."

We observe self-production phenomena intuitively in living systems. The cell, for example, is a complex production system, producing and synthesizing macromolecules of proteins, lipids, and enzymes, among others; it consists of about 10^5 macromolecules on the average. The entire macromolecular population of a given cell is renewed about 10^4 times during its lifetime. Throughout this staggering turnover of matter, the cell maintains its distinctiveness, cohesiveness, and relative autonomy. It | produces myriads of components. Yet it does not produce only something else – it *produces itself*. A cell maintains its identity and distinctiveness even though it incorporates at least 10^9 different constitutive molecules during its life span. This maintenance of unity and wholeness, while the components themselves are being continuously or periodically disassembled and rebuilt, created and decimated, produced and consumed, is called "autopoiesis."

BASIC CONCEPTS

In order to achieve a more precise characterization of autopoiesis, only intuitively introduced above, it is necessary to define some of the basic concepts that enter into its definition.

Unity. An entity distinguished from its background by the observer, either as "a whole, without referring to its component" (simple unity), or through identifying its components (composite unity).

Zeleny M. (1981) What is autopoiesis? In: Zeleny M. (ed.) Autopoiesis: A theory of living organization. Elsevier North Holland, New York NY: 4–17.

Production process. Any process of synthesis, transformation, or destruction realized in the space of components. For example, disintegration of macrocomponents “produces” substrate on which other processes of production can “act.”

Organization. A complex of relationships among components and component-producing processes that must remain invariant in order to constitute a unity distinguishable within its identity class.

Structure. A particular spatiotemporal arrangement of particular components through which the underlying organization is realized in a given space and at a given point in time.

Closed organization. A particular (circular) organization of processes that recursively depend on each other for their maintenance and realization; they form a recursive closure. Compare with linear or serial chains or “trees” of processes, forming an open organization.

Autonomous unity. A unity distinguished (or described) as a composite unity integrating its components. A nonautonomous (controlled) unity is then distinguished as a simple unity (i.e., as a component of a larger system within which it operates). The autonomy or control mode of description depends on the cognitive preference of the observer.

REMARK. It is fair to note Varela’s *closure thesis* (Varela 1979) at this point: “Every autonomous system is organizationally closed.” In our | view, autonomy being a derived and observer-depen- | 6
dent notion, it is organizational closure that is sufficient, but not necessary, for perceived autonomy. Thus, *every organizationally closed system is autonomous* would be more in line with our current exposition. Equating autonomy with organizational closure (or autopoiesis) leads to mixing two non- intersecting domains of discourse and would make the concept of autonomy redundant. □

System. A composite unity characterized by its organization *and* structure. Referring to its organization identifies only the class of unities to which a system belongs: describing its structure identities its concrete space of components. Neither mode is sufficient for fully describing a system.

Topological boundary. The part of a system’s structure that allows the observer to identify it as a unity.

Many concepts, for example, existence, purpose, observer, and reproduction, need to be adequately defined. The reader is referred to Maturana’s paper in this volume and to references at the end of this chapter (Varela 1979: Maturana and Varela 1980) for a more complete treatment.

It is one of the contributions of autopoiesis that these concepts are now being more precisely defined and their prevailing *metaphorical* usage recognized.

DEFINITION

We are ready to define an *autopoietic system*:

Autopoietic system. A unity realized through a closed organization of production processes such that (a) the same organization of processes is generated through the interaction of their own products (components), and (b) a topological boundary emerges as a result of the same constitutive processes.

In this definition, the organization of components and component-producing processes is maintained invariant through the interactions and flux of components. This invariance follows from the definition: should the organization change we would have a change in system's identity class.

What changes is the system's structure and its parts, as, for example, a topological boundary in response to the perturbations in the environment of the system's autopoiesis.

The type of self-producing and self-maintaining closed organization described above is referred to as *autopoietic organization*. The nature of the components themselves and their spa- | 7
tiotemporal relations are secondary and refer to the structure of the system. Consequently, the system's topological boundary is a structural manifestation of the underlying organization, subject to change and compensatory adaptations. It does not constitute the system's organization: it represents its structural manifestation under certain conditions in a particular field of components.

This does *not* mean that the topological boundary (and structure) is not conducive to or even necessary, through creating a favorable environment of components, for the maintenance of an autopoietic organization. Both organization and structure are mutually interdependent.

