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Review Artcle

Autopoiesis: A notion of life

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Abstract

H.R. Maturana and F.J. Varela are two Chilean biologists who were not satisfied with the traditional definition of life that is based upon enumerating its properties, viz. metabolism, reproduction and evolution. They tried to define what makes a minimal life. In this attempt, they proposed the theory of autopoiesis. This theory focuses on the dynamics and systemic nature of living systems and tries to establish that living systems are autonomous systems as they are able to self-create their own components. It also describes how a living system and its environment are inter-related.

Introduction

Traditionally, we have been trying to define life by its certain essential properties, such as, metabolism, reproduction and evolution. However, the Chilean biologists, Humberto R. Maturana and Francisco J. Varela were not satisfied with the idea of enumerating properties of living systems in order to define life. In an attempt to find a more rational definition of life and discover the characteristic organization of a minimal life, they proposed in 1971 an alternative notion of life which they called 'Autopoiesis' (Andrew, 1979). Since then, a huge build up of literature on autopoietic theory has been created (Bachman *et, al*., 1992 and Dewey, 1978). Apart from this, some websites are also available citing literature on autopoiesis (Randall Whitaker's Observer Web and Encyclopedia Autopoietica, for example).

H. R. Maturana (1928) was initially a neurobiologist at University of Chile in Santiago, well known for his work with Jerome Lettyin on the neurophysiology of vision in frogs (Etxeberria, 2004). During the 1960's, Maturana was trying to understand the biology of cognition. Later, he tried to define life afresh. F. J. Varela (1946-2001) was a student of Maturana at Santiago till 1967 when he completed his post-graduation. After finishing his doctoral work at Harvard under the supervision of Nobel laureate Torsten Wiesel, Varela returned to Chile, now as a colleague of Maturana. Here, during the period from 1970 to 1973, Varela and Maturana formulated their famous theory of autopoiesis. After working for many years in Chile and US, Varela finally shifted to Paris where, most unfortunately, he died in 2001.

The theory of autopoiesis

Autopoiesis is a neologism to express the dynamics of living systems and focuses on their autonomy. The term autopoiesis is formed by synthesis of two Greek words- auto (= self) and poiesis

(= production). Thus, the literal meaning of this term is 'self-production'. As is evident by this meaning, Maturana and Varela have attempted to characterize living beings as living machines that can make their own production possible.

'An autopoietic system is one that continuously produces the components that specify it, while at the same time realizing itself to be a concrete unity in space and time; this makes the network of production of components. Autopoiesis simply means processes interlaced in the specific form of a network of production of components which realizing the network that produced them constitute it as a unity' (Brre, 2004). In a nutshell, an autopoietic system is one that can produce its own components and maintain its identity. Thus an autopoietic system is at the same time the producer and the product, and autopoietic systems realized in the physical space are living systems. The theory emphasizes the systemic nature of living beings. 'Autopoiesis means that the organism maintains itself as a unity, not by its parts *per se*, but by virtue of the relationship among its parts (Fleischaker, 1988). This theory opposes the biological approach to define life on the basis of reproduction and evolution (Goolishian). Rather, it focuses on the autonomy of the living systems. According to Maturana, living systems exist as autonomous entities in the form of self-contained closed molecular dynamics of self- production, open to the flow of molecules through them. Maturana and Varela claim that autopoiesis is both the necessary and sufficient condition for the constitution and realization of living systems.

Autopoietic theory proposes that living system is the dynamics of the molecules, not the molecules themselves. Maturana uses the example of a tornado- it is the dynamics of air and dust particles in the tornado, not the air and dust particles themselves that is called tornado. I find this point to be very interesting. Actually the living system depends not only upon a dynamics of molecules within the system, but also upon a dynamics of molecules between the system and its environment. Here it can also be safely added that it is not only a dynamics of molecules, but also a dynamics of energy, governed to a large extent by natural thermodynamics laws. Here we are tempted to recall the 'Schrodinger paradox'. Schrodinger wondered how the organisms perpetuate, and even increase their oprganization in a universe governed by the second law. Then he suggested, organisms continue to exist and grow by importing high quality energy from outside their bodies. They feed on what Schrodinger termed 'negative entropy'- the higher organization of light quanta from the sun (Hejl, 1984). According to autopoietic theory, there are certain essential attributes of an autopoietic system briefly discussed below.

