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Problems of Autonomy and Discontextuality in the Theory of Living Systems

Abstract

In the theory of living systems any description of self-organizing processes is confronted by a very central problem concerning the role of the system's boundary, i.e., there is the necessity of a simultaneous formal representation of the inside and the outside of the system.

On the other hand, in a theory of self-organization restricted to changes of states within a system, which may be defined by some physical state variables, the question of the boundary has been eliminated and the distinction between a system and its environment (its inside and outside) generally is interpreted as an information process between both, the system and the environment.

In the theory of autopoietic systems (TAS), on the other hand, it is the autonomy of a system which plays a fundamental role and therefore the TAS represents a theory of self-organization in relation to a system and its environment and not primarily a theory of self-organization of states within a system. This, however, results in the logical problem of circularity as an immediate consequence of the postulated closure of any living system.

As a result of closure principle, the distinction between a system and its environment (the boundary of a system) interpreted as an information transfer in the theory of self-organization cannot be established any longer as a primarily relevant process in the theory of autopoietic systems.

For an adequate description of closed systems it is the discontextuality between autonomous and non-autonomous systems which takes the place of the 'system-environment-relation'. On the basis of the theory of poly-contextual logic discontextuality between a system and its environment results as an explication and conceptual precision of the 'structural coupling concept' as introduced in the theory of autopoietic systems.

1 Historical Notes

The scientific concept of both 'cybernetics' and 'general systems theory' was founded in the early forties within the biological sciences, and the declared aim of cybernetics was the modeling, simulation, and technical reproduction of living processes [Wiener, 1943]:

"... a uniform behavioristic analysis is applicable to both the mechanistic and living organisms, regardless of the complexity of their behavior." (1)

The correlation between biology and techniques was established by a common scientific approach [Wiener, 1943]:

"Given any object, relatively abstracted from its surroundings for study, the behavioristic approach consists in the examination of the output of the object and of the relation of this outputs to the input. By output is meant any change produced in the surroundings by the object. By input, conversely, is meant any event external to the object that modifies this object in any manner By behavior is meant any change of an entity with respect to its surroundings." (2)

The attempt to develop a scientific description of living systems in the sense of the holistic (non-reductionistic) 'theory of the living' (not based on the terminology of physical sciences) has resulted in the fundamental change of the scientific paradigm concerning the role of an observer during the process of observation [von Foerster, 1980]:

* veröffentlicht in: Informatik-Fachberichte 275 der GI; Analyse dynamischer Systeme in Medizin, Biologie und Ökologie (D.P.F.Moeller & O.Richter, eds.), Springer Verlag, Berlin, 1990; p. 3-12.

"A living organism is an independent autonomous organizationally closed unity;"

and

"an observing organism is part, partner, and participant in its world of observation." (3)

It is the inclusion of the observer into the description of living systems as claimed by modern cybernetics which causes several basic scientific and logical problems.

2 Autonomy and Closure

According to the postulate (3) given above, all living systems are autonomous, i.e., self-regulating organisms. If the prefix "self-" is substituted by the corresponding noun, the meaning of "autonomy" becomes synonymous with "regulation of regulation". In the terminology of cybernetics this means:

"A living system regulates its own regulation." (4)

This statement stipulates operational closure in the sense that systems have to be described with no inputs and no outputs in order to emphasize their autonomous constituents [Varela, 1979]:

*"Closure Thesis:
Every autonomous system is organizationally closed."* (5)

This point of view is alien to the Wienerian idea of feedback *simpliciter*.

