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The cybernetics of viability: an overview

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A three-level approach to viability is developed, considering (1) living systems, (2) a niche, understood as the area within the reach of their actions, and (3) an environment. A systematic analysis of the interrelations between these levels shows that living systems emerge with matter/energy processing systems. These can add controller structures when producing excess energy. A three-sensor controller structure enables a living system to deal with unfavourable and scarce environments. Further evolution of these controller structures offers improved ways to act on niches. Maintaining niches in scarce environments can require technology or economy. So social systems emerge, which are understood as aggregates of living systems. Basic patterns of interactions within social systems are analysed. So the introduction of the notion of the niche into the discussion of viability allows us to explain phenomena ranging from properties of single living systems to societal organization.

Keywords: viability; living systems; social systems; cybernetics; systems theory

1. Introduction

Maintaining viability is obviously a crucial task for all forms of life. But, surprisingly, viability as a holistic concept has not received much attention in either biochemistry and theoretical biology or in systems theory and the formal sciences.

Therefore, we will try to outline a general concept of viability in this paper, with a focus on cybernetic structures and processes. We begin here with a preliminary, pragmatic, and short definition of viability (Nechansky 2010a), which seems to us to be sufficient to get started and a valid statement about a complex phenomenon defying complete coverage in one sentence: we understand viability as the ability of a system to continually maintain its functions and its structure within a certain environment. We do not discuss the minimum of ‘continually’, but suggest that a longevity of structures over a year, reported by biology or history, seems a safe first guess.

Let us explicitly point out that we restrict our investigation with this definition to the already existing structures, and just discuss determinants of their maintenance. We will only touch questions of the emergence of viable structures and completely leave out their reproduction.

Based on this definition, we select the literature we have to consider: with Schwaninger (2006), we agree that just three major theories on viability exist currently, namely those of Miller (1978), Beer (1979, 1981), and Aubin (1991). We will additionally look into the work of Bunge (1979, 1985) and address some aspects of the theory of autopoiesis (Maturana and Varela 1980, Mingers 1995). We start with brief surveys of

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these theories and how they correspond and complement each other. Based on that, we will try to develop a more holistic approach.

2. System theories dealing with viability

2.1 *A short account of Bunge's biosystems*

Bunge (1979) develops a systems approach to 'biosystems' for which he demands the following.

1. As basic properties (1) a composition including structural and functional proteins and nucleic acids for reproduction, (2) an environment providing precursors of all its components, and (3) a structure enabling metabolism, self-repair, and reproduction.
2. A differentiation of at least five levels, with (1) chemical composition, (2) structure, (3) cell, (4) organism, and (5) environment.
3. A list of 13 postulates, which have to be fulfilled so that life can emerge. These include some chemical components and inner processes, being part of some supersystem (organism), reproduction, internal control, external adjustment to the environment, and competition or cooperation with other systems of the same species.

Based on that, Bunge (1979) considers phenomena such as control, development, adaptation, evolution, and coevolution and tries to relate them to chemical components and processes. Bunge (1985) provides a discussion of emergent phenomena of life, such as the mind, psychology, and sociology, yet surprisingly without clearly relating it to his own earlier definition of biosystems.

We cannot go here into any further details. We just want to point out what, respectively, we find and do not find in Bunge's (1979, 1985) approach:

1. Bunge's main concern seems to develop a 'biosystemism' distinguished from other philosophical approaches towards life, like vitalism and mechanism. His point is that any systems approach towards life must be finally traceable to chemical phenomena.
2. Bunge speaks occasionally about subsystems, without ever specifying them. So his systems approach lacks any intermediate levels between cells and organisms.

2.2 *A very short account of autopoiesis*

We can only touch here on the theory of autopoieses and name three main aspects.

1. The notion of 'autopoiesis' was primarily applied to the phenomena of the emergence of life (Varela *et al.* 1974), referring to the molecular 'self-production' of their structures. (As stated in the Introduction, emergence of life is not our topic here.)
2. Based on investigations of the molecular functioning of nerve cells and their limited processing abilities, Maturana (1970) developed an autopoietic theory of cognition. It claims that the principles determining single nerve cells would be the very principles which would unequivocally govern and limit the cognitive ability of whole living systems, independent of their internal structural differentiation (Maturana 1970, 2002, Maturana and Varela 1980). Accordingly, this theoretical body quickly moves from a chemical level to structurally hardly defined 'observers' and their assumed cognitive limits and abilities, which include language.

