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Topological Aspects of Biosemiotics

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Abstract: According to recent work of Bounias and Bonaly (2000), there is a close relationship between the conceptualization of biological life and mathematical conceptualization such that both of them co-depend on each other when discussing preliminary conditions for properties of biosystems. More precisely, such properties can be realized only, if the space of orbits of members of some topological space X by the set of functions governing the interactions of these members is compact and complete. This result has important consequences for the maximization of complementarity in habitat occupation as well as for the reciprocal contributions of sub(eco)systems with respect to their structural mutualism. In this present paper it will be shown what this more technical result means in philosophical terms with a view to the biosemiotic consequences. As this approach fits naturally into the Kassel programme of investigating the relationship between the cognitive perceiving of the world and its communicative modeling (Zimmermann 2004a, 2005b), it is found that topology as formal nucleus of spatial modeling is more than relevant for the understanding of representing and co-creating the world as it is cognitively perceived and communicated in its design. Also, its implications may well serve the theoretical (top-down) foundation of biosemiotics itself.

Keywords: topology, cognition, design, meta-theory

1 Introduction: Search for a Method

As far back as in the well-known book of Jantsch, it is the complexity of systems dynamics visualized as a mediation of organizational microlevels and macrolevels both in terms of a systems perspective as well as in terms of an environmental perspective which is at the origin of bio-molecular communication (Jantsch 1982: 297). For the case of *social* communication this has been discussed in detail in my “Bologna project” presented at other occasions (Zimmermann, Soci 2004 for a recent summary, the basic idea is in Zimmermann 1986, see also Zimmermann 2004a in more detail). For Jantsch, the basic characteristics of the processes involved can be collected under the heading of *endosymbiosis* which describes the autopoietic transformation within systems creating a new level of semantics at the same time. Jantsch thus visualizes a complete hierarchy of endosymbiotic stages within an organic system, where the explicit endosymbiosis of molecular types implies the constitution of procaryote cells, if conceptualized in terms of Eigen’s hypercycles, this being continued by an appropriate endosymbiosis of procaryotes to eucaryotes, of eucaryotes to multicellular organisms (Ibid. 298). However, this symbiosis is for Jantsch always a *symbiosis of information* in the first place. Not only does he start from some communication therefore, on an already cosmic scale, but he also does interpret genealogical communication as a backbone of evolution, ranging from the

DNA up to social systems (Ibid. 271). Referring to the *Schnur ansatz* of Bastin and Noyes here, of 1978, which was put forward as a result of the co-operation of these two with the Weizsäcker group at the time, Jantsch makes this particular aspect quite clear, some twenty years, *before* Stuart Kauffman and Lee Smolin envisage the same topic in terms of modern spin network theory which in turn is relating this genealogical communication to the communication of fundamental agents underlying worldly evolution (S. Kauffman 1996: lecture 7). Even more, conceptualizing the *concept of memory* in order to describe a procedure which is able to save the information actually being processed, Jantsch arrives at what he calls *epigenealogical principle* and states: "Only within a semantic context is in-formation useful for life" (Ibid. 277). In particular, he notes that the utilization of old information within a new semantic context is decisive for the onset of evolution. (A topic also discussed at the time by Brian Goodwin in the tradition of the Waddington school.)

In Jantsch, the hierarchy can be structured by the levels of fusion, symbiosis, communication, and interaction, respectively (top down): While the last defines a neutral exchange of system and environment, communication refers to an exchange while conserving mutual autonomy (Jantsch explicitly mentions the "re-orientation of oneself with a view to the self-presenting of another system" – an important concept in the existential philosophies of the French school, thus transforming *cognition* into *re-cognition*, and *presentation* into *re-presentation*.) – symbiosis then refers to the giving up of a part of one's own autonomy, gaining participation in the other system; fusion, obviously, is the giving up of all of one's own autonomy and the becoming of one single self altogether (Ibid. 279).

Hence, we find in Jantsch already the two central aspects of what might point towards a foundation of biosemiotics: *On the one hand*, it is the *complexity of systems* which is at the foundation of a relevant processing of information expressed in terms of communication among evolutionary agents. *On the other hand*, this processing of information can only be utilized reasonably, if related to a *semantic context*. So, after all, we deal with a semiotics for bio-communication, hence with *biosemiotics*. Note that this definition, arrived at however on a different line of argument, does indeed conform with most of the recent concepts proposed at other occasions (see e.g. Taborsky 1999; also the works of Ellersdorfer, Hofkirchner 1994, Fenzel 1996, Fenzel, Hofkirchner, Stockinger 1998, though relating to a different terminology, follow the basic aspects of this approach).