REMARK. The reader should he aware that the definition and interpretation of autopoiesis presented above differs from those of Maturana and Varela (see the papers in this volume and the reference list at the end of this chapter). Namely, "production" is defined in more general terms, "autonomy" is treated as being fully observer-dependent, and "topological boundary" is recognized as pertaining to structure. We cannot engage in an extended discussion here, but the works of others may be consulted (Zeleny 1978, 1980). □

An open organization of components and component-producing processes (linear, treelike, or other noncyclical concatenations) leads to allopoiesis: that is, the organization is not recursively generated through the interactions of its own products. In this sense, the system is not *self*-producing; it produces something other than "itself." This particular (allopoietic) concatenation of processes is capable only of production, not self-production. Allopoietic organizations are still invariant and can be spontaneously concatenated (under favorable conditions).

A particular concatenation of production processes can be assembled by humans through a purposeful design. We then speak of *heteropoiesis.*

Man-made machines and contrivances, and their own productions as well, are heteropoietic – they are produced by another system. A machine, for example, is characterized by an organization of components produced by other processes (a person or another machine), and of processes of production whose products do not constitute the machine itself. So far, all heteropoietic systems are allopoietic (i.e., nonliving).

COMPUTER MODEL OF AUTOPOIESIS

The best understanding of the previously defined concepts can be achieved by contemplating computer simulation outcomes of modeling the simplest autopoietic organization of production processes.

Consider Figure 1, which summarizes the essential building blocks of the so-called APL- | 8
AUTOPOIESIS model. The three processes – production (P), bonding (B), and distintegration (D) – are postulated as being feasible because of the specific properties of components moving randomly over a two-dimensional tesselation grid. These processes, in turn, determine the interactions that take place in the space of components.

<u>Components</u>

⋆ <u>catalyst(s)</u>, represented by an asterisk

( ) <u>holes</u>, represented by a blank space

o <u>substrate</u>, represented by a small circle

□ <u>free link</u>, represented by an empty square

-⍞ <u>singly-bonded link</u>, represented by a square with a quota inside and a single dash

-⌹- <u>fully-bonded link</u>, represented by a square with an APL division sign inside and two dashes

<u>Organization of Components</u>

PRODUCTION (P): ⋆ + o + o → □ + ⋆ + ( )

A catalyst and two units of substrate produce one free link and a hole as a byproduct. The catalyst is neither affected, nor does it change its position. This stipulation can be relaxed. Production can take place only when the two units of substrate are within a predetermined neighborhood of the catalyst.

BONDING (B): □ + □ → ⍞-⍞   -⌹-⍞ + □ → -⌹-⌹+⍞

Two free links can be bonded together to start a chain. One free link can be bonded with an existing chain of bonded links, making the chain longer.

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-⌹-⌹           ⍞      -⌹-⌹      ⍞
     \     +    |  →       \     |
     ⌹-⍞      ⍞-⌹          ⌹-⌹-⌹
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Two existing chains of bonded links can be bonded into a longer chain.

□ + ( ) → o + o

DISINTEGRATION (D): -⌹-⌹-⍞ + ( ) → -⌹-⍞ + o + o

<u>Any</u> link, free or bonded, can disintegrate into two units of substrate provided there is a hole (space) available in the immediate neighborhood of such link so that the additional unit of substrate can occupy the space.

Figure 1. APL-Autopoiesis: A Model of the Cell

The processes can be organized in a number of ways, acting independently, in series, and so on. Consider, for example, production acting alone: all substrate would be simply transformed into links and the process of production would cease. Or, we can concatenate production and bonding: all substrate is transformed into links; links subsequently bond form- | ing a linearly | 9 growing structure(s), a crystal. The underlying organization is open, the system allopoietic.

The reader can continue with these "mental exercises." For example, consider the environment of *links* and concatenate the processes of bonding and disintegration: all the links are ultimately transformed into the substrate's environment, with some intermittent bonded chains emerging and disappearing in the process. In neither of these cases were the terminal products necessary for fueling the processes themselves – there was no organizational closure.

Consider the simplest organizational closure: production and disintegration. Each process, in order to maintain itself, is dependent on the products of the other process. The processes are interdependent and concatenated in a circular manner. Depending on the relative rates of both processes, the result would he a mixture of substrate and links oscillating around some equilibrium proportion.

