# A Calculus for Autopoiesis

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ABSTRACT: The paper looks once more at the understanding and definition of autopoiesis as developed by Humberto R. Maturana, Francisco J. Varela, and Ricardo Uribe. We will focus on the question whether George Spencer-Brown's *Laws of Form* presents us with a possibility of translating Maturana's definition into a kind of a calculus. We look at Maturana's emphasis on components, networks, and boundaries and try to figure out how this emphasis can translate into an understanding of form that knows about self-reference, paradox, and play.

## *Autopoiesis*

This paper looks once more at the understanding and definition of autopoiesis as developed by Humberto R. Maturana, Francisco J. Varela, and Ricardo Uribe (Varela/Maturana/Uribe 1974; Maturana 1981; Maturana/Varela 1980; Varela 1979a). We will not go into the philology of comparing the different versions of the understanding and definition of autopoiesis, into the different attempts to get its record straight, or into the question whether not only living but also social systems may be considered autopoietic by well-defined criteria (Zeleny 1981; Zeleny/Hufford 1992; Fleischaker 1992; Geyer 1992; Bourgine/Stewart 2004; Luisi 2003). We will instead focus on just one question: whether George Spencer-Brown's *Laws of Form* (2008) presents us with a possibility of translating Maturana's definition into a kind of a calculus. Francisco J. Varela tried to do this, only to discover that he had to add a further autonomous state to the calculus of indications to make it fit for modeling self-reference (Varela 1975, 1979b). We share criticism of this attempt that addresses the idea that the distinction itself, in the form identical to the observer (Spencer-Brown 2008: 63) is already the autonomous state Varela thought he needed to introduce (Kauffman 1978; Varga von Kibéd 1989).

Instead of going into this extended discussion at this point, we turn to another discussion on social systems as autopoietic systems that establish and unfold their own paradox into a play with their distinctions, frames, and values that equals their iterative reproduction (Luhmann 1990a, 1992; Hutter 1979: 194-200, 1989: 28-33, 1990). That is, we look again at Maturana's emphasis on components, networks, and boundaries and try to figure out how this emphasis can translate into an understanding of form that knows about self-reference, paradox, and play.

*Element, Network, Boundary*

Let us start with a definition of autopoiesis as proposed by Humberto R. Maturana (1981, pp. 21/2): "We maintain that there are systems that are defined as unities as networks of production of components that (1) recursively, through their interactions, generate and realize the network that produces them, and (2) constitute, in the space in which they exist, the boundaries of this network as components that participate in the realization of the network. Such systems we have called autopoietic systems, and the organization that defines them as unities in the space of their components, the autopoietic organization."

The first term we look at is 'component', which in a more general version of systems theory beyond its peculiar understanding in biology and neurophysiology we propose to read as 'element'. We begin by asking what elements a system may consist of to allow it, satisfying all the criteria mentioned, to be considered an autopoietic system and thus a unity.

We know from Maturana that his understanding of autopoiesis was developed in part as an answer to Heinz von Foerster's question about what constitutes a stimulus for the central nervous system (Maturana 1991: 122). And we know from Heinz von Foerster that his own answer to this question focuses not on agents or operations to understand what any neuron is able to do, but on networks somehow both emerging from these agents and their operations and controlling, via their enabling of communication, the performance of these agents and their operations (von Foerster 1967).

Once again we will not go into the discussion of the mathematical apparatus of a network analysis developed with respect to an understanding of neurophysiological specifics, but opt instead for the mathematical apparatus proposed by George Spencer-Brown. We thus retain the idea that elements might be looked at in terms of network. And we emphasize that a focus on networks from the outset is rather new to social systems theory, which has preferred to focus on self-reference and operational closure and has not really paid attention to Maturana and von Foerster's interest in networks. The 1990s and 2000s saw a renewed interest in networks (Strogatz 2001), ecouraging us to probe a little deeper into the issue.

Maturana's first proposition, wrapped in the recursive terms and formulations that may well turn out to be the true message of the whole definition, reads as follows: components, or, as we prefer to say, elements generate and reproduce recursively through their interactions the network that produces them. The minimal network to be found in Spencer-Brown's first propositions about his calculus is the distinction being drawn itself, considered to be "perfect continence" (Spencer-Brown 2008: 1), that is to contain everything. A distinction can only contain everything when one assumes that it indeed contains (a) its two sides, that is the marked state and the unmarked state, (b) the operation of the distinction, that is the separation of the two sides by marking one of them, and (c) the space in which all this occurs and which is brought forth by this occurrence.