Hence, starting from Jantsch, we realize that the route is cleared and prepared, beginning in fact, with recent advances in physics, chemistry, and biology, including insight gained in computer science (as we shall see elsewhere, cf. Zimmermann 2004d, 2005b, 2005c) and philosophy indeed. Obviously, it is not excluded then, to actually refer such insight to ancient approaches in philosophies with a semiotic viewpoint. (The development of such philosophies starts earlier than usually known – cf. Zimmermann 1992b, 1995, 1998c, 2000, 2001b, 2002a, 2002b, see also again 2004a.) This is doubtlessly useful in the case of Charles Sanders Peirce. However, such references can at most confirm a general framework of approach, they cannot be utilized for the purpose of forecasting scientific results. Hence, it is always re-assuring to notice structural similarities in the thinking of many renowned colleagues of the last centuries, but only, if visualized as a *post-hoc* confirmation rather than as an actual precursor of the governing theory. The latter can instead only be found, if taking the *present state of the art* into view and collecting the relevant results so gained. So what we will do here is to assemble terminology and method according to what is the state of the art in complexity theory and semiotics. We will nevertheless not forget about the philosophical context also.

The original idea of Freud's was to look forward to a *cognitive meta-theory* from which other theories can be derived. In other words, the assumption was that to any theory (ranging from physics to sociology), there is such a cognitive meta-theory which *explains the explaining* of the original theory. Recently, Patricia Kitcher has discussed this aspect of Freudian psychoanalysis in more detail (Kitcher 1992). Now, instead of psychoanalysis, of which Freud certainly thought it would actually provide such a meta-theory, biosemiotics could be also a very good candidate. (It may even include aspects of psychoanalysis.) The question is of course, of how to concretely gain a foundational basis of those ingredients which are present in biosemiotics: biology and thus physics, communication, semiotics.

What we will do here therefore, is to choose the viewpoint of Bounias as a starting point for reformulating aspects of complexity theory and systems theory, and thereby demonstrating the relevance of the systems theory of Edgar Morin, internationally not well-known until today, although it has been developed effectively in the seventies and eighties of the twentieth century already. Our thesis for the time being is the following then:

Thesis

Cognition is the product of a generative loop among the physical processes which lie at the foundation of both biological and anthropo-social processes, the latter being founded on the former, and lying in turn at the foundation of the physical processes. *Communicated* cognition outlines the semiotic framework for the modeling of the world being represented by means of spaces exhibiting a specific topology which is equivalent to the appropriate representation of dynamical systems as well as to the connectivity of looped network structures.

2 The Basic Idea of Bounias

We summarize shortly the main results of Bounias 1990 and Bounias, Bonaly 2000: Under this perspective, life, as well as any kind of matter, is being embedded in mathematical spaces. And we have thus to look for means to sustain by studying the structure of these spaces. From the beginning on, we will have to read the ideas of Bounias in terms of “two registers”, because there is some sort of onto-epistemic deficiency in this approach: We should rather re-formulate that *if models deal with mathematical spaces, then representations of life/matter can be such that both of them appear to be embedded into a formal framework of that kind.* This differentiation of formulating is necessary in order to visualize physical properties of systems (and hence also biological properties) as a result of human cognition which is initializing the modeling in the first place and defines some sort of specific disposition with respect to the world. This is what I have called the “onto-epistemic” aspect (utilizing the terminology of Sandkühler) earlier (Zimmermann 1989, 1991a, 1991b, 1998b, 2004b, 2004c). As it turns out, correcting the formulations of Bounias with a view to the onto-epistemic principle contributes to the clarification of his concepts.

In order to sustain, what we need then is a condition of localized similarity which implies a criterion of formal stability of what is being perceived. Note that the structures involved are of essentially classical nature such that the activity of modeling shows up here as a direct consequence of (human) cognition which relies on essentially classical approaches in the first place. Hence, Bounias can formulate accordingly:

The global planetary ecosystem and its subsystems have properties of a topological space (X, τ) where X is the set of biotic and abiotic members and τ a rule of combination such that interactions among the components of X are being mapped.