All three processes, concatenated in a circular fashion, are necessary for autopoiesis. In Figure 1 such a closed organization is implied. Putting aside the notion of origin and examining an ongoing system, observe that disintegration "produces" the substrate necessary for production,

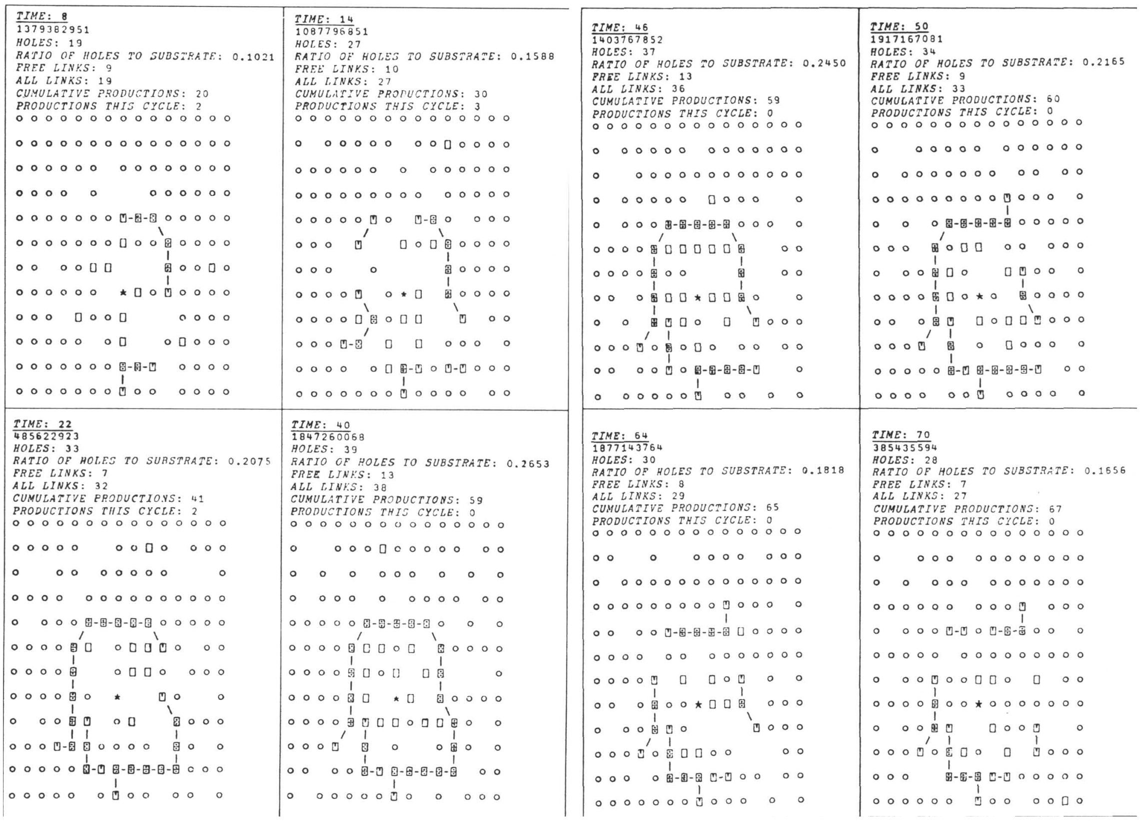

Figure 2

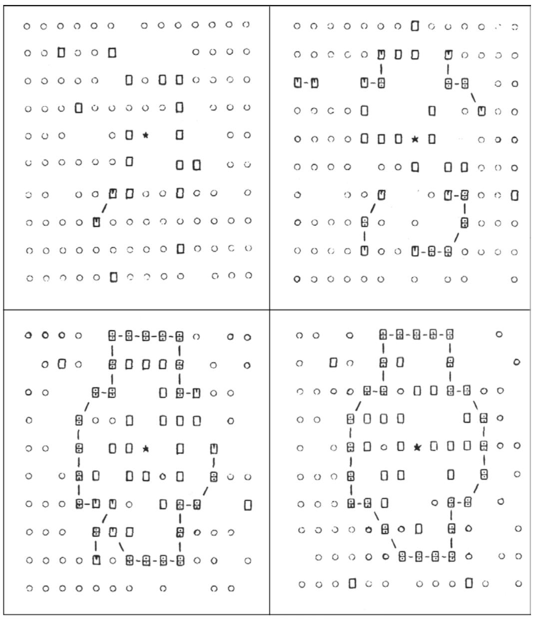

Figure 3

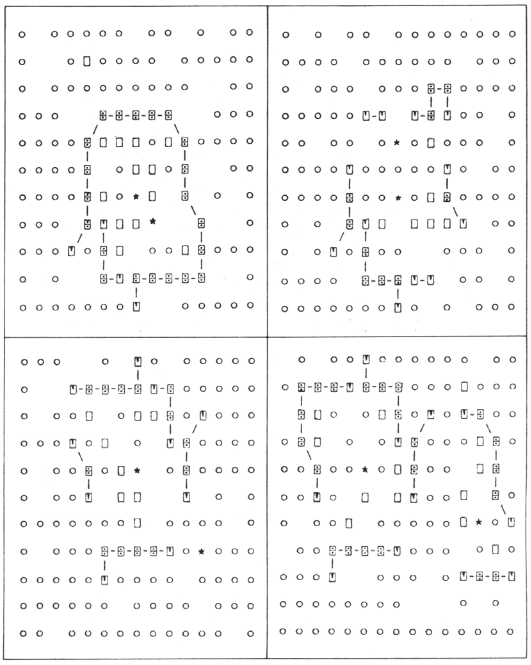

Figure 4

production "produces" the catalyst necessary for itself and the links necessary for bonding, and bonding "produces" the stuff necessary for disintegration.

Yet, the circular organization of processes is still not sufficient. The rates of "production" must be in harmony. A too "vigorous" rate of disintegration would never allow bonded chains to form a viable topological boundary: a too low disintegration rate would lead to "crystallization," and so forth. In Figure 2 we present "snapshots" from a particular history of a balanced autopoietic organization. The topological boundary emerges at about TIME 40 (fourth frame), and it allows the unity to maintain its autopoiesis indefinitely. In this particular run we allow the rates to get out of balance and the unity gradually loses its autopoiesis and ultimately disappears.

A series of interesting experiments can be performed with the APL-AUTOPOIESIS program. In Figure 3 observe how the same autopoietic organization manifests itself in a different structure, in response to simulated environmental perturbation. In Figure 4 observe that the same organization (no additional complexity interjected into the rules of interaction is needed) is capable of self-reproduction if a component (second catalyst) is "placed" within the original enclosure. Autopoiesis itself, under favorable conditions, begets self-reproduction, heredity (similar structure and components), and ultimately evolution.

It is not our intention to describe all the variety and details pertaining to the APL-AUTOPOIESIS model. The program is commercially available and interested readers can duplicate and creatively extend all of the | experiments described.[1] For more complex "nesting" of rules and for | 10
a full mathematical description of the model the reader should consult Zeleny (1977). | | 13

One more note. We mentioned the random movement of components. By contemplating the development of the space of autopoiesis in Figure 2, observe that the space becomes progressively restructured, "deformed." and the processes, although controlled through a random number generator, do not take place in a random fashion. They become constrained in space and time, they become "canalized" and predictable from a macroscopic viewpoint although not microscopically. The re | markable structural coupling of the unity and its environment, mutually | 14