3. From these starting points, the notion of autopoiesis was applied to many other fields (Mingers 1995), including sociology (Luhmann 1987), while the validity of this move was objected to by Maturana (2002).

It is difficult to grasp and do justice to autopoietic theory in a short account, first because it did not yet develop any agreed-on definitions, what has to go on structurally on lower levels so that higher level autopoiesis might show. Second, it uses an opaque language, which refers hardly to other theoretical bodies and developed various branches. Mingers (1995), struggling to find a mutual core, summarizes autopoiesis as sort of a metatheory trying to conceptualize necessities and limits resulting from the structural organization of life.

Well, we can here only summarize what, respectively, we find and do not find in autopoeitic theory.

1. Autopoietic theory reminds us that the structural and functional limits of the molecular level of living systems must somehow determine and limit the performance of the whole system.
2. The cognitive theory of autopoeisis not only widely ignores but also may even go so far as to deny (Maturana 2002) the importance of any structural differentiation between the molecular level and the level of whole living systems. Similar views can be found in sociological applications, where the importance of individual living systems for communication systems is neglected (Luhmann 1987).

2.3 *A short account of Miller's living systems theory*

Miller (1978, for an overview see Miller and Miller 1990, Schwaninger 2006, Nechansky 2010a) aimed in his living systems theory at finding functional necessities and commonalties of all forms of life. He claimed that all living systems have to contain one of the 20 different subsystems:

1. ten subsystems for processing information ('internal' and 'external sensor', 'channel', 'timer', 'coder', 'associator', 'memory', 'decider', 'decoder', 'effector' – we use here our differently defined notions, where applicable, see Nechansky 2010a);
2. eight subsystems for processing matter–energy ('ingestor', 'distributer', 'converter', 'producer', 'extruder' and 'matter/energy storage', 'motor' and 'supporter'); and
3. two subsystems for processing matter–energy and information ('reproducer' and 'boundary').

In addition to identifying these 20 subsystems, Miller found that these have to occur on eight different levels of organization of living systems: (1) cells, (2) organs, (3) organisms, (4) groups, (5) organizations, (6) communities, (7) societies, and (8) supranational systems.

Let us summarize what, respectively, we find and do not find in Miller's (1978) approach.

(1) Miller shows similar *functional* requirements of living systems on different levels of organization. These functions concern internal and external data acquisition and mutual *data processing*. And they concern the *processing of matter/energy* to maintain all processes and the structure of the system. Finally, Miller addresses *reproduction* to ensure long-term viability by reproducing parts or even the whole system.

(2) Miller did not provide a *structure* for a living system (we developed a solution for that in Nechansky 2010a) and did not detail the necessary *content* of data processing.

2.4 *A short account of Beer's viable systems theory*

Beer (1979, 1981, for an overview see Schwaninger 2006, Nechansky 2010a) developed his viable systems theory as a new approach to organization. As a model, Beer took the way that the human brain organizes the actions of the body. He derived from that a structure of five interacting systems that would be needed in any viable system according to his theory. These five systems are as follows.

> *System 1: Operations*. This is the lowest level of an organization, where a number of the so-called *primary units* carry out operations (like production or services) and locally control them.
> *System 2: Coordination*. Here the primary units are coordinated, i.e. it is made sure that the different operations in System 1 lead to interactions serving the whole organization.
> *System 3: Optimization*. In this level, the optimization of Systems 1 and 2 is planned, initiated, and monitored.
> *System 4: Strategy*. Here the focus is on surveying the environment and its developments, to detect relevant trends, and to respond with strategies and action plans for future activities.
> *System 5: Policy*. Here decisions on policy are made, i.e. which strategies and action plans to realize, to achieve an appropriate performance serving the highest goal values of the system.

Again we cannot go into further details. But let us say what, respectively, we find and do not find in Beer's (1979, 1981) approach.

(1) Beer gives a rough outline of the *overall controller structure* of an organization, but with black boxes for all his Systems 1–5. His focus is on necessary *content*, making explicit the various interrelated issues that have to be dealt with in his Systems 1–5, so that an organization can cope with a changing environment.
(2) Beer leaves open any *structural details* and does not address any *functions* necessary to process the issues he identified, nor does he deal with any functions for *matter/energy supply*.