What is essentially described here is the (mathematical) category of ecosystems ECO, where the objects are *agents* and the morphisms are *interactions* among agents. We utilize here the terminology of (mathematical) category theory (or *topos theory* rather), because, as we shall see, this will prove useful for a unified presentation of the problems involved here. For the time being we will just remember that a *topos* is a Lindenbaum algebra for a logical theory whose models are the points of a space. In other words, we can visualize a whole theory by means of a space such that topologically, the open sets of that space are the propositional formulae and the sheafs are the predicate formulae. A continuous map is then nothing but a transformation of models that is definable within the geometric logic. (Such topoi are commonly referred to as *locales*.) For a recent general introduction see Lawvere, Rosebrugh (2003). Despite the shortness of this interlude we can already recognize the unifying elegance of category theory which we will need desperately when trying to arrive at the onto-epistemic foundations of biosemiotics.

Back to Bounias whose assumption is that

optimum properties [of worldly spaces as introduced above] can be arrived at iff the *space of orbits* of members of X under τ has appropriate topological properties (namely is compact & complete).

The elementary definitions (which are actually based at most on what many people learn at school in a somewhat simplified version) have been left to the appendix to this section. We can also show that

any metric space M can be isometrically embedded in a complete metric space N such that M is dense in N (N = clo(M)).

Hence, for Bounias, the sustainable future of the world relies on two conditions:

a) the maximization of complementarity in habitat occupation & resource ultilization,
b) the reciprocal contribution of subsystems (mutualism).

(Actually, Bounias can show that these conditions are such that the actual identification of an X implies the concrete possibility that a proposition P – of some theory *about* this world – is true.) Then an object is *physical*: if the interaction with others can be observed (on the condition that the object be topologically closed) – which relates the concepts of systems and forms with each other. And an object is *biological*: if there is *a self* generated by some “perception function” caused by perceptive input mapped essentially to one and the same entity (which is called a *terminal set*). This condition is indeed fulfilled by the actual existence of fixed points or parts in the neuronal sequences mapping that input. Hence, the *topology of brain space* may be metric or not (if time is visualized as derived from ordered sequences of Poincaré sections in the embedding space).

We have then with Bounias the following two results (which we re-formulate at once according to the aforementioned principle):

Result 1: An ecosystem has properties of a mathematical space. [!] $\Leftrightarrow$ Ecosystems are modeled such that they have properties of a mathematical space.

Result 2: The set of ecosystems can constitute a topological space. [!] $\Leftrightarrow$ Topological models are such that they can constitute representations of sets of ecosystems.

(The re-formulations secure that the respective model property corresponds to the modality of the world which signifies a material property of the world’s reality. This is nothing but a re-phrasing of Spinoza’s celebrated “identity theorem” of his *Ethics* 2p7. We can utilize this instance to show how classical philosophy actually *does* enter science, but only in a post-hoc re-construction of formulations.)

So we can finally say what an ecosystem actually is for Bounias:

Ecosystem: X set of living species E together with a set of nonliving entities including habitat and resources H, τ being interactions of all sorts (transformations of states) = manifold of self-mapping of E $\cup$ H. [Magmas: fractal lattices of Boolean type]

We recognize from the appearance of Boolean logic that we are invited to replace the underlying Boolean algebra by an appropriate Heyting algebra in order to arrive at the topos terminology.

3 Appendix to Section 2 (Mathematics)

We collect here some elementary definitions which can be easily related to the sort of mathematics which is usually learnt at school when dealing with simplified cases:

Embedding = injective immersion (A differentiable mapping f is an *immersion* iff the set of germs of functions on the domain coincides with the reciprocal images under f of the germs of functions on the codomain.)

Germ (of a function) = equivalence class of functions which coincide in the neighborhood of some point. (Germs form an algebra and a vector space. A tangent vector is a derivation of the algebra of germs of differentiable functions.)

Topological Space (Topspace): Set S and {O} collection of subsets of S called open sets.

1. Union of any number of open sets is open set.
2. Intersection is open set.
3. S and ∅ are open sets.

Limit point p of a subset $X \subset S$: every open set containing p also contains a point of X distinct from p. [Relevance for Hausdorff spaces in order to actually define points reasonably!]

Subset $X \subset S$ is *closed*, if C(X) in S is open. *Closure* of X: clo(X) := Union of X with all its limit points. If $X \subset S$, then X is closed iff X = clo(X).

Compact: S topspace, and if a finite subcollection of {O} covers S. (A collection is a covering of S, if the union of all its sets conatins S.)

Complete: A subset of a top. (vector-) space is complete, if each Cauchy net converges to some point in it. (Sequence which is a Cauchy net is a *Cauchy sequence*.)

Every compact metric space is complete. A space homeomorphic to it is called topologically complete. (Completeness is orginally not a topological invariant.) [Relevance for Hausdorff spaces!]

Fixed point $x \in S$: f self-mapping, then f(x) = x.