We have to look at the 'form' of the distinction to discover by a calculus of indications the network structure any indication that is also a distinction is calling forth and relies on. Without iterating the construction of the calculus presented by Spencer-Brown we can consider four of its decisive steps. The first is to look at an operation that occurs, called *cross* (ibid.: 5):

cross

Seemingly out of nothing and at no specific point of time it produces a marked state marked as a distinction (ibid.: 3):

$$\overline{\quad}\!|$$

It is "a sign in space", to quote a story by Italo Calvino (1976), the Italian original of which appeared in 1965, well before the 1969 *Laws of Form*, with the qualification that space and time in Spencer-Brown's calculus exist only the moment they appear as correlates, as elements of the network structure of the mark indicating the operation.

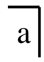
Bringing in algebra in addition to the arithmetic of the mark of distinction, we have the form

$$\overline{a\,}|\; b$$

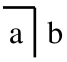
which allows us to talk about the two sides of the distinction, marked by the values *a* and *b*. Of course, without quite knowing how and certainly without having hitherto reflected on the issue, we already face the ambivalence of, on one hand, bringing in the mark of distinction and the values for the two sides of the distinction and, on the other, attempting to analyze the structure of the cross independently of our observations. We will see that this ambivalence is also an element of the network structure, calling for an observer who disregards himself when observing the cross.

The question now is what *a* and *b* tell us about the mark of distinction. If we remember the mark of distinction marking the occurrence of a cross, then *a* tells us about the indication of the inside of a distinction, which, being the mark of a cross, also refers back to the other side of the distinction, now valued *b*. This is what is called the 'form' of the distinction, both sides taken together with the operation separating the sides and bringing forth the space in which this occurs.

Now if *a* refers back via the mark of distinction to *b*, then we may say, as Spencer-Brown (2008: 91) does in Appendix 2, 'The Calculus interpreted for logic', that

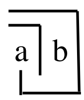


indicates *a* as the negation of *a*, or ~*a*. This negation, however, does not express the annihilation of *a*, but its relation back to what it is not, the outside of the distinction, here valued as *b*. Thus, as Spencer-Brown puts it,

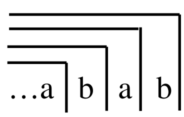


is to be read as the negation of *a* to imply *b*. The mark of distinction is thus a combination, in terms of logic, of negation and implication. In our case, it reads ~*a* in order to $a \supset b$. Unfamiliar as this may sound to an old-European philosophy enamored of Aristotle's law of noncontradiction, ~(A ∧ ~A), accords well with a destruction and deconstruction of this philosophical tradition to handle the necessity of supplements for any unit to be able to be identical to itself (Heidegger 1967; Derrida 1982).

Yet we need a fourth step in our reading of Spencer-Brown's *Laws of* Form to come up with a unit element of a network structure that allows us via a calculus of indications to infer and reconstruct the way it operates. This fourth step links the negation of *a* and implication of *b* back to the indication of *a* we began with when observing what a cross amounts to. This link back is performed by so-called re-entry of the distinction into the form of distinction (Spencer-Brown 2008: 53), or



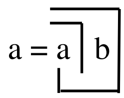
This is the same as (ibid.: 46/7)



and means that we have to move from finite to infinite expressions when trying to make sure that *a* negating itself and implying *b* does indeed refer back to itself as well. "Self-reference, as Louis H. Kauffman (1987: 54) emphasizes, "is the infinite in finite guise." The infinite is the indication of *a* implying itself, *a*, while negating itself with respect to an implication of *b* and taking account of the fact that the indication of *b* calls for another distinction negating it and implying, in the most simple case, *a* as its complement.

Note that in such an infinite or re-entering expression *a* and *b* iterate themselves inside a form that both oscillates between its values and memorizes these values while having to identify and distinguish them at the same time: *a* negating itself and implying *b*, which negates itself and implies *a*, is not the same as *a* being *a*, or *b* being *b*. Oscillation and memory are terms of their own, not only adding to the identities of the algebraic values but in fact expressing that they are indications produced by crosses in the first place.

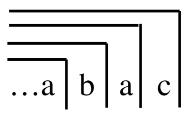
This gives us our unit element of networks, which we propose to write as follows:



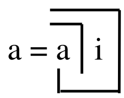

This is to say that any *a*, as observed by an observer indicated by the equal sign, "=", is identified as the value of an indication produced by a crossing of a boundary, which, as this boundary, assumes a *b* on its other side that is both the implication and the negation of *a*. The equal sign, "=", indicates the assumption of the observer, that any *a* is the product of a crossing within the states of a network, which are to be spelled out as the inside, the outside, and the space of a distinction.