2.5 *A short account of Aubin's viability theory*

Aubin's (1991) mathematical approach differs completely from the other theories named before. Put briefly, Aubin's viability theory may be described as a set theory-based general approach to control. It investigates evolutionary paths of systems, understood as sequences of states $x(t) \in X$ that characterize the behaviour of a system in time, with X being a constrained state space $X \in \Re^n$. And, particularly, it looks for the following.

1. 'Viability kernels' K, i.e. constrained subsets of states $K \subset X$, so that any evolutionary path $x(t)$ starting in a state $x_o \in K$ remains within K for all time.
2. 'Capture basins' C, i.e. further constrained subsets of states $C \subset K$, so that any evolutionary path $x(t)$ starting in a state $x_o \in C$ reaches a goal value (a target) $x_G \in K$ in finite time.

Evolutionary paths of systems could be just trajectories of single systems, i.e. $x'(t) = f(x(t))$. But more interesting are the evolutionary paths $x'(t) = f(x(t), u(t))$ that are the result of the development of a first system $x(t) \in X$ influenced by the regulating actions $u(t) \in U(x(t)) \subset Y$ of a second system, with $Y \in \Re^n$ being another constrained state space.

Then, it is of particular interest:

1. if there is any evolutionary path $x'(t)$ leading the first system to a viability kernel or a goal value and
2. which regulating actions $u(t)$ of the second system enable such evolutionary path(s).

This general approach allows us to investigate analytically if and how the interactions of a first, *controlled* system (constrained to develop in X), with a second, *control* system (constrained to develop in Y), may lead the first system towards stable areas of restricted behaviour (i.e. a 'viability kernel' $K \subset X$) or even towards a goal value (i.e. a 'capture basin' $C \subset K$ from which it approaches a goal value $x_G \in K$).

Let us summarize what, respectively, we find and do not find in Aubin's (1991) approach.

(1) Aubin deals with *limits* and *goal values* of viability, addressing that the existence of the system is possible only within certain ranges, and that there are usually preferred states within this range. And he makes explicit that regulating *actions* have to keep the system within these limits and have preferably to lead it to the goal values. Aubin makes explicit, too, that viability involves *more systems*, dealing with three, controller, controlled system, and environment.

(2) What is missing in Aubin's work, as in all formal theories, are the questions of *structures* providing certain *functions* to process specific *contents*, that actually enable a system to achieve its goal or at least to stay within its limits. As an aside let us mention, too, that Aubin's theory is restricted to feedback and does not address feedforward.

Now, let us leave these theories here. We will discuss next what we take from them and then develop our approach. We will come back to these theories at the end of the paper.

3. Towards a more holistic approach to viability

Now we suggest a framework for a unifying, more holistic view of viability. We outline here what we take from the theories discussed above and make some suggestions for the important additions. We will detail our approach in the sections below.

We do not go down here to the chemical level, which is Bunge's (1979) concern. And we will not use autopoietic theory. We build mainly on Miller's functional approach, rely on its grounding in biochemistry, and add the following aspects to develop our approach with three levels and two sublevels.

1. The *environment* defines the external constraints (explicit only in Beer 1979, 1981) that a living system faces. We distinguish here ranges of physical conditions (particularly temperature) and available resources (such as water, food, materials, and energy).
2. We introduce here the notion of the *niche*, which we understand as the region within the environment that is within the reach of the actions of a living system. Maturana (2002) uses this notion, but with a much more narrow meaning, while such an intermediate zone around a living system is at least explicitly missing in all other theories. We will try to show below that considering a niche can explain many phenomena related to viable behaviour.
3. The *living system* itself is defined by the characteristics of its structure (explicit in Beer 1979, 1981, more detailed in Miller 1978). These define the available functions and, with them, too, the constraints of the living system itself (explicit in Aubin 1991).

Derived from our basic structure for a living system according to Miller (for more details see Nechansky 2010a, for an enlarged structure see Figure 1), we suggest that all but their most simple forms contain two functionally different parts.

(a) The *part for matter/energy supply* (explicit only in Miller 1978) has to process matter and/or energy from the niche to maintain the functions and the structure of the system.

(b) The *part for data processing* (a basic form shown in Miller 1978, an advanced one in Beer 1979, 1981) has three main functions. Internally, it has to control matter/energy supply and existential conditions (particularly concerning temperature). Externally, it has to survey the niche for matter/energy supply and has to provide appropriate inputs.

Now let us explore these levels and the different functions they can have for viability.