Poincaré sections: (space-time-like) non-linear convolutions of morphisms (⇒ space-time related to ordered perceptions of existence, not to existence itself).

Topological filter: Family of nonempty subspaces (ecosystems) whose properties are being conserved ⇒ defines an order relation by inclusion ⇒ ecosystem hierarchies (This is relevant for the epistemic side of Morin's systems theory!)

4 Examples

We give one example in more detail and refer to some others shortly.

The *first example* deals with the representation of the *DNA structure* in terms of self-interactions of containers and extainers. This approach goes back to Louis Kauffman who is one of the leading protagonists of mathematical knot theory. (Kauffman 2005, see also Boi 2005) We follow here the argument from Kauffman 2002:

Be DNA = < > = C (container); extainer = > < = E,
then: EE = > < > < = > C < ; CC = < > < > = < E >.

Then also: $DNA \Rightarrow < E > = CC = DNA\ DNA$ (double strands).

Call the strands “Watson” and “Crick”, respectively, then:

$DNA = < W \mid C >$.

Replication is organized following strand separation initialized by a polymerase enzyme. The basic pairs are AT and GC, thus, if $< W \mid\ = < \ldots$ TTAGAA $\ldots \mid$, then $\mid C > = \mid \ldots$ AATCTT $\ldots >$.

Hence: $< W \mid + E \Rightarrow < W \mid C > = DNA$ and
$E + \mid C > \Rightarrow < W \mid C > = DNA$,

with $< W \mid C > \Rightarrow < W \mid + E + \mid C > = < W \mid C > < W \mid C >$.

Therefore, $E \Rightarrow \mid C > < W \mid$ represents the process by which the environment supplies complementary base pairs. *So E is the identity element in this algebra of cellular interaction.*

This algebra is in fact a precursor of the Temperley-Lieb algebra which relates the Artin braid group with the Jones polynomial invariants of knots and links. And they in turn can be visualized as quantum computers:

cup $:= \mid a > : C \rightarrow V \otimes V$ (creation operator)

cap $:= < b \mid : V \otimes V \rightarrow C$ (annihilation operator)

This defines a computation of a link amplitude (“state sum”):

$Z_K = <$ cup $\mid M \mid$ cap $>$

(M: braiding / unitary)

The Jones Polynomial plays a central role in quantum computation of the kind described here:

$< K > := \sum_{\sigma} < K \mid \sigma > d^{\|\sigma\|}$

(See also Kauffman 2001.)

This is not only a playful mathematical formalism: Instead, the algebraic aspects of what is shown here tell us that there is a close relationship between the biological structure of the DNA molecule and the physical processes underlying the organization of the world. This is mainly so, because the Jones polynomial can be utilized in demonstrating that quantum gravity (which signifies the most fundamental level of physics) is essentially equivalent to quantum computation. Hence, the exchange of information according to the aforementioned definition of Jantsch shows up here in terms of a communication taking place among fundamental physical agents (which are the spin networks in fact). And the biological structure of the DNA can be derived directly from the physical structure of that communication *without crossing chemistry explicitly*. It is the computation of link amplitudes of spin networks which can be shown to *actually produce* the biological structure (among others). This confirms the unifying role of a theory which strives for the foundations of biosemiotics!

On the other hand, we learn something important about the human production of signs: The meaning derived from essentially meaningless symbols (of containers and extainers) can be readily fitted into a productive context (in fact, probably into *any* such context) which serves as the conceptual base for developing a theory (Zimmermann 2004c). This is a very useful demonstration of what we have called *onto-epistemic* earlier: The mere manipulation of symbolic, i.e. abstract, form *produces* an associative meaning which serves a theory built on associative abduction rather than on concrete deduction. (In semiotics, this has been an important insight of Umberto Eco's.)

In fact, it is Boi (in Boi 2005) who can show that the action of the *topoisomerase* which is responsible for the DNA replication can be visualized as the cutting of the molecule, letting a strand pass through it and recombine. The single-strand molecule (type I) and the double-strand molecule (type II) can also be described as looping and tangle in a writhing process which is due to a site-specific re-combination called *recombinase*. There are combinatorial invariants then which obey the rule:

$$Lk\ (C1,C2) = Tw(B) + Wr(B),$$

where the C are the backbone curves of the closed strands and twist and writhing numbers refer to the ribbon B along the axis C. Here, Lk is the linking number. In other words, knots, catenanes, and also supercoiling are relevant for the DNA, but absent from RNA, polysaccharides, and lipids. Hence, the evolution of such knotting properties has essentially opened the way for the DNA to enfold an increasing number of components, hence to produce a *complex topology* of the molecule. In fact, most properties of the DNA are affected by closed circularity and the deformations associated with supercoiling (Ibid. 246 sq., 250, 264) Earlier Thom has already stressed the significance of topology for the evolution of biological forms (Thom 1975, 1983). See also my Zimmermann 2001a.