3 Cognition and Autopoiesis

Parallel to the discovery of the special role of an observer in the 'theory of living systems' great importance is attributed to the relation between a system and its environment which has to be seen under the aspect of the cognitive abilities as primordial attribute of 'The Living' [Maturana, 1980]:

*"Living systems are cognitive systems, and living as a process is a process of cognition.
This statement is valid for all organisms, with and without nervous systems."* (6)

A milestone on the way to a theory of living systems is given by the concept of 'autopoiesis' introduced by Maturana and Varela [Maturana, 1980; 1985; Varela, 1979]:

*"An autopoietic machine is a machine organized (defined as unity) as a network of processes of production (transformation and destruction) of components that produces the components which:
through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them;
constitute it (the machine) as a concrete unity in the space which they (the components) exist by specifying the topology domain of its realization as such a network.
...autopoietic machines are autonomous...
...autopoietic machines have individuality...
...autopoietic machines do not have inputs or outputs...
...autopoietic is necessary and sufficient to characterize the organization of living...
...a physical system, if autopoietic, is living."* (7)

Again it is the conception of 'autonomy' and 'closure' which is of importance in characterizing autopoietic machines, i.e., living systems. It should be emphasized that in the theory of autopoietic systems the concept of 'information' has been excluded for the description of living systems, because information does not exist independent of an organization that generates a cognitive domain from

which an observer-community can describe certain elements as informational and symbolic. In other words, information does not exist *sui generis*.

4 Mathematical Consequences

The basic epistemological point in the 'Theory of Autopoietic Systems' results from the insight that 'closure' and 'autonomy' of living systems are incompatible with any representation of a system from its system-environment relationship. The system's boundaries defined by an observer of a system (and its environment) always differ from the boundaries generated by an autonomous system itself in relation to all other systems. It is this different description of a system,

- i) form a point outside the system (from the view of an observer) and
- ii) from the inside of its autonomy,

which is of fundamental importance for any theoretical description of the living.

The transition from so-called 'first order cybernetics' (the cybernetics of observed systems) to 'second order cybernetics' (the cybernetic of observing systems) is demonstrated by comparison of the postulates (1) and (2) representing the classical (first order) situation with the postulates (3)-(7) reflecting the position of 'second order conceptions'.

In order to demonstrate the fundamental difference of both positions a topological analysis is given in figure 1.

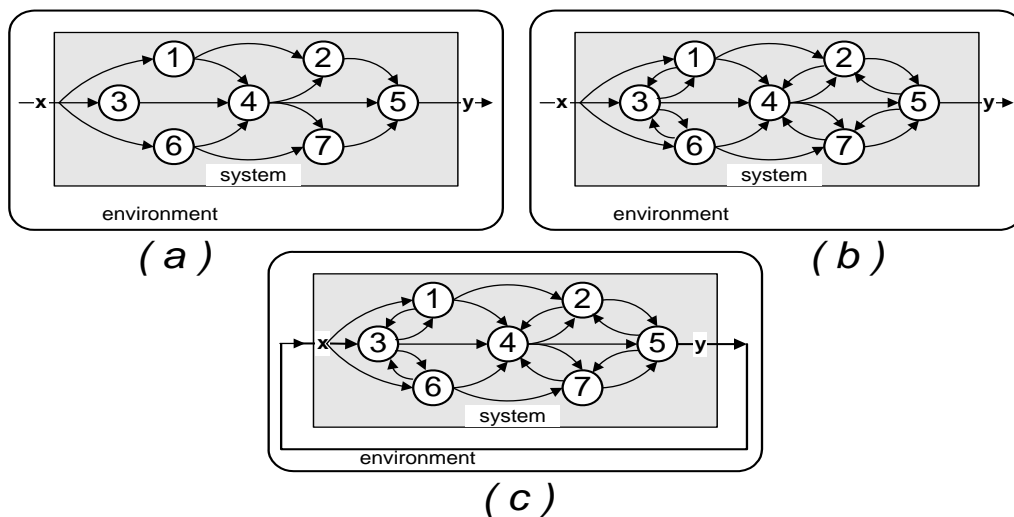


Figure 1: A system as a set of elements and relations in interaction with its environment.
 (a) : a classical input-output system;
 (b) : a classical input-output system with closed loops and recurrent connections;
 (c) : a autonomous closed system with no inputs and no outputs.
 x : input variable; y : output variable; n_i : state of element n