4. The environment

We understand the environment as defining the boundary conditions for a living system, being as a whole beyond its reach. The living system can just deal with a part of it, we call the niche (see Section 5). So the environment as a whole provides a directly unchangeable frame that is characterized by certain facts. We distinguish two categories of facts.

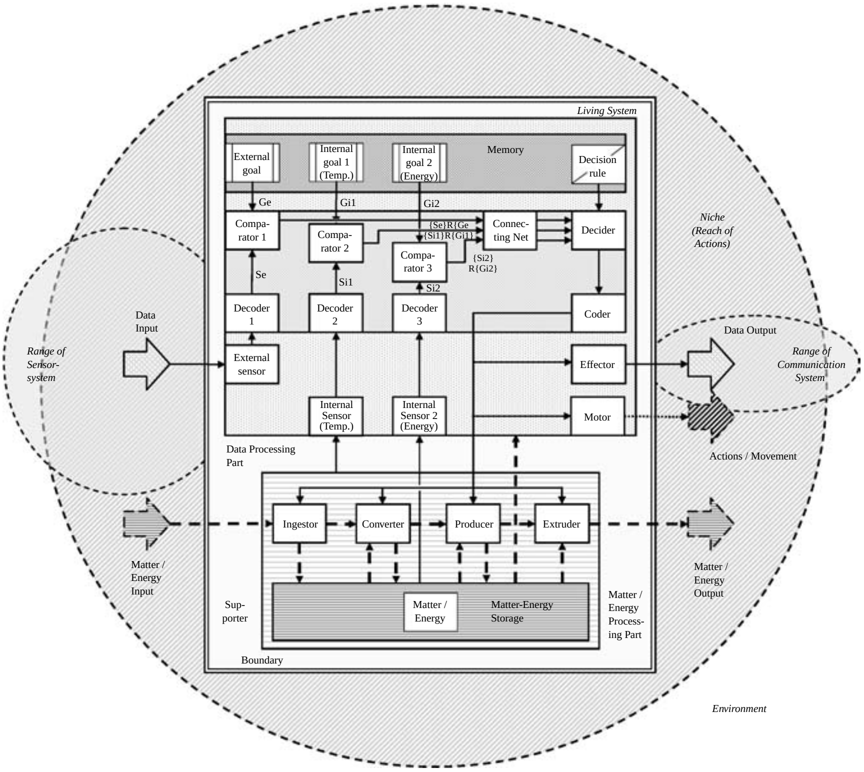

Figure 1. The minimal structure of a living system for controlling internal existential conditions and needs and the external actions towards the niche. Shows possibly different areas of interactions between the living system and its environment.

(1) There are certain ranges of physical *environmental conditions*. The most important is temperature, but there are others such as humidity, hours, intensity of sunshine etc.

(2) The environment provides certain physical and chemical *resources*. These are the forms of matter/energy, such as water, food, certain materials, and certain forms of energy, etc.

    At a place certain resources may be completely missing, may be available in fixed amounts (e.g. minerals), or may be available at certain rates (water or sunshine per area or per time).

Here, we understand physical conditions as something interacting with the *structure* of the living system, while resources are something usable for the *processes* of matter/energy supply. We need that distinction to define the role of the niche below. A clear separation between the two seems only possible in relation to a certain living system, being complicated by the fact that what may be a threat for a structure may be good as a resource (e.g. intensity of sunshine).

5. The niche and its functions

We understand a niche as the region within the environment that is within the reach of the *actions* of a certain living system. We might distinguish here a short-term range of the niche within the reach of immediate actions, a mid-term range within the reach of actions without need of providing anew external energy supply, and a long-term range within the reach of actions in the lifetime of a living system.

Anyway, the function of the niche for viability can take different forms, depending on environmental facts.

5.1 *The niche in the favourable and abundant environment*

The environment may be sort of a system-specific ‘paradise’, providing both (1) good living conditions (the range of conditions, e.g. concerning temperature, is equal to or greater than the range of existence of the living system and without extremes) and (2) sufficient resources for matter/energy supply.

In that case, the function of the niche is negligible: it is just that region of the environment that is within the reach of the living system by chance. The living system can just enjoy the plenty. There are no external limits to viability.

5.2 *The niche in the unfavourable but abundant environment*

The environment may provide (1) unfavourable living conditions (the range of conditions, e.g. concerning temperature, is outside the range of existence of the living system or may have occasional extremes) but (2) sufficient resources for matter/energy supply.