The *second example* deals with the celebrated *slime mold aggregation* from population dynamics, going back to the famous work of Keller and Segel (1970). The case has been discussed in great detail by Prigogine (1976, 1979) as example for his theory of self-organization and formation of structure. (I have discussed this process under a somewhat different perspective in Zimmermann 1991b: 87-94 in the appendix I. See also Zimmermann 2004a: 599-608.) Hofkirchner and Ellersdorfer (2005) have also discussed this process with a view to the not-yet-developed unified theory of information as part of a theory of evolutionary systems, stressing the aspects of cognition, communication, and co-operation in living systems. The slime mold *Dictyostelium discoideum* is an eukaryotic micro-organism that commonly occurs allover the world. It is formed by amoebae which accumulate to a collective organism by means of chemotaxis. There is a macrocycle of the phenotype which forms a retroactive loop as shown in the following picture (taken from the paper of Hofkirchner and Ellersdorfer 2005):

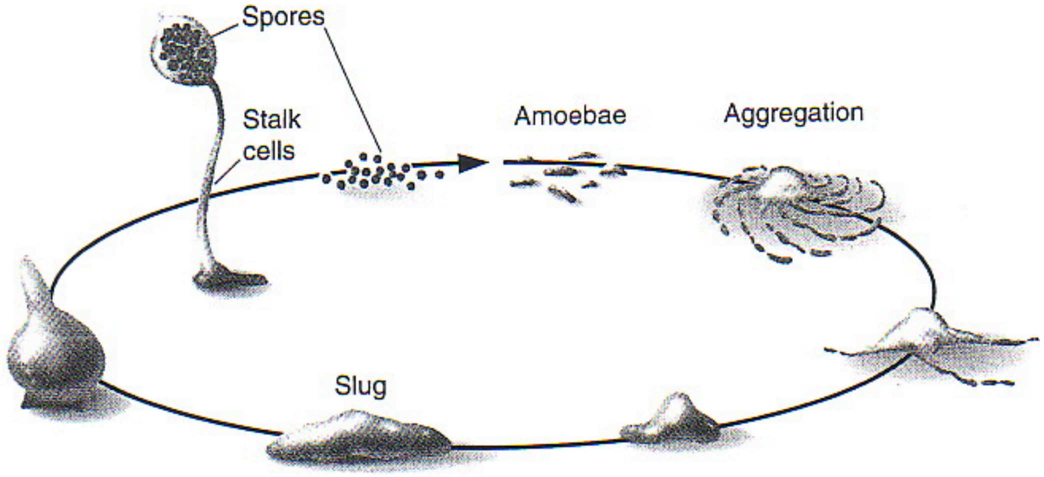

Figure 1

The point is that the loop from step 1 through step 5 leads to a change of the evolutionary stage of the amoebae involved, when the pseudoplasmoid is being produced by the aggregation which can reach a size of up to 2 mm consisting of 500.000 cells then. The slug is in fact *qualitatively different* from the population of amoebae. (I have discussed this process in terms of a concrete onset of a dialectic negation of negation.)

Jantsch (1982: 263) has shown that there is also a microcycle which corresponds to the aforementioned macrocycle such that a chemotactic cycle of katalysis mediates the intercellular communication among those amoebae which accumulate to a slime mold. This is mainly due to the action of cyclic AMP which is the active element of the acrasine steering the chemotaxis. This cycle has a diagrammatic form of the following kind:

↱ E1 ⤵ ⤹ ATP
cAMP → E3 → 5’AMP → E4
⤴ ⬑ E2 ↩
ATP

Here, E1 and E2 are the important enzymes pyrophosphohydrolate and adenylzyklase, respectively. Hence, what we have here is a concatenation of micro- and macroloops which together are *generative* in the sense of steering a dialectic process of forming structures. In the meantime, tools have been developed to actually simulate this process by means of cellular automata. The MIT Medialab has provided a simplified StarLogo routine for these simulations (Resnick 1997). There is an interesting relationship to the above mentioned conception of Louis Kauffman referring to quantum computation and the cellular automata utilized for the simulations here. Also, the *principle of decentralization* invoked in the book of Resnick’s is of very general relevance for the organizational structure of processes of this type.