The mathematical description of the system in figure 1a is given as:

$$\frac{d}{dt}n_i = f_i(x; u_1, u_2, u_3, \dots, u_n)$$

$$y = g(x; u_1, u_2, \dots, u_N) \quad \text{with } i = 1, 2, \dots, n-1, n, n+1, \dots, N \quad (8a)$$

If there are closed loops caused, for example, by mutual interactions such as indicated in figure 1b, the mathematical corresponding description becomes,

$$\begin{aligned} \frac{d}{dt}n_i &= f_i(x;u_1,u_2,\dots,u_N) \\ y &= g(x;u_1,u_2,\dots,u_N) \quad \text{with } i = 1,2, \dots, n-1,n,n+1,\dots, N \end{aligned} \quad (8b)$$

The difference between eq.(8a) and eq.(8b) is given by the indices. While eq.(8a) can be solved under certain conditions, eq.(8b) cannot be reduced any further which means that the system in figure 1b has to be described by a different model.

For a closed system defined in the sense of the closure thesis with no inputs and no outputs as it is shown in figure 1c the corresponding differential equation becomes:

$$\frac{d}{dt}u_i = f_i(u_1,u_2,\dots,u_N) \quad \text{with } i = 1,2, \dots, n-1,n,n+1, \dots, N \quad (8c)$$

Because of its recursive form eq.(8c) cannot be solved unless an input-output function is introduced which, however is in contradiction to the definition of the closure condition for an autonomous system. In other words, on the basis of the 'closure thesis' a mathematical description of an autonomous system cannot be given if the closure of the system is to be maintained within the theoretical description.

5 Cognition and Volition

In the previous postulates, the process of cognition was attributed to be an essential feature of all living systems. Combined with the idea of computation, cognition appears as self-reference which means that an autonomous (cognitive) system must be able to produce an image of the system (itself) and its environment (inside the system).

As a result of the closure thesis, however, a paradoxical situation emerges concerning the relationship between an operationally closed system and its environment:

$$\textit{"The more closed an autonomous system appears, the more open is its relation to the outside world."} \quad (9)$$

In other words, the concept of cognition alone turns out to be inadequate for any consistent representation of the living able to generate a cognitive domain where information is imposed on the environment and not picked up from it, as it is demanded categorically by 'second order cybernetics' [Varela, 1979; p.238].

That means, no self-reference is possible unless a system acquires a certain degree of freedom. But any system is only free insofar as it is capable of interpreting its environment and choosing between different interpretations for regulation of its own behavior [Guenther; 1968, p.44], Therefore, decision making processes (volition) also have to be considered for an adequate description of systems with the capability of self-generation of choices and the ability *to act* in a decisional manner upon self-generated alternatives.

6 Self-Organization

In the following a distinction between two completely different processes of self-organization will be demanded:

- a) self-organization of data (elements, components, objects, processes) inside a system from the view of an observer of the system, and

- b) self-organization of the system (itself) in relation to its environment from the view of the autonomous system itself.

In other words, for the description of self-organization 'first order conceptions' again have to be distinguished from 'second order conceptions'.

6.1 Self-Organization of 1st Order

In this category a system is defined by an observer, i.e., a clear distinction between the system and its environment exists from the view of the observer of the system and its environment. However, this boundary between the system and the environment will not be reconstructed by the (autonomous) system itself. The boundary only exists for the external observer and both domains of distinction are well defined: *what belongs to the system, belongs to the system; what belongs to the environment, belongs to the environment*. Both tautologies are dualistic, i.e., *what does not belong to the system, belongs to the environment, and what does not belong to the environment, belongs to the system*.

In other words, the unambiguity of the difference between the system and the environment as defined by an observer does not affect the laws of the classical (mono-contextual) logic. On the contrary, the uniqueness of the difference confirms, the validity of the logical identity principle. The changes of the system described by the (external) observer are changes within the system represented by a set of parameters chosen by the observer for the definition and adequate description of the system under consideration.