In that case, the main function of the niche is to provide shelter (like caves or housing) against unfavourable conditions. Having shelter, the living system can occasionally leave it to take from the plenty. So, here viability depends on certain *places*.

5.3 *The niche in the favourable but scarce environment*

Now the environment may provide (1) good living conditions but (2) insufficient resources for matter/energy supply.

In that case, the function of the niche is to secure areas (e.g. gardens, fields, and markets) in which resources are collected, exploited, combined, etc., and/or stored to maintain a sufficient matter/energy supply. Here viability depends on certain *regions*.

5.4 *The niche in the unfavourable and scarce environment*

Finally, of course, the environment may provide (1) unfavourable living conditions and (2) insufficient resources for matter/energy supply.

Then, the niche has to provide places for shelter and areas for securing matter/energy supply, and viability depends on both certain *places and regions*.

So the relation between the conditions and the resources of the environment to the existential conditions and needs of the living system determines the function of the niche for viability. The more the importance of this function increases the worse the environment. And the worse the environment the higher are the demands on the living system to develop appropriate cognitive models as well as actions *to control a niche*, i.e. to maintain, exploit, change, or defend it. This aspect is missing in the current theories of viability discussed above.

Let us explicitly point out, too, that we introduce here the notion of ‘scarcity’ into the discussion of viability. The notion of ‘scarcity’ plays an important role in microeconomic theory. So, we see here the point of departure where economic considerations follow from the basic questions of viability.

As an aside let us mention that the ‘noble savage’, who is often considered as an ideal for human conduct since Rousseau (2009) introduced him in political literature in the 1750s, usually lived in a ‘paradise’ (Section 5.1). No wonder an easy going living was possible there. And, of course, economical, organizational, and political questions to deal with scarcity did not arise. We will briefly touch these below. Here, we just want to point out that ignoring the function of the niche can lead to very distorting simplifications of our understanding of viability.

6. The living system

We present here a structure for a living system (Figure 1) derived from Millers’ (1978) approach and our structure developed for that (Nechansky 2010a), but containing additional functional elements for data processing. Let us discuss the properties of this structure and the reasons for this choice.

6.1 *The whole living system*

The structure of the whole system determines the two crucial aspects of viability.

1. Existence of the structure requires certain physical *existential conditions* that have to lie within a *range of existence*. This concerns primarily a range of temperature, below which a structure may freeze or chemical reactions stop and above which it may decompose, melt, or chemical reactions run away.
2. Maintenance of processes requires serving certain *existential needs* concerning matter/energy supply, primarily to secure energy demands to carry out all processes and secondarily to maintain the material structure.

   These existential needs consist of demands for certain *forms* of matter/energy as well as for certain supply *rates*, i.e. forms of matter/energy needed in time.

We approach here inside-out what we approached above outside-in starting from the environment: these aspects determine if the system can live anywhere in the environment (see Section 5.1), needs certain places (Section 5.2) or certain regions (Section 5.3), or both (Section 5.4).

6.2 *The part for matter/energy supply*

The structure of the matter/energy supply part of the living system, of course, determines part of the range of existence of the whole system and part of the needs for matter/energy supply.

But, more importantly, it determines what forms of matter/energy the system can process. This determines, first, what is a resource for the system and, therefore, second, what is an abundant environment (see Sections 5.1 and 5.2) and what is a scarce one (Sections 5.3 and 5.4).

6.3 *The data processing part*

The structure of the data processing part of the living system, of course, determines part of the range of existence of the whole system and part of the needs for matter/energy supply.

The data processing part has three main functions, we already sketched in Section 3.

1. Internally, it has to control matter/energy supply and maintain it by triggering appropriate internal actions.
2. Internally, it has to observe existential conditions (e.g. temperature) and has to trigger actions to maintain them (e.g. external actions to find appropriate conditions in the niche).
3. Externally, it has to survey the niche for appropriate resources for matter/energy supply and has to trigger appropriate external actions to provide them as inputs to the ingestor.

For these functions, a system needs at least three different sensor systems, one more than demanded by Miller (an internal sensor for energy supply and one for body temperature, which is not included in Miller's approach, and an external sensor to identify resources in the niche). In Figure 1, we show a basic structure for that. The data processing part is an enlarged feedback system, a form of a one-level adaptive system (Nechansky 2010b). It can trigger the following forms of behaviour to adapt to the various internal and external states it can detect.