Finally, as a third example, we can refer more directly to the central role of topology with a view to the dynamical structure of explicit interactions. René Thom has visualized his collection of elementary catastrophes as a *set of generic transformation loops* such that the interaction shows up as a looped topology (which is actually quite compatible with what Sebeok has discussed with a view to biosemiotics). Thom (1975) introduces e.g. a topological representation of a predator-prey interaction of the symbolic form

predator ⤵

⬑ prey

such that the loop characterizes the successive chain of operative action taken by the predator: The latter detects the prey, hunts it, and devours it in terms of a self-loop which is equivalent to Thom’s concept of *chreod*. (This can be visualized as a behaviourial equivalent of concept.) Hence, the interaction can be visualized as a self-interaction. The state space of this interaction is structured by such loops. In other words: Degree and frequency of interaction determine the degree of connectedness of the underlying state space so that we have a space with a number of handles attached to it. It is comparatively straightforward to recognize that *any* interaction space (of free play) can be characterized by the connectivity of its underlying state space.

5 Systems (Morin)

There is a large number of relationships between what we have said so far and the systemic approach of Edgar Morin who aims at a universal theory of hierarchically organized systems covering all fields of the world, as is expressed by the following symbolic diagrams:

species ▽ individual
society

This diagram symbolizes the interwoven network of micro- and macrolevels.

↺ Physics → Biology → Anthropo-Sociology ↻

This next diagram symbolizes the looping mediation of the various fields of research. (We use here Morin's convention of depicting the loops such that those components which carry a loop at their side are being connected with each other.)

↺ Disorder → Interaction → Order → Organization ↻

This third diagram symbolizes the dynamical types of evolutionary processes involved. In principle, all three diagrams are also interwoven and steer thereby the processes of this world (Morin 1977). The underlying dynamical structure is of explicitly systemic kind. And *the system's structural skeleton* is the network of agent interactions. At the same time, the network is also the skeleton of space, where space means primarily *state space* here, so as we have used it before. On the other hand, the network itself is a *graph* in mathematical terms, hence, it is a graphical representation of both the state space and the system of interactions. This reciprocally mediated dependence can be expressed in terms of the next diagram which I have introduced myself (in the epilogue to the German edition of Morin's book):

↱ graphical representation of the ↴
⮥ ⮤
Space Network System

⮤ Skeleton of the ↵ ↳ Skeleton of the ⮥

The important point is that also in the case of Morin's approach, the organizing centre of the processes is some self-activity, called the "Itself":

↺ Itself (se) ↻.

This dynamical nucleus is actually what organizes the generic aspects of the dynamical consequences of these processes. In this sense are they really *self-organizing* (to be more precise: they are actually *itself-organizing*).

Autonomy
↗ ↑ ↖
↙ ↗ ↓ ↘ ↘
Existence ↔ ↺ Itself ↻ ↔ Being
↖ ↖ ↑ ↙ ↗
↘ ↓ ↙
Individuality

On the other hand, this dynamical mediation is also coupled to the thermodynamic (thus classical) basis of processes given by the organizational hierarchy of the kind

Organization ↰
↓
Negentropy ↰
↓
Information ↥

which, by virtue of its productivity, initializes the generative loop, in which generativity itself is being inserted into the thermodynamical mediation:

↺ NEG → GEN → INF ↻

In fact, what we really have here is a kind of commutative diagram in the sense that generativity is co-organizing with regeneration, because a self-loop is essentially recursive:

$$\begin{tikzcd}
\mathbf{GEN} \arrow[r] & \mathbf{INF} \arrow[d] \\
\mathbf{NEG} \arrow[u] & \mathbf{REG} \arrow[l]
\end{tikzcd}$$

6 Conclusions

We can give a number of conclusions now which follow from what we have said so far:

1. Self-Reference of Systems: There is an Itself as organizing centre of what becomes Self.
2. Difference of System & Environment: There is a hierarchical organizational structure of a system.
3. Graphic Mediation of Modeling: The cognitive aspect of process mediation secures the recognizability of graphical representations of systems.