affecting each other and adapting to each other, supports most beautifully our intuitive (though not scientific-rational) understanding of living systems.

SUMMARY OF IMPLICATIONS

The implications and conjectures that can be derived from the presented framework of autopoiesis are neither complete nor consensual, as witnessed by the remarkable variety of views and interpretations presented in this volume. This introduction presents only one view, intended as a template against which all other views can be tested, understood, and recreated.

Autopoietic systems are characterized by a closed organization of production processes and by an internally produced topological boundary.

Organizational closure is necessary but not itself sufficient for autopoiesis. The closure of processes must be "balanced" so that a topological boundary can be formed.

A topological boundary belongs to the domain of structural adaptations and is independent of the underlying organization. It is necessary, under certain conditions, for the maintenance of balanced organizational closure.

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1 APL-AUTOPOIESIS interactive modeling package and User's Manual are available from Computing and Systems Consultants, Inc., P.O. Box 1551, Binghamton, N.Y. 13902. This package is fully equipped with standard special purpose subprograms and allows users to create and implement their own programs and experimental variations through an un locked APL control program AUTO. Inquire also about a video record of autopoietic simulation on Sony videocassette, U-matic, KC-30.

Organizational closures that do not form a topological boundary, although they might be self-producing in a broader sense, are not recognizable by the observer and not classified as autopoietic at this stage.

Structure is not simply emergent from the functioning of an autopoietic organization, but it affects the maintenance and viability of such an organization in a given environment.

Organizationally closed processes defined in a different space of components (e.g., social systems) could be autopoietic as they define their topological boundaries in the same domain. Such boundaries would of course be different from physical membranes. compartments, and the like. Their recognition requires different sets of criteria appropriate to the given domain.