(i) A boundary wall

The first and foremost requirement of an autopoietic unit is a boundary wall (of course a semi-permeable one) that is also self-created. This boundary separates the autopoietic unit from its medium. All reactions and transformations required to produce the components of the unit, thereby serving the purpose of self-maintenance, take place within this boundary. However, these reactions and transformations require nutrients and energy from outside (Dewey, 1978 and Luhmann, 1984). Luisi argues that the capacity to make its own boundary is the most important criterion for assigning the autopoietic status to a system. All living cells are able to produce their own boundary (cell membrane), hence can be assigned the autopoietic status. Going by this criterion, he further suggests, a virus is not autopoietic as it does not produce its own protein coat from within its boundary. I think, however, that we can use a term like 'semiautopoietic' to describe a virus.

(ii) Operational closure

The next important attribute of autopoietic theory is operational closure. It implies that all the operations of the system are contained within its boundary. A living system, complete within its boundary, is circular, closed dynamics of molecular productions open to the flow of molecules through them (Luisi and Varela, 1989). In 1970, Maturana proposed that living systems are dynamic systems constituted as autonomous unities through being closed circular networks (he used the word concatenations) of molecular productions in which the different kinds of molecules that composed them, participated in the production of each other, and in which every thing can change except the closed circularity of the networks of molecular productions that constitute them as unities (Beer, 2004 and Luisi, 2003). Maturana and Varela further expand this view by saying that –'a composite unity whose organization can be described as a closed network of productions of components that through their interactions constitute the network of productions that produce them and specify its extension by constituting its boundaries in their domain of existence, is an autopoietic system; and that a living system is an autopoietic system whose components are molecules (Beer, 2004).

According to Varela, the organization of autopoietic systems is characterized by processes such that- (i) the processes are related as a network, so that they recursively depend on each other in the generation and realization of the processes themselves, and (ii) they constitute the system as a unity recognizable in the space in which the processes exist'. Luisi[11] describes operational closure as, 'In the cell, or in the autopoietic unit- which is equivalent- the boundary determines a network of reactions that in turn produces the molecular components that assemble into the organized system that determines the reaction network---- and so on---- with no beginning nor end'. Operational closure does not mean that autonomous systems are unresponsive to their environment; it only means that their changes of state in response to changes in their medium are realized and propagated solely within the network of processes constituting them (Maturana *et.al.,* 1992).

(iii) Autopoietic systems exist in molecular domain

Maturana claims that living systems are molecular autopoietic systems. Autopoiesis occurs when the conditions for its occurrence are satisfied by the dynamic structural architecture of the molecular domain of a system. Autopoietic systems exist only in the molecular domain because it is the only domain in which the interactions between the elements that define it produce elements of the same kind as a spontaneous result of their structural dynamics.

(iv) Structure and Organization

Another fundamental attribute of autopoiesis lies in the distinction between structure and organization. The term structure is derived from the Latin verb 'struere' which means 'to build'. Thus this term refers to construction of a system, its components and their relations. Structure determines how the parts of a system are physically articulated. On the other hand, organization of a system specifies its identity, or its class. The word organization comes from the Greek term 'organon' which means 'instrument'. It refers to the instrumental participation of the components in the constitution of a composite unity. It specifies the relations between components that specify a system. Maturana and Varela (Beer, 2004) explain that the organization of a machine is independent of the properties of its components which can be any, and a given machine can be realized in many different manners by different kinds of components. In my view, this explanation is liable to attract some criticism. While the above statement seems to be justified in reference to machines that can be produced in many different manners by different kinds of components, it can only be theoretically, and not practically,

applied to living systems. The organization of a living system is totally dependent upon the properties of its component molecules- be it the proteins or the nucleic acids. We know that the enzymatic properties of a protein molecule emerges from its three dimensional structure and not the individual amino acids. However, no other way can be devised even theoretically to construct an enzyme without the help of amino acids, barring ribozymes as exceptions.

The relations that define a system as a unity, and determine the dynamics of interactions and transformations which it may undergo as such a unity, constitute the organization of a system (Matunana *et. al*., 1992). A system preserves its identity as long as its organization is conserved, even if its structure keeps changing. The moment its organization changes, the system loses its identity. The key feature of a living system is its organization. It remains alive as long as its organization is conserved, though its structure can keep changing throughout its life. However, whenever the structure changes in such a way as to change its organization, the living system becomes dead. This is why Maturana and Varela call living beings as structure-determined systems, a concept also called as 'structural determinism (Matunana *et. al*., 1992). What happens to a system in a given moment depends on its structure in this very moment. Autopoiesis is the process by which a living system generates and specifies its own organization through the production of its own components (Bitbol and Luisi, 2004) 'Autonomy means that the organism subordinates all changes in the environment to the maintenance of its organization, no matter how its structure may have to change in order to do this. The autopoietic process works to keep the organization constant, not the structure (Flreischaker, 1988). Organization and structure are mutually dependent, complementary to each other. One cannot exist without the other.