If we now look back at Maturana's definition of autopoiesis we gain an idea of how an element generates and realizes the network that produces it, but we still lack ideas on how a plurality of elements does the same, as part (1) of the definition states, let alone on how these elements constitute the boundaries of the network, which participate in the realization of the network, as stated by part (2) of the definition.

To add further elements is easy,




yet has the dramatic effect that we can now can only write:




with *i* indicating a complex value consisting of mutually substitutive *b*, *c*, and so on, dealing, as we may have to take into account, with the unmarked state,   , at the outside of the form. The complex value, *i*, indicates that we no longer know which values are implied by *a* negating itself to indicate itself via others. The complex value, *i*, indicates at the same time that what has hitherto not been accounted for outside of the form, the unmarked state,   , may well have its impact on *b*, *c*, and further elements, including *a*, in negating and implying each other while nevertheless taking note of the primary cross emerging from this unmarked state.

Note that there are two laws of form, the first being the law of calling,

$$\overline{\phantom{x}}| \; \overline{\phantom{x}}| \; = \; \overline{\phantom{x}}|$$

and the second one being the law of crossing,

$$\overline{\overline{\phantom{x}}|}| \; =$$

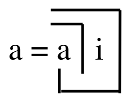
such that operations of negation and implication inside an infinite expression can both call themselves again and cancel themselves without being able to decide the matter, since "the excursion to infinity undertaken to produce it has denied us our former knowledge of where we are in the form" (Spencer-Brown 2008: 47/8).

This lack of knowledge has the fortuitous effect of turning the unmarked state, always a possible result of some negligent operation, into an argument of the form, a value always to be considered. This value, as we are inclined to assume, is the proxy for the boundary, which has been produced by the preliminary operation crossing it but is now lacking among the constants and the values of the form. The boundary is neither one of the marks of distinction nor one of the algebraic values indicated as *a*, *b*, *c*, …, *i*, but is all these marks and values taken together in distinction to the outside of the form, itself an argument of the form, the unmarked state.

Thus we understand how the boundary and possibly more boundaries participate in the realization of the network produced by and producing, the elements of the network. It is only the boundary that saves all elements of the network from being identical to, that is being confused with, the void.

*The Paradox of Capital*

If



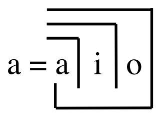
is our unit element of a network of an autopoietic unit we need two more aspects to develop our calculus of autopoiesis. We may call those two aspects time and space, if by both we understand that they do not precede autopoiesis but are themselves further elements of the network of elements produced by it and producing the elements. Thus time and space are internal, not external to our network, which means that they are variables, not constants. It cannot be otherwise since we have only a cross and an observer to look at when developing our calculus. There is nothing else we can take for granted, or, better, everything else we would like to take for granted must be developed at some point out of the calculus of the network which autopoietically produces and reproduces itself. Even and foremost our plea to take something for granted is an element of that network and should be inquired into most attentively at some point.

Time in Spencer-Brown's (ibid.: 48) calculus of indications is the representation of an imaginary state produced by a negation, in an infinite expression, indicating itself without being equal to either the marked or the unmarked state. In Hegel's (1991: § 88) *Encyclopaedia Logic* it would be called Becoming as the unity of Being and Nothing. Its interpretation in the calculus of indications is an oscillating memory which is indeterminate in being resumed either as the calling again of a marked state or as the cancellation of a cross. Thus, time invades and infects, so to speak, a form with a subversion of itself. It is the representation of a boundary being crossed without being certain whether the unmarked state has indeed been left for a marked state. Time, as Luhmann (1997) would have it, turns indeterminacy operative.

A possible understanding of this in social-science and social systems terms is to read time as capital. Capital, as we know (Marx 1990; White 2002), is a stock and flow of network resources gained from combinations (networks) of people, organizations, tools, and upstream and downstream markets. These combinations are risky in that they there is not only uncertainty about what sacrifice now for production or investment will produce future benefits, but there is also the risk that by taking decisions one invites others to take adverse decisions. As capital theory tells us, capital is a term for calculating the uncertainty of future benefits from present sacrifice in terms of people’s willingness to work, of the right time for sacrifice and for harvesting, of tools to be developed and already in use, and of market reliability or unreliability, weighing any moment in time with an interest rate depending on uncertainty, risk, and time horizon.