In the domain of social interactions, the close coexistence and interspersion of autopoietic, allopoietic, and heteropoietic organizations makes their identification and separation more difficult than in a purely physical space.

Autonomy is an observer-dependent concept. All autopoietic systems can be viewed as being controlled within the larger system they constitute.

All living systems are autopoietic. All autopoietic systems are organizationally closed. The reverse implications cannot be asserted at this stage. | 15

REFERENCES

In addition to these references, directly related to the preceding remarks, an annotated bibliography of autopoiesis as of 1980 is appended.

Maturana, H. R., and Varela, F. J., (1980), *A*utopoiesis and Cognition: The Realization of the Living, Boston Studies in the Philosophy of Science, Vol. 42. Reidel, Boston.

Varela, F. J., (1979), Principles of Biological Autonomy, Elsevier, New York, pp. 55–60.

Zeleny, M. (1977), Self-Organization of Living Systems: A Formal Model of Autopoiesis, International Journal of General Systems 4 (1), 13–28.

Zeleny, M. (1978). APL-AUTOPOIESIS: Experiments in Self-Organization of Complexity, in Progress in Cybernetics and Systems Research, Vol. 3, edited by R. Trapp! et al., Hemisphere, Washington, D.C., pp. 65–84.

Zeleny, M., ed. (1980), Autopoiesis, Dissipative Structures and Spontaneous Social Orders, Westview, Boulder, Colo.

AUTOPOIESIS 1980: AN ANNOTATED BIBLIOGRAPHY

In addition to the papers this volume comprises, a sizable bibliography of works on autopoiesis has emerged over the past decade. Although the concept of autopoiesis has many intellectual precursors, here we list only the works related directly to its modern embodiment, thus employing the very term "autopoiesis" as a discursive vital core. The order of the listing is roughly chronological.

Maturana, H. R. (1970), The Neurophysiology of Cognition. in Cognition: A Multiple View, edited by P. Garvin, Spartan Books, New York, pp. 3–23. Possibly the first time autopoiesis is actually proposed (although the term itself is not used yet). The nervous system is viewed as a closed, state-determined system for the first time. In the same year, Maturana (The Biology of Cognition, Biological Computer Laboratory, BCL Report 9.0, University of Illinois, Urbana, 1970) discusses the observer-dependent operation of distinction.

Maturana, H. R., and Varela. F. J. (1973), De Mtiquinas y Seros Vivos, Editorial Universitaria, Santiago. The first, and now largely inaccessible, exposition of autopoiesis in Spanish. Work on this manuscript started in 1970–1971 through a close interface of both authors.

Varela, F. J., Maturana, H. R., and Uribe, R. B. (1974), Autopoiesis: The Organization of Living Systems, Its Characterization and a Model, Biosystems 5(4), 187–196. This is the first exposure of the principles of autopoiesis in English: it also contains the first computer tesselation automaton of autopoiesis. This paper was probably the most influential in communicating autopoiesis to Western science.

Maturana, H. R. (1975), The Organization of the Living: A Theory of the Living Organization, International Journal of Man-Machine Studies 7(3), 313–332. A rather philosophical treatment of autopoiesis, rich in new insights, pure | and undiluted Maturana. Discussions of the ner- | 16
vous system, structural coupling, ontogeny and evolution, self-reproduction, and linguistic domains.

Maturana, H. R., and Varela, F. J. (1975), Autopoietic Systems. Biological Computer Laboratory, BCL Report 9.4, University of Illinois. Urbana. The first English translation of the original Maturana – Varela monograph (1973). Its subtitle: “A Characterization of the Living Organization.” It also contains the famous Preface by Stafford Beer.

Beer, S. (1973), Preface to Autopoietic Systems, in Maturana and Varela (1975), pp. 1–16. Beer states, What I am now sure about is that they are right. Nature is not about codes: we observers invent the codes in order to codify what nature is about. These discoveries are very profound. – And elsewhere, “yes, human societies are biological systems.”

Zeleny, M. and Pierre, N. A. (1975), Simulation Models of Autopoietic Systems, Proceedings of the 1975 Computer Simulation Conference, Simulation Councils, Inc., La Jolla, Calif., pp. 831–842. Mathematical formalization of a computer model of autopoiesis, exploring its relationship to Conway’s “Game of Life,” and introducing the notions of bioalgebra and social autopoiesis.