All non-linear theories of dynamical systems and processes such as the 'theory of dissipative structures', 'synergetics', or the 'theory of determined chaos' belong to the concept of '1st order self-organization'.

6.2 Self-Organization of 2nd order

Self-organization in the sense of autonomy is the self-realization of an autonomous system in its environment by at least two parallel simultaneously interacting processes:

☞... a volitive (decision making) process structuring the environment by a determination of relevances and a corresponding context of significance within the semantical domain produced by (ii) ... (10a)

(i) ... a classification and abstraction of the data by cognitive processes producing a representational structure of content and meaning within the context in (i) ... ☞ (10b)

Both processes are complementary to each other, i.e., neither of the two can be considered or described separately. The situation may be visualized by the following scheme [Kaehr, 1989]:

$$\left\{ \begin{array}{l} \text{Distinction}_1 : (\text{system } \underline{\mathbf{O}} \mid \text{environment } \mathbf{O}) \\ \text{Distinction}_2 : (\text{system } \underline{\mathbf{O}} \mid (\text{system } \underline{\mathbf{O}} \mid \text{environment } \mathbf{O})) \end{array} \right\} \quad \begin{array}{l} (11a) \\ (11b) \end{array}$$

The braces in relation (11) symbolize the complementarity of the two simultaneous processes in the sense of a parallelism which cannot be represented sequentially without describing a completely different process. Thus the operator (program) of the volitive process (11a) becomes the operand (data structure) of the cognitive system and what has been the operand of the cognitive process (11b) may change during the process into the operand of the volitive system. The logical criterion for an adequate formal description of such closely interwoven processes is the existence of a logical system that allows several simultaneous successions of deductive steps in different logical domains mediated to each other.

Only if the representation of the system is restricted to some aspects of itself as in the project of 'computational reflection' [Maes, 1988],

"... a reflective system is a system which incorporates to some aspects of itself presenting aspects of itself ..." (12)

no logical problem will appear. However, since the autonomy of a living system is not related only to some parts of the system but to its wholeness, an unambiguous self-explication of living systems is not the linguistic framework of the classical sciences.

7 Towards Modelling

It is the irreducible difference, the dis-contextuality, between an autonomous system and its environment which has to be realized in modeling a system processing its self-determined boundaries. In other words, the fundamental structure necessarily has to be repeated in the tools (the methods of notation) for any (formal) description of these processes, i.e., the system of notation must reflect the dis-contextual structure of the process if modeling is to avoid assimilation of the difference between the system/environment which is constitutive for the self-organization of an autonomous system.