In fact, magmas as abstract lattices in the sense of Bounias do actually guarantee the physical substratum (or *space*) ⇒ *cancelli sive spatium*. We can conclude that starting from perceptive aspects, experimental sciences give rise to theoretical descriptions of hidden features of the surrounding world. On the other hand, *mathematical proof theory* teaches us that any property of a given object must be consistent with the characteristics of the corresponding embedding space. As far as the looped representation of interactions is being concerned, we find a correspondence of the type:

Generative Loop (Morin) ⇔ Organizing Knots (Louis Kauffman/Spencer-Brown)

This is indeed what *the abstract Kauffman scheme* does tell us: The boundary algebra of containers and extainers is to biologic what Boolean algebra is to classical logic. And more than that: Utilizing cellular automata for the simulation of lattice dynamics, we find that *shape* in general can be visualized as *memory space* according to Leyton (2001). This leads us back to what we have said in the beginning with respect to the role of biosemiotics according to Jantsch. We can indeed illustrate this aspect quite easily by utilizing Kauffman's knot theory (Kauffman 1995, 20):

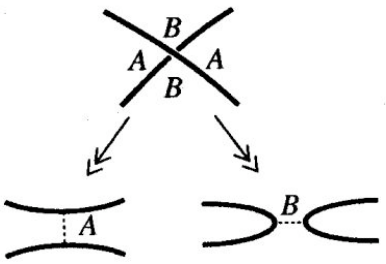

Figure 2

Here we define two ways of cutting knots (or unfolding them rather in the process of unknotting). Then we can re-construct the possible branches of the unknotting and define a *cognitive history of shape formation* by reversing the procedure (Kauffman 1995, 21):

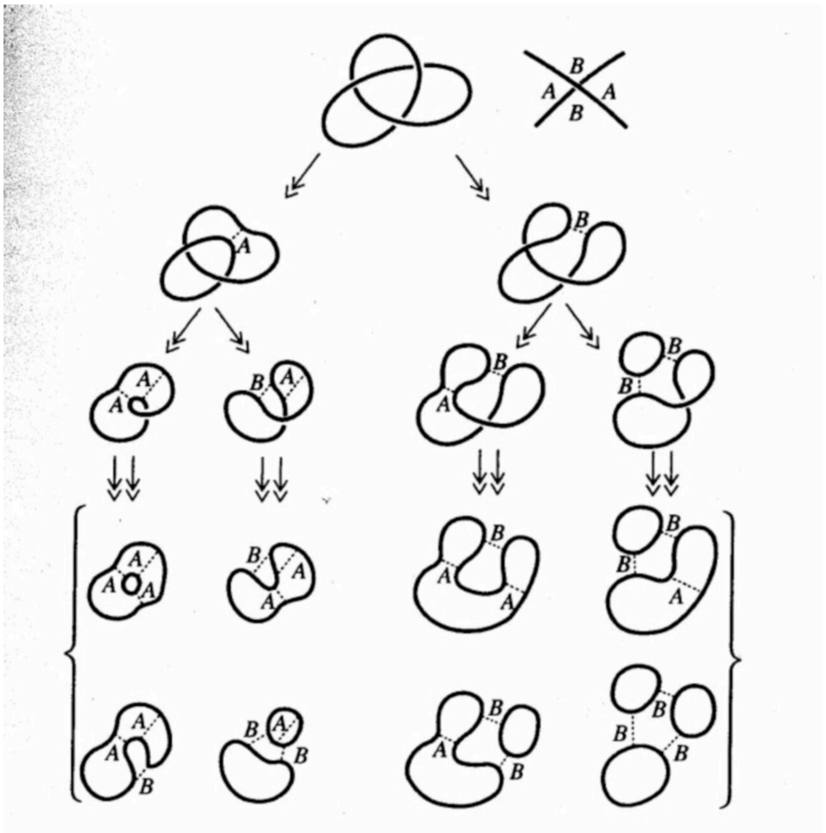

Figure 3

We can recognize here a shape history for the simple case of the trefoil knot.

This has one more consequence to which Bounias has already alluded to when mentioning proof theory: As Carbone (2005: 386) has shown, there is a structural analogy between the complementarity in formulae and logical connectives as used in proof theory and Watson-Crick complementarity of sequences (as we have discussed here in the first example). Proof theory proceeds with two principal rules (the contraction rule and the cut rule, respectively) such that a *formal proof* is a manipulation of sequences of formulae ending up with a sequence called theorem (Ibid. 387). In the process of elimination of cuts, the logical flow graph of a proof undergoes significant topological changes. And this points to the combinatorial idea underlying cut elimination: Given a logical graph of the proof, the procedure chooses a subgraph of it and resolves some of the focusing and defocusing points by duplicating it – which is obviously reminiscent of the enzyme recombinase in DNA as we have mentioned earlier (Ibid. 393).