Zeleny, M. and Pierre, N. A. (1976), Simulation of Self-Renewing Systems, in Evolution and Consciousness, edited by E. Jantsch and C. H. Waddington, Addison-Wesley, Reading, Mass., pp. 150–165. Popular and simple exposition, including the principles of human systems management.

Zeleny, M. (1977), Self-Organization of Living Systems: A Formal Model of Autopoiesis, International Journal of General Systems 4 (1). 13–28. Complete formalization of the APL simulation model of autopoiesis. Also, the questions of the origin of life and social autopoiesis.

Zeleny, M. (1977), Organization as an Organism, Proceedings of the SGSR Annual Meeting, Denver, Colo., SGSR, Washington, D.C., pp. 262–270. Basic notions of social autopoiesis and an institutional example.

Zeleny, M. (1978). APL-AUTOPOIESIS: Experiments in Self-Organization of Complexity, in Progress in Cybernetics and Systems Research, Vol. 3, edited by R. Trappl et al., Hemisphere, Washington, D.C., pp. 65–84. Includes detailed descriptions of autopoiesis simulation experiments: growth, circadian rhythms, morphogenesis, mitosis, etc. Full APL-AUTOPOIESIS modeling package and user’s manual is now available from Computing and Systems Consultants, Inc., P.O. Box 1551, Binghamton, N.Y. 13902.

Varela, F. J. and Goguen, J. A. (1978), The Arithmetic of Closure, in Progress in Cybernetics and Systems Research, Vol. 3, edited by R. Trappl et al.. Hemisphere, Washington, D.C., p. 125. Complementing the concept of autopoietic organization by a broader notion of organizational closure. Reprinted in Journal of Cybernetics 8(3,4) (1978), 1–34.

Varela, F. J. (1979), Principles of Biological Autonomy, Elsevier, New York. Varela’s summary and interpretation of autopoiesis, organizational closure, and the calculus of indications.

Faucheux, C., and Makridakis, S. (1979), Automation or Autonomy in Organizational Design. International Journal of General Systems 5(4), 213–220.

Andrew, A. M. (1979), Autopoiesis and Self-Organization, Journal of Cybernetics 9(4), 359–368. | 17

Maturana, H. R. and Varela, F. J. (1980), Autopoiesis and Cognition: The Realization of the Living, Boston Studies in the Philosophy of Science, Vol. 42, Reidel, Boston. First and revised commercial publication of the original Maturana-Varela monograph (1973 and 1975), including S. Beer's preface.

Zeleny, M.. ed. (1980). Autopoiesis, Dissipative Structures and Spontaneous Social Orders. AAAS Selected Symposium 55, Westview, Boulder, Colo. Includes contributions of Boulding. Maturana, Jantsch, Dtichting, Allen, Gierer, and Zeleny. It covers a wide range of methodological approaches and strives for their transdisciplinary unification.

Boulding, K. E., Foreword, in Zeleny (1980), pp. xvi – xxi. Boulding characterizes autopoiesis's implication that chaos is unstable as somewhat shocking for a generation raised on the concept of entropy. Yet, he foresees that "the idea is likely to have a considerable impact on a good many disciplines, from thermodynamics to sociology."

Jantsch. E. (1980). The Unifying Paradigm behind Autopoiesis, Dissipative Structures, Hyper- and Ultracycles. in Zeleny (1980). pp. 81–87. An attempt at unification of a group of "new paradigms" employed in the study of self- organizing and spontaneously generated phenomena in physical. biological, and social systems.

Maturana, H. R. (1980). Autopoiesis: Reproduction, Heredity and Evolution, in Zeleny (1980). pp. 45–79. Maturana's most recent and undiluted views on the phenomenology arising from the assumption of autopoiesis. A challenging presentation: "I claim that nucleic acids do not determine hereditary and genetic phenomena in living systems."

Zeleny, M. (1980). Autopoiesis: A Paradigm Lost? in Zeleny (1980), pp. 3–43. A long-needed attempt at a historical embedding of autopoiesis, tracing the thoughts of Trentowski. Bernard, Leduc, Menger. Bogdanov, Smuts, von Hayek, Weiss, and others.

Zeleny, M., ed. (1981). Cybernetics Forum, Special Issue on Autopoiesis: contains reprints of articles by Varela, Maturana and Uribe, and Maturana, and Zeleny.

Zeleny, M. (1981), Autopoiesis Today, in Zeleny (1981). Review of the current state of autopoiesis research models, literature, and interest groups.

Zeleny, M. (forthcoming), Autopoiesis of Life: Rebellious Thoughts.