Two specters haunt this kind of capital, emphasizing and framing its indeterminacy: the specter of alienability (Marx 1990; Arrow 2000; Serres 1982) and the specter of addiction (Stigler/Becker 1977; Becker/Murphy 1988), which equally tend to both call on themselves and cancel each other, thus re-entering the indeterminacy into itself. Alienability is a double feature, which means that capital in time is to be produced only both at the expense of network elements discovering their exploitation, and at the risk of it being tapped and channeled off for other purposes. And addiction means that networks tend to enforce the rationality of using the resources one knows even if this use is known to produce harmful effects for everybody involved and to produce lock-in. The paradox of capital consists in having to rely on capital, that is asset specificity, in order to be able to benefit from opportunistic behavior, which switches from one network to another (Williamson 1975). Yet, that kind of opportunism as a solution to a problem just adds to the specters of alienability and addiction and thus seals the capital's calculus of uncertainty in terms of indeterminacy.

Opportunism is an apt term to describe a calculus dependent on uncertain times (chances, risks, dangers, opportunities) to constantly compare opportunities for any element of a network to stay within it with opportunities to leave it and switch to another. We thus add the term 'opportunism', *o*, with regard to our unit element of network to indicate the indeterminacy added to the network by the aspect of an understanding of time that is both the product of accumulated resources and the presentation of the risk of lock-in:

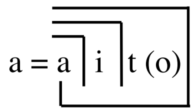



Note that with the introduction of *o* our expression for the unit element of a network gains explicitness in what has already been expressed implicitly with the variable *i*, which here stands for any *b*, *c*, …, to vary the distinction and thus indication of *a*. Thus, for all possible cases, *n*, we have *n (a) = n (i) = n (o)*.

Added, however, is an explicit understanding of *a* and *i* reproducing themselves within their network of the determination of *a* as the condition of opportunities, *o*, to get their impact, in the first place. As we have said, time is produced by *a* and *i* mutually recalling themselves while exploring their realm of negation and implication. It depends on how they negate and implicate themselves with respect to the void with which they constantly deal, whether there is a time considered to offer, and threaten with, opportunities or not.

Added therefore is an explicit understanding of time to prepare for and to expect something from. While it would be misleading to think about time in abstract terms it is nevertheless helpful to introduce it as a variable separate from the states already realized. All variables add the potential to the actual with respect to each other and thus mobilize 'meaning' to avoid confusing a variable with its present value (Luhmann 1990b; Godart/White 2010), but time, if it is special at all, distinguishes more clearly than all others between moments when there are decisions to be taken, and others, most especially past and future ones, when this is not possible because they are already gone or have not yet arrived.

We may thus also write



provided that *t (o)* is considered a time produced, because referred to, by opportunities, not a time passing in some abstract chronological way. Even if biorhythms, socio-rhythms, and other forms of planned and unplanned obsolescence seem somehow to be obeyed, they depend on specific events, moments, and happenings seeking their impact.

The variable *t (o)* once again is a complex variable because its values depend on an irresolvable distinction between the opportunity arising (*fortuna*), on one hand, and either being not yet there (*fatum*) or being already passed (*paenitentia*), on the other (Orr 1972). There is always a *momentum* framing, and being framed by, the moment. Out of this irresolvable distinction emerges, depending on social structure and semantics, the complexity of a recursive concatenation of before and after, of fleeting instant and eternity, of past, present, and future. Any indication and distinction of *a* negating itself and implying *i*, referring back to itself by negating *i* as well, and searching for the boundary to be produced by crossing it, becomes the matter of a complex architecture of mutually inferring time horizons or else of a whim of the moment trying to do away with any complexity to think about.

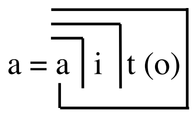
Note that there still is and will always be the unmarked outside of the form implied by all values of the marked states of the form. This unmarked outside of the form in turn implies that there is no value of the marked states of the form that would be able to insist on its value no matter what. They all depend on crosses being observed and therefore on questions to be answered regarding the values of any one of the variables.

### *Playing with Values*

The last remarks of the previous paragraph already concern not only the time but also the space the crossing calling forth the network of the form produces and is reproduced in. Space is orthogonal to time, as statics is to dynamics (Comte 1979) or differentiation to reproduction (Luhmann 1980). It is one thing to check on the insides and outsides of a form and an altogether, yet in the form identical, different thing to check on the possibility of again crossing a boundary.