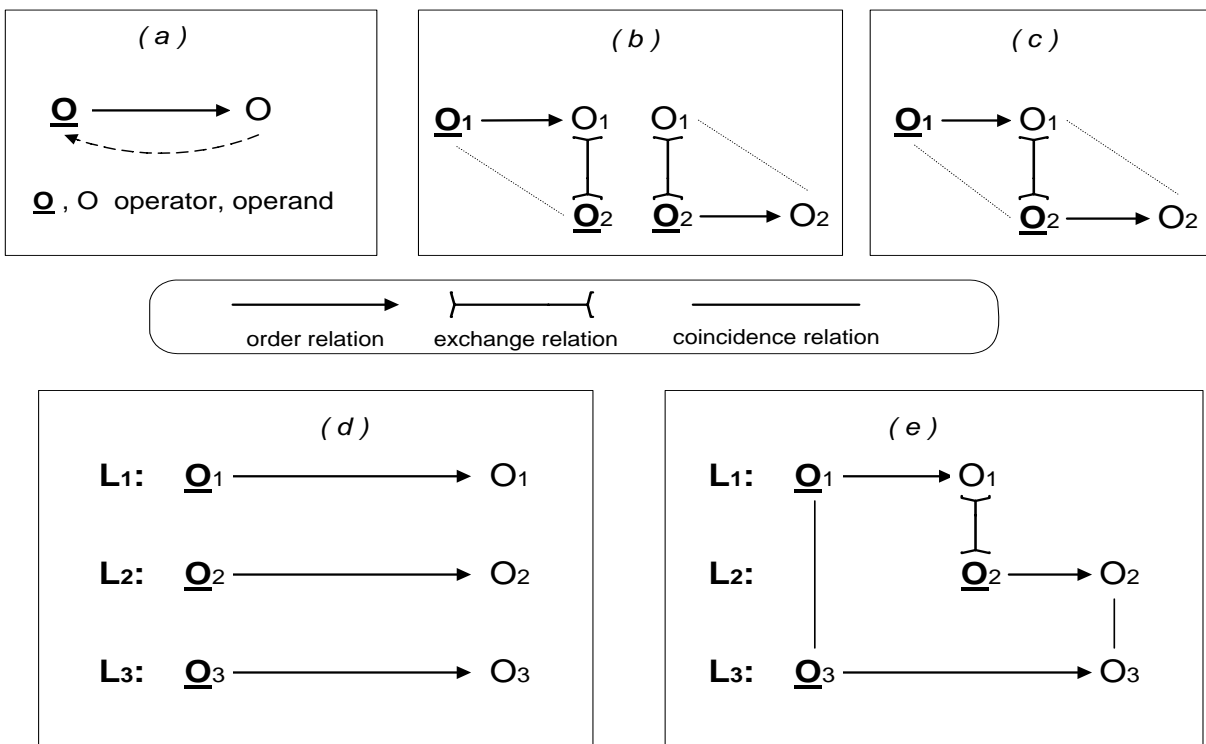


Figure 2: A simplified graphical representation of mono- and poly-contextuality
 a) circularity caused by self-reference in a mono-contextual system;
 b) circularity distributed on two logical (mediated) domains;
 c) composition of (b);
 d) three logical domains $L_{1,2,3}$ which are isolated (not mediated), the indices may be attributed to three different types in Russell's theory of logical types;
 e) three logical contexts (a three-contextual system) $L_{1,2,3}$ as smallest (irreducible) unit in a poly-contextual system.

A theoretical framework which offers the complexity necessary for an adequate and unambiguous modeling is given by the 'Theory of Poly-Contextuality' introduced by Guenther [Guenther, 1980] and Kaehr [Kaehr, 1981]. This theory represents a formal and operative

system of mathematical logic. Figure 2 summarizes not only the main arguments of the foregoing discussion but also gives a qualitative impression of the idea behind a poly-contextural logical system. For details refer to the literature [Kaehr, 1981; 1988; 1989].

Figure 2a which corresponds to figure 1c, illustrates the circularity (*circulus vitiosus*) arising from any representation of self-reference, i.e., for cognitive processes if described on the basis of a mono-contextural logical system. It is well known that the name or the image (operator) of an object belongs to another logical type than the corresponding object (operand), i.e., Russell's theory of logical types (cf. fig.2d) suffices for any classification. For an operative modeling of processes such as the one given by relation (1), however, transitions between the different logical types or domains in figure 2d are necessary as indicated in figure 2b.

Figure 2b depicts two logical domains (contextures) $L_{1,2}$ in such a way that circularity (compared to fig.2a) is distributed among the two different logical domains provided the meaning of the terms are retained during the transition from one domain to another. On the other hand, the relationship between the operators and operands distributed on different logical domains escapes any circularity (or ambiguity) if the individual process is discriminated during transitions between different contextures as indicated by the indices in fig.2b. Fig.2c shows the composition of fig.2b and fig.2e gives a graphical representation of the smallest irreducible unit (three contextures) in the theory of poly-contextuality. Such an interchange, i.e., the distribution and mediation of domains is designed as '**heterarchy**'. Heterarchically organized structures or processes belong to the category of autonomous and not to the class of input/output systems. In the terminology of poly-contextuality all descriptions (of systems or processes) are hierarchically structured. Intra-contexturally, i.e., within a logic of a contexture (domain), the transitivity law holds rigorously, as do all classic logical rules.