1. Internally, it can observe matter/energy supply and maintain it by triggering the internal processes of the part for matter/energy supply. Particularly, it can trigger ingestion, when there is supply and demand for input, trigger production from inputs or from storage, or just trigger distribution of matter/energy available in the storage.
2. Internally, it can check, too, temperature. If it is too high or too low, it can start to move, till finding a *place*, where existential conditions are met.
3. Externally, it can survey the niche for appropriate resources and can trigger appropriate actions to provide them as inputs to the ingestor of the matter/energy supply part, whenever there is demand, because the level of internal matter/energy supply is low. When external resources are scarce or missing, the system can move on searching for them in a *region*.

   Let us mention that we make here a further deviation (Nechansky 2010a) from Miller's approach: we see the motor (the effector for external movement) as part of

> the data processing system and not the matter/energy supply part, because it presupposes some form of control to serve the whole system in a goal-orientated way. Without control it may just run all the time, run stochastically or never; of course, then its usefulness for the system would remain doubtful.

The main function of the data processing part is to observe, decide, and trigger goal-orientated actions serving the viability of the whole system. To achieve that, it needs a *model* of how to use observations for actions. We have argued elsewhere that the *content* of this model consists of decision rules (Nechansky 2010b), relating observations to goal values to determine deviations from the goal, and to trigger goal-orientated action to oppose and correct such deviations. For an enlarged feedback systems as shown in Figure 1, the decisions rules have the form:

if {[(external sensor data Se) (Relation e) (external goal-value Ge)] OPERATOR 1
[(internal sensor data Si1) (Relation i1) (internal goal-value Gi1)] OPERATOR 2
[(internal sensor data Si2) (Relation i2) (internal goal-value Gi2)]},
then {trigger for a goal-orientated action}.

The relations possible in such decision rules are relations of order (such as $<$, $\leq$, $=$, $\geq$, $>$, or $\neq$) or some system specifically defined, maybe fuzzy or rough, form of equivalence ($\approx$), while the OPERATOR may be any logical operation AND, OR, NAND, NOR, XOR, or, respectively, NOT (Nechansky 2009).

In these decision rules, the highest goals must always be the *existential goal values* for existential conditions (such as a preferred body temperature) and existential needs (such as a preferred level for energy supply). Only then is it guaranteed that the all decisions lead to actions serving the viability of the system, and not that any decision may lead to actions endangering it (Nechansky 2010b).

Given priority to the existential goal values for existential conditions and needs, still a surprising number of relations between the contents of single decision rules and the conditions in the niche and the environment have to be maintained, to enable goal-orientated behaviour (Nechansky 2010b). So a model has always to be in accordance with a certain niche in a certain environment.

Finally, let us explicitly point out here that the structure shown in Figure 1 is not a must for a viable system. We present it here because it shows the minimum cybernetic structure to trigger all the different forms of behaviour in niches we distinguished in Section 5. Next, we will place this structure in an evolutionary chain.

7. Overcoming the limits of viability: the evolution of living systems

7.1 *The decisive limits of viability*

After introducing our basic model for explaining elementary phenomena of viable behaviour, let us make some unusual proposals, what we see as the decisive limits for viability.

1. The viability of living systems depends on continuously maintained processes.
2. At the core of viability is a matter/energy supply system, determining what resources the system can process and has to process, and therefore needs in its *environment*.
3. The most limiting factor of viability is the need to ingest resources, i.e. to get them right in front of the system in its *niche*.

We suggest that all further developments of living systems, which we will explore below, are developments to overcome the severity of these limits, by developing the ability to store resources, to find them in the environment, to act on them, etc. But all these are and have to be additions to an already viable core.

Accordingly, we find living systems emerging out of structures for matter/energy supply, just able to maintain themselves. Of course, such structures are totally at the mercy of the environmental conditions and any resources that may occasionally show upright in front of them. So they can only emerge and survive in their specific ‘paradise’ (Section 5.1), but can do nothing but end whenever the ‘paradisiacal’ conditions end. Seen from that point of view, it seems not surprising that chemical cycles, which are seen as the basic form of life, emerge in far from equilibrium conditions (Prigogine and Stengers 1985). Only such conditions, providing a rich supply of resources (i.e. a ‘paradise’), allow maintenance of the unidirectional chain of reactions that makes up the chemical cycle. Moving towards chemical equilibrium conditions, where some supply is reduced, increases the likelihood that one or some reactions start to run backwards. But, of course, any *one* reaction running backwards breaks up the unidirectional chain and ends the cycle.