The calculus of indications, which we here try to read as a calculus for autopoiesis, has its own notation for the matter of space and thus for the matter of differentiation. Difficult as the calculus is to read and use with respect to questions of time–imagining *o* at any instant *t (o)* to inform *i* such that *a* loses and regains its specific valuation, depending on memory and oscillation–it is relatively easy to read with respect to space. There are spaces differentiating between insides and outsides, and between further insides and further outsides, fractally scalable ad libitum (depending on the autopoiesis of the network, to be sure), which actually know of only one dimension, depth (Spencer-Brown 2008: 6).

Our unit element of a network produced by and reproducing the autopoiesis of a form




features four spaces, the deepest, $s_3$, being the space where *a* is indicated, the shallowest, $s_0$, being the space of the unmarked state, $s_2$ containing *i*, and $s_1$, *t (o)*. The two marks of distinction and the one mark of re-entry use the two dimensions of a diagram on a sheet of paper to write down the one dimension of depth, which has two interpretations, one of number and one of order (ibid.: 9). Order refers to the vertical reading of the form, referring to the asymmetry of values indicated in spaces of different depth, which means that one value in a shallower space dominates another value in a deeper space. To change a value in a deeper space is only possible if there is a change of values in a shallower space, but to change values in some shallower space need not lead to a change of a value in some deeper space. Thus, 'domination' here does not mean causal determination but contingent conditioning.

At the same time, however, there is a horizontal reading of form, which re-symmetrizes the values of the indications by re-entering the form into itself and thus regaining indeterminacy out of determination. The values of the variables are now distinguished according to their number, which means that any value of a variable is to be changed only with respect to all other values of the variables determined or re-determined as well, without this time paying attention to relationships of domination. The relationship of number places the variables all at one depth of their space to cancel their order and facilitate their subversion (ibid.: 51). One may think of Gotthard Günther's (1979) proemial relationship between order and exchange to understand how the one dimension of depth here is used to distribute, collect, and re-distribute the values of the variables.

Any play with values is thus constrained by respecting the order of the form to determine any one value while nevertheless using its number to change that determination. Gregory Bateson's (2000; see Baecker 1999) understanding of the notion of play as the observation and reflection of a frame from inside and outside without actually suspending that frame fits well in this context. This frame may in fact be considered a boundary that is crossed and referring, in being crossed, to the network of a form autopoietically produced and reproduced, which always has more reasons to it than catch the eye when one begins to play with it.

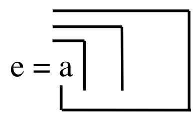
## *Expressions*

Our calculus for autopoiesis draws attention to networks being indispensable for the production and reproduction of systems understood as unities. We are thus naturally dealing with complex systems, as complexity is defined as the variety constituting a unity, and vice versa. And we leave open the question whether the network works its net only inside a system or also outside a system. As the notion of network is considered to feature a calculus of uncertainty (White 1992), it is perhaps more attractive to define a network as not having a boundary even if it constitutes a boundary (Karafillidis 2009).

This means that we re-enter Niklas Luhmann's (1995) understanding of systems into W. Ross Ashby's (1960) understanding of them, calling for the production and reproduction of a form the "essential" (Ashby) variables of which are distributed across system and environment, and thus calling for an observer indicating and distinguishing this form as one crossing between system and environment. This understanding of form combines operation, that is system, with structure, that is environment-cum-system drawing a distinction within that environment. We have Heinz von Foerster's (2003), Humberto R. Maturana's, and Francisco J. Varela's (1980) 'operational closure' together with Maturana's and Varela's (1980) 'structures' of the realization of that closure within a specific domain, and 'network' as the term describing how operational closure necessarily draws on these structures. And we have Niklas Luhmann's (1995) distinction between self-reference (*Selbstreferenz*) and other-reference (*Fremdreferenz*) to indicate the assumed necessity for any operation to indicate and distinguish itself and some other in a constant and thus indeterminate oscillation between the two references.

Our understanding of $a$, $i$, and $o\ (t)$, developed within a calculus for autopoiesis and considering the elements of a network produced by and producing a system defined as a unity is conceived of here as a shortcut to these different terms of system, environment, operational closure, structures, and complexity provided by a rich tradition of general systems theory and second-order cybernetics. The shortcut invites empirical research undertaken as the description of the memory of an interaction between a crossing and an observer, the variable of the calculus providing us with the necessary means to code the data produced by this interaction.

If we take just one more step towards generalization we may even drop our assumption that *a* = *a* and instead simply deal with expressions, *e*, in an attempt to come up with a network calculus describing the autopoiesis of *a* within its network of autopoiesis:




You are welcome to add your own values for variables that you feel important when considering the emergence of *a* with a network of crosses produced by being both negated and implied by it. And then of course to test them to code your data for a description of *a*.

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