(v) Structural Coupling

Though autopoietic systems are operationally closed entities, yet they are intimately related with their environment and this relationship is mutually affecting. They are modified and shaped by their interactions with the environment. On the other hand, the environment also gets modified by its interactions with the system. This mutual interrelation of the system and its environment is called structural coupling. It implies that whenever the structure of an autopoietic system is affected or perturbed by the environment, the environment in turn also gets affected or perturbed. Thus, it is a two- way interaction and, as a result, the system and the environment continually change together. Thus, we see that living system is both autonomous as well as, simultaneously, dependent upon external medium. This is a beautiful contradiction and Luisi (Dewey, 1978) says that the living must operate within this contradiction.

The structural coupling is the result of another important attribute of autopoietic system that Maturana and Varela call 'cognition'.

(vi) Cognition

The term cognition literally means 'to know'. Consequently it seems to imply the involvement of nervous system. However, in the autopoietic theory of Maturana and Varela, it refers to the mutual interaction between the organism and its environment. It is the set of all the interactions in which an autopoietic system can enter without loss of identity (Benseler *et. al.,* 1980) . Cognition is the capacity of an organism to operate in dynamic structural congruence with its medium. Maturana explains living system as a cognitive system and living, as a process, a process of cognition (Benseler *et. al.,* 1980) .

The theory suggests that the autopoietic system selects those elements of environment to which it can respond.

Maturana does not see cognition as an information processing phenomenon. As such, it is not a product of nervous system. However, evolution of nervous system has of course provided unlimited horizons to the domain of cognition. The manifestation of cognitive ability by an organism appears to an external observer what he calls behaviour. 'Behaviour is a description an observer makes of the changes of state in a system with respect to an environment with which that system interacts---- the nervous system does not invent behaviour, but expands it dramatically (Bitol and Luisi,2004). Cognition gradually increases as we proceed from lower to higher groups of living beings, with the cognition level of bacteria being the lowest and that of man being the highest (Beer, 2004 and Maturann, *et.al*., 1999) . The two authors have held cognition as a fundamental aspect of life and also equated life with cognition. However, Luisi (Dewey, 1978) does not seem to agree with this view.

The autopoietic theory goes further in explaining the mutual interaction between the organism and its environment by saying that the very existence of both is dependent upon each other. 'An organism exists only in its connection with the medium and that connection is actually its history of interactions (Flreischaker, 1988). Maturana and Varela have used the term 'enaction' to specify this interdependence (maturann *et. al*., 1980.1978.1999). Luisi (Dewey, 1978), however, suggests another term, 'co-emergence' to symbolize this property.

From Cognition to Language

Maturana and Varela have proposed that when two autopoietic systems perturb one another over a long period of time, language arises. They have characterized this phenomenon as 'behavioural coordination through mutual and recursive structural change'. 'Behavioural coordination' refers to the way in which two mutually perturbing systems affect one another's structure, which in turn affect their behaviour. 'Recursive' refers to the ongoing cycle of interaction. Thus, according to these authors, language is an ongoing activity, and they use the term 'languaging' to reflect this nature of language.

Extensions of autopoitic theory

The autopoietic theory is based on dynamics and relationships of components, not the particular constitution of a system. This is why the theory has appealed to a variety of other academic disciplines, viz., sociology, psychotherapy (Maturann, 1980), management, anthropology, organizational culture, neurophenomenology and many others. The autopoietic theory has also been used in the field of artificial life synthesis (Maturann and Varela, 1970). Ramalho-Santos has used this theory in stem cell biology. But the theory has attracted greatest attention from the field of sociology (Ramalho-Santos, 2004). Cotton (Rudrauf, *et. al*., 2003) has critically analyzed autopoietic theory with respect to the social and behavioural sciences. However, Maturana is not very happy with the use of autopoietic theory in social sciences. He has suggested that social systems are not autopoietic themselves; instead, they arise as a result of the autopoietic properties of the individual components of the system.