So cyclic chemical reactions seem to be the beginning of viable matter/energy processing systems. And viruses seem still to be a more advanced form of that, still without any higher level controller structure. We do not know the stages in between. But let us discuss in the following evolutionary possibilities that enhance the viability of given already viable matter/energy processing systems.

7.2 *Evolution of the matter/energy processing system*

To overcome the main limits of a matter/energy processing system, the following improvements seem to be the most important.

1. Enabling the matter/energy processing system to process more resources.
2. Enabling the matter/energy processing system to produce from its resources more usable matter/energy than immediately necessary to maintain itself.
3. Adding and/or increasing a matter/energy storage: this is a very crucial factor determining how long a system can survive without having any resources immediately available for ingestion, and thus, indirectly, how far it may move in the environment, extending its niche in a region, to find resources.

That a matter/energy processing system can continuously provide more usable matter/energy than necessary to maintain itself (either from production from a niche with sufficient resources and/or from storage) is the prerequisite for the next step: only then, it can become the matter/energy supply part of a living system able to develop and maintain controller structures, which cannot produce the matter/energy they need by themselves.

7.3 *Evolution of the data processing system*

Given an excess of matter/energy supply, the matter/energy processing system has the base to add a data processing system and maintain its functions. Minimal form of such a controller structure is a feedback system (Nechansky 2006), which uses the inputs of one (internal or external) sensor, compares these with a goal value (for internal existential conditions or needs, or external useful matter), to decide for goal-orientated actions (to improve existential conditions, or to serve existential needs, or to use external matter) of the one effector. We discussed elsewhere the evolutionary paths for goal-orientated systems departing from feedback systems (Nechansky 2010b, 2011a), so we review them here only briefly.

1. *Evolution of the number of effectors.* A feedback system may add any number of effectors. In Figure 1, we show just two such effectors, one is called 'motor'. (The most extreme example for that development is a centipede.)
2. *Evolution of the complexity of effectors.* Effectors may develop towards complex structures (e.g. consisting of arms, hands, and fingers), controlled by various levels of motion control, subordinated to one highest level (a 'brain').
3. *Evolution of the number of sensors.* More internal sensors (for energy supply, body temperature, etc.) or external sensors (such as 'eyes' and 'ears') may be added to a feedback system. In Figure 1, we show two internal sensors and one external sensor.
4. *Evolution of the processing of sensor data.* Once more sensors are added and appropriately connected, there may be further evolution of such a simple 'brain' by adding more internal functional elements to connect, store, and/or mutually process the available sensor data. This data processing has to happen between the data input from the sensors and the decider (in the field called 'connecting net' in Figure 1), where the results are used to trigger actions.

These evolutionary paths can happen partly independently, partly only interrelated (Nechansky 2010b, 2011a). But that does not concern us here. Here, we just want to briefly outline the main steps of the evolution of data processing systems and their contribution to viability:

1. A living system according to Miller (1978) with just two sensors can be viable when external conditions, e.g. concerning temperature, are favourable (Sections 5.1 and 5.3). It can recognize demand for resources and move till finding some. But having found resources it may happily feed, while freezing to death with no possibility to even recognize that.
2. Our three-sensor structure of Figure 1 is the minimal system to show all the forms of behaviour in niches we discussed above. But it is a *pre-programmed adaptive system* with a certain repertoire of behaviour and no possibility to improve it (Nechansky 2010b).
3. Evolution of the pre-programmed system to an *adaptive system that can develop individual behaviour* (Nechansky 2010c) adds the possibility that the system can develop new forms of individual behaviour to deal with *pre-programmed* patterns it can recognize in its niche.
4. Further evolution of the adaptive system to a *learning system with pattern recognition* allows the system to learn and later to recognize certain features of the niche. To deal with any newly learned standards for pattern recognition, the system must use a trial and error process to develop new behaviour towards them. And the criterion to judge such behaviour as 'successful' and to select it for future activities is the internal evaluation of its effect on the highest existential goal values of the system. So here, we find an internal 'emotional' evaluation of individual behaviour towards externally observed patterns. So at this stage, individuality and 'individual psychology' emerge as a cybernetic necessity (Nechansky 2011b) and remain to be a cybernetic necessity in all further evolutionary steps building on pattern recognition.
5. Evolution towards a *sequence learning system* additionally enables learning and recognition of sequences of patterns, i.e. certain changes and paths in a niche, and to develop behaviour to use them. (We analyse that in forthcoming work.)
6. Further evolution to *anticipatory systems* allows anticipation and/or consider future developments of the niche and development of behaviour to act and/or prepare

towards them. There seem to be differently complex forms of anticipatory processes and related behaviour, with the highest forms only available for humans. (We will analyse these forms in future work.)