There is another interesting aspect to this: According to what we have said just now, logical flow graphs of formal proofs are equivalent to trees of derivation (Ibid. 390). And this relates the ideas displayed here to my earlier conception of a playable version of the *glass bead game* (Zimmermann 2005a). The relevance is the following: Because the essential problem of finding an adequate language for phrasing the foundational operations laying the grounds for biosemiotics is (as it is actually the case for all theories which are genuinely interdisciplinary) to find an "intermediate" set of lexicology, syntax, and semantics rather than utilizing nothing but specialized mathematical language. Hence, a playful language of simple rules for a logical game based primarily on the topology of two-dimensional graphs e.g. represents a comparatively promising approach. The idea of the glass bead game (visualized in terms of the conception discussed elsewhere) is mainly to derive tree structures of the aforementioned kind and detect their bifurcation points, connectives to other planes of argument, count evolutionary steps, and so forth. Hence, the descriptive activity is essentially of combinatorial and topological kind. In particular, the consistency of propositions placed as tokens into the space of free play and their logical connectives shall be expressed in terms of the shape generated by this procedure, which is observable on the screen. Hence, this approach also provides a kind of formal correspondence between logical derivation and intuitive association of forms, thus of associative abduction, as we have mentioned it above.

There is actually a number of "traces of consent" with what we have said here in other works:

1. [Alexei Sharov] (1992)
Sign processes represent systemic organization: Sharov refers to Sebeok's endosemiotics (cf. also Jantsch above) – carried over to the environment of some organization (organism): "Organization is the message". He also utilizes Petri nets to discuss self-production, and there are many parallels to cellular automata, Kauffman's knots, and Conway's game of life.

2. [Liane Gabora] (1999)
Discrete memories are woven into a coherent worldview: This implies an autocatalytic closure of cognitive systems. The co-operative work of Gabora with Aerts and Broekaert (1999) deals also with the non-classical contextuality of cognition, which can be related to similar ideas of Crutchfield and Mitchell (1995) and more recently of Yair Neuman (2003).

3. [Erhard Bieberich] (1998, 1999)
He deals with a fractal approach to the topology of self-perceiving implying that the connection of self & world is achieved by algorithmic compression of spatial information – according to the fractal structure of the neuronal network. For him, the self [itself!] has always been an immanent property of nature, but has become conscious not before an appropriately organized physical set up.

4. [Debora Hammond] (2005)
Her work on systems ethics & praxis carries strong relationships with the ideas of Edgar Morin.

A final remark now on *topoi*: Probably, the solution of what we might call the *foundation problem* of biosemiotics can be found in an explicit combination of the structural aspects of the glass bead game as discussed above and a conceptual introduction of topos theory which for us today appears to be the simplest and easiest attainable language of the mathematical field available. As far as semiotics is being concerned, there is already a practical approach to a similar problem worked out in detail: It is in fact Guerino Mazzola who has developed the musicological equivalent of a foundation as we would like to have it for biosemiotics (Mazzola, w.d. 2002). His basic idea is to start from a complex ontological topo-graphy of music assuming that the latter *is* communication, *has* meaning, and *mediates* on the physical level between its mental and psychic levels. The multi-perspectivity of (interpretations of) music is then comparable to the infinity of mathematically equivalent orthonormal de-compositions of a periodic function according to Fourier's theorem. This topography is local and recursive, and it relies on the mediation of spaces with respect to the representation actually undertaken, i.e. the *form of a denotator* represents the space where the denotator lives – which relates this conception to topos theory in a straightforward manner. In fact, a denotator is simply a point in a space called form. Hence, morphisms among denotators are transformations of forms. So we deal here with a category which shows up as a syntactical structure of the semiosis which in turn admits of geometrical interpretations. The aesthetical criteria are actually being extracted by means of the classification of local and global compositions under topological similarity. As the production of meaning refers primarily to equivalence classes, the classification can be visualized as an instance of a supplementary semiosis in poetical contexts. In semiotic terms then, can predicates be visualized as connotational signs built upon denotators. Obviously, if applied to performance itself, this method opens the pathway towards *social contexts of harmony*, and may serve as a formal foundation of what can be intuitively observed, e.g. with a view to certain musical styles which tend to dominate at a given time (Noll 1995). [By the way: In chemistry, a similar approach to harmony has been started in the works of Achim Müller and co-workers, cf. Müller et al. (2004). The development of a coherent *design science* in the sense of Buckminster Fuller is very much on the same line of argument.]

Indeed: A similar approach has to be undertaken with respect to a foundational basis of biosemiotics visualized as a cognitive meta-theory in the sense defined in the beginning. The observations made in systematic and methodological terms when discussing the approach of Mazzola et al. point to a confirmation of the conjecture we have formulated earlier in this paper, which promises useful insight, if one tries to combine the glass bead game approach with a topologized logic of associative abduction.

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