Conclusion

Autopoietic theory is a theory of cellular life and it defines the conditions of a minimal life. These conditions can be summarized as- (i) living systems are singular entities, able to conserve their identity (ii) the organization of a living system is determined by its structure at molecular level (iii) living systems are closed networks of molecular productions, open to the flow of molecules, in which the

molecules produced form the same network of molecular productions again (iv) living systems interact with their environment in such a way as both are affected by each other and the effects on the living systems are determined by its structure and (v) there are two domains of living systems- one is the domain of their totality that shows their identity and the other is their molecular domain that makes them autopoietic entities. As a result of autopoiesis a cell produces cell-forming molecules, or an organism keeps renewing its defining organs and a social group produces group maintaining individuals.

The theory postulates that a living system remains alive as long as it conserves its autopoiesis (also called as law of conservation of autopoiesis). However, Maturana later on postulated another law of conservation- law of conservation of adaptation that is necessary for realization of living systems. According to him, 'the biosphere is a historical wave front of co-evolving living systems in the systemic reproductive conservation of both autopoiesis and adaptation (Ruiz-Mirazo,and Moreno, 2004). It implies that biological evolution is not based on changes in an organism, rather it depends upon the continuous conservation of autopoiesis and adaptation, in the course of which, different changes can occur in it. Here I can recall someone's statement, 'we change to remain the same'. Maturana further proposes a hierarchy in autopoietic systems. He calls modern prokaryotic and eukaryotic cells as first order autopoietic systems because their autopoiesis does not involve more basic autopoietic subsystems. He calls multicellular organisms as second order autopoietic systems because their autopoiesis depends upon more basic autopoietic units. However, he reminds that besides being second order autopoietic systems, multicellular organisms are simultaneously of the first order too, as they are closed networks of molecular productions that involve both intercellular as well as intracellular processes.

Some other workers had earlier proposed theories that had some resemblances with the autopoietic theory. For example, the transactional theory of Dewey and Bentley Thompson *et. al.,* 2001, Varela and Maturann, 1988) proposed that the person and its environment always co-occur. Palmer (Varela *et.al*., 1974) has made a comparison of the two theories. Dell (Varela *et. al.,* 1991) has compared the works of Bateson and Maturana and concludes that they are compatible, though there are limitations. He claims that the essential message of both is that social systems and all human activities must be understood in the light of our being biologic entities.

Fleischaker (Varela, 2000) concludes that all that is alive must be autopoietic. Luisi (Dewey, 1978) accepts that 'autopoiesis is the only available simple theory that is capable of providing a unitary view of the living, from the molecular level to the realm of human perception'. However, the theory has also faced objections from many corners. Andrew (Varela, 1979) claims that autopoiesis cannot suffice for studying self-organizing systems. Ruiz-Mirazo and Moreno and Bitbol and Luisi (Varela, 1997) have argued that autonomy may be a necessary condition but not the sufficient condition for life. But despite these objections, Beer (Varela, 1981) is hopeful that the autopoietic theory has the potential to transform the conceptual foundation of biology as well as the cognitive, behavioural and brain sciences. The theory has also found application in autopoietic self-reproduction of fatty acid micelles and vesicles (Varela, 1996; Walde, 1994), an attempt towards synthesis of artificial cell.