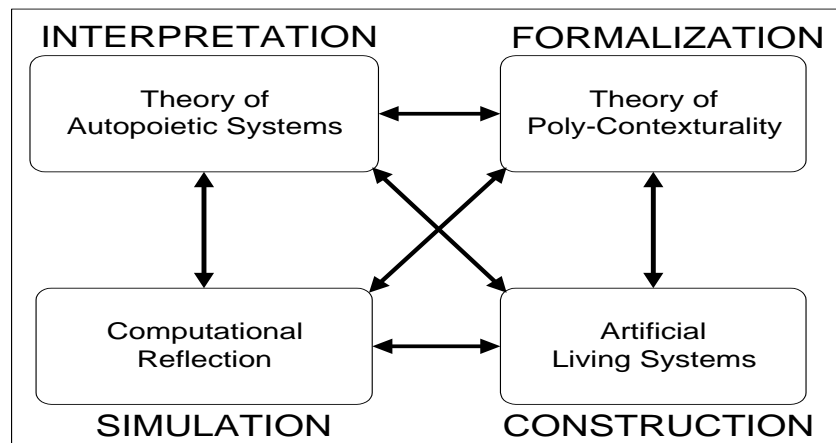
The essential point of 'poly-contextuality' results from the mediation by order and exchange relations between different (at least three) contextures which is achieved by new (non-classical) logical operators such as the '**transjunction**'. This allows the modeling of bifurcation from one logical domain into at least two parallel, simultaneously existing contextures. Thus a parallelism is constituted by a distributed circularity of operator and operand, which is no longer reducible to linearity as would be demanded for an adequate (formal) description of volitive and cognitive processes according to relation (11). For more details concerning the transjunctional or the multi-negational operations it is referred to the literature [Kaehr, 1981; 1989].

8 Conclusions

The 'Theory of Autopoietic Systems' represents the scientific attempt of a purely semantic, i.e., non-formal theory of living systems with the declared intention to develop a biological conception – this is its merit. What cannot be achieved on this basis is a symbiosis of computer and bio-logical sciences – the declared aim of cybernetics.

Figure 3:

A scientific allocation of the different approaches towards a theory of living systems. Cybernetical research, which is founded by its interdisciplinary and transdisciplinary methodology, has to be allocated between the fields represented by the four corners. This is symbolized by the interconnections in the diagram.



Although the principal logical difficulties arising from the description and modeling of cognitive (self-referential) processes have been recognized, no efforts have been undertaken to overcome these limitations in the sense of an extension of the logical axiomatic basis. Any technical reconstruction of cognitive processes, however, necessarily requires their unambiguous representation.

The 'Theory of Poly-Contextuality' offers a semiotic framework with the degree of complexity as demanded for a non-reductionistic representation of living processes.

The project of 'Computational Reflection' for the simulation of reflective processes only describes partial autonomy since for simplicity's sake all senso-motoric aspects of the living have been excluded.

The situation is presented in figure 3 where the four corners represent 'formalization', 'interpretation' or 'modeling', 'simulation', and 'construction', reps. It is the region of the interconnections between these different scientific activities which is of special interest for modern cybernetical and systems research.

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This work was supported by the "Volkswagen Stiftung" within the project "Theorie komplexer biologischer Systeme"

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ISSN 1619-9324

How to cite:

Goldammer, E. von & R. Kaehr, "Problems of Autonomy and Discontextuality in the Theory of Living Systems", in: Informatik-Fachberichte 275 der Gesellschaft für Informatik—Analyse dynamischer Systeme in Medizin, Biologie und Ökologie (D.P.F. Moeller & O. Richter, eds.), Springer Verlag, Berlin, 1990; p. 3-12.

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