So the evolution of data processing systems starts with pre-programmed controller structures with a fixed set of unchangeable *abilities*. They evolve to complex structures enabling certain forms of individual behaviour, like adaptation, or learning of new patterns, sequences, or even anticipation. These offer certain *capabilities* to change, add, and/or delete decision rules in their models. Here, the structures alone cease to be an explanation for the actual behaviour of systems and their viability. Processes enabled by the structures allow them to individually increase the variety of their behaviour, which is necessary to improve their control (Ashby 1957) of the niche.

Let us mention here that Beer's (1979, 1981) viable systems model presupposes complex anticipatory capabilities, particularly to develop strategies in his Systems 4 and 5. So our short account of the evolution of data processing systems supports our view that Beer's approach does not cover viability (Nechansky 2010a), but just deals with a form of complex controller structures.

Let us explore next the possibilities for interactions between a living system and its niche that result from these developments.

8. Interactions of living systems with a niche: coevolution

8.1 *The base for interactions between a living system and a niche*

From our analysis of the structure of living systems and its possible evolutionary developments, it follows that available functions and possible behaviour in a niche are closely interrelated.

1. Matter/energy processing systems without controllers depend widely on 'paradise' (Section 5.1). In scarce environments, storage may help for a while.
2. The interactions of living systems having controller structures with their niches depend on the availability of certain sensors.
    (a) Internal sensors for existential conditions (such as temperature and pressure) allow a system to search places in a niche (Sections 5.2 and 5.4) where conditions are favourable. All other threats to their structure (e.g. X-rays and radioactivity) remain unknown.
    (b) Internal sensors for existential needs (such as hunger and thirst) allow a system to search the niche for resources (Sections 5.2 and 5.4) where demands are met. Of course, it 'knows' only needs it can sense.
    (c) Sensors for external features (such as eyes and ears) allow a system to survey the niche and perhaps the environment beyond it, depending on their range (indicated in Figure 1). Of course, of all other features, a system remains ignorant (such as blind and deaf).

        Use of external observations has to be subordinated to the abilities according to the points 2(a) and 2(b), i.e. internal 'emotional' evaluations determine, if external observations characterize 'good' or 'bad' conditions; respectively, 'favourable' or 'scarce' availability of resources.
3. All higher level cognitive abilities (adaptation, learning based on pattern recognition, sequence learning, anticipation) can obviously only build on any available sensor systems according to point 2. But they need not be developed equally for all available sensor systems (e.g. external pattern recognition need not

come with any internal pattern recognition).

4. Finally, any cognitive abilities can only trigger the available actions of the effectors, which may set the limit for maintaining viability.

So any behaviour but mechanically ingesting available resources depends primarily on available sensor systems and secondarily on the internal complexity of data processing to steer available actions of effectors:

The three-sensor system discussed above can show all forms of behaviour we find in niches (Sections 5.1–5.4). With structures enabling system-specific adaptation and learning based on pattern recognition, it can develop individual behaviour towards observed external features. But we suggest that only with sequence learning in relation to external observations can a living system start to systemically improve its niche. Only then is it able to identify chains of cause and effect and can it recognize which actions lead to results serving its existential conditions and needs.

8.2 *Enhancing viability in unfavourable and scarce environments*

We do not consider here how the interaction of a living system with its niche can permanently change its environment, either by depleting it from its resources or by polluting it with outputs, and so can change a 'paradise' into an unfavourable and/or scarce environment. These developments can be precisely described with logistic *S*-curves (see e.g. Marchetti 1986, Modis 1994). Here, we just want to consider options to improve a niche that is already in such an unfriendly state.

1. In unfavourable environmental conditions, just the maintenance of favourable conditions in places (caves, houses, etc.) can help. This maintenance may need additional resources (e.g. to heat).
2. In scarce environments, there are some options to improve viability in niches.
    (a) Developing some *technology* can allow exploitation of new resources to produce useful matter/energy externally (this includes