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References

1. Andrew Alex M. (1979). Autopoiesis and Self-Organization. *J. of Cybernetics*, 9(4): 359-367
2. Bachman PA, Luisi PL, Lang J. (1992). Autocatalytic self-replicating micelles as models for prebiotic structures. *Nature*, 357: 57-59
3. Bachman PA, Walde P, Luisi PL, Lang J. (1990). Self replicating reverse micelles and chemical autopoiesis. *J. Am. Chem. Soc*. 112: 8200-8201
4. Beer R.D.(2004). Autopoiesis and Cognition in the game of life. *Artif. Life*, 10 (3): 309-26
5. Benseler F, Hejl P, Kock W. 91980). Autopoiesis, communication and society: the theory of autopoietic systems in the social sciences. Campus, Frankfurt
6. Bitbol M, Luisi P.L. (2004).Autopoiesis with or without cognition: defining life at its edge. *JR Soc. Interface,* 1(1): 99-107
7. Capra, F. (2002). The hidden connections: a science for sustainable living. Harper Collins, London
8. Cotton, R. (2002). The Third Epistemology: Extending Maturana's Structure determinism, *American J. of Family Therapy*, 17(2): 99:109
9. Dell P.F. (2985). Understanding Bateson and Maturana: Towards a biological foundation for the social sciences, *J. Marital and Family Therapy*, 11(1): 1-20
10. Dewey, J. and Bentley AF. (1949). Knowing and the known. In R Handy and EC harwood (Eds), Useful Procedures of Inquiry. Great Barrington, MA, Behavioural Research Council.
11. Dewey, J. (1978). Contributions to a Cyclopedia of Education. In J. A. Boydston (Eds) John dewey: the middle works (Vol 6 pp. 357-467). Carbondale: Southern Illinois University Press
12. Etxeberria, A. (2004).Autopoiesis and Natural Drift: Genetic Information, Reproduction and Evolution Revisited. *Artificial Life*, 10(3): 347-60
13. Fleischaker G. (1988). Autopoiesis: the status of its system logic. *BioSystems,* 22: 37-49
14. Goolishian HA, Lee Winderman (1988). Constructivism, Autopoiesis and Problem determined systems. *The Irish J. of Psychology*, 9(1): 130-143.
15. Hejl P.M.(1984) Towards a theory of social systems: Self organization and self maintenance and Syn-Reference, (Ulrich).
16. Luhmann, K. (1984). Soziale Systeme. Suhrkamp, Frankfurt.
17. Luisi PL, Varela F. (1989). Self-replicating micelles: a chemical version of minimal autopoietic systems. *Origins Life Evol. Biosphere*, 19: 633-643
18. Luisi, P.L. (2003). Autopoisis: a review and a reappraisal. *Naturwissenschaften.* 90: 49-59
19. Maturana, H, Lettvin, J, McCulloch, W., Pitts W. (1960). Life and Cognition. *Gen Physiol*. 43: 129-175
20. Maturana, H., Mpodozis J.M. (1992). Origin de las Especies por medio de la Dariva Naturaf. Publicacion Occacional, N 46
21. Maturana H, Mpodozis J.M. (1999). Origin of Species by means of Natural Drift. Revista Chilena de Historia Natural.
22. Maturana, H., Varela, F.J. (1978). The Tree of Knowledge: The Biological Roots of Human Understanding. New Science Library, Shambhala, London.
23. Maturana, H. and Varela, F. (1980). Autopoiesis and cognition: the realization of the living. Reidel, Boston.
24. Maturana, H. (1980). Biology of Cognition, in Autopoiesis and Cognition, by Maturana and Varela. Reidel, Boston

25. Maturana, H., Varela, F. (1977). De maquinas y seres vivos: Una teoria de la organization biologica (Santiago: Editorial Universitaria) Zeleny M. Self organization of living systems, formal model of autopoiesis. *Int. J. Gen. Syst.* 4: 13-28
26. Palmer, D.K. (2003).The Transactional view and Autopoietic theory. TransactionalView.org Online article. Last updated 24.04.04
27. Ramalho-Santos M.(2004). Stem cells as probabilistic self-producing entities. *Bioessays*. 26(9): 1013-6
28. Rudrauf, D., Lutz A., Cosmelli, D., Lachanx, J.P, Le Van Quyan, H. (2003). From Autopoiesis to Neurophenomenology: Francisco Varela's exploration of the biophysics of being. *Biol. Res*., 36 (1): 27-65
29. Ruiz-Mirazo K, Moreno A. (2004). Basic Autonomy as a fundamental step in the synthesis of life. *Artif. Life.*10(3): 235-59
30. Schneider E.D. and Sagan D. (2009). Into the cool, Energy flow, Thermodynamics and life. Chelsea Green Publishing.
31. Thompson E: Francisco J.Varela (1946-2001): A Tribute. *J. Consc. Studies*. 2001 8(8): 66-69
32. Varela, F., Maturana, H. (1988). The tree of knowledge (rev. edn.) Shambala, Boston.
33. Varela F, Maturana H, Uribe R. (1974). Autopoiesis: the organization of the living systems, its characterization and a model. *Biosystems*, 5:187-195.
34. Varela F, Thompson E, Rosch E. (1991). The embodied mind: cognitive science and human experience. MIT press, Cambridge, Mass.
35. Varela, F. (2000). El fenomeno de la vida. Dolmen Esayo, Santiago, Chile.
36. Varela, F.(1979). Principles of biological autonomy. North Holland/Elsevier, New York.
37. Varela, F.J. (1997). 'Patterns of Life: Interwining Identity and Cognition', *Brain and Cognition*, 34: 72-87
38. Varela, F.J. (1981). Describing the logic of the living. In Zeleny M (Ed), Autopoiesis: A theory of living organization. Oxford: North Holland.
39. Varela, F.J.(1996). The early days of autopoiesis: Heinz and Chile, *Systems Research*, 13 (3): 407-416
40. Walde P, Wick R, Fresta M, Mangone A, Luisi, P.L. (1994). Autopoietic self-reproduction of fatty acid vesicles. *J Am. Chem. Soc*. 116: 11649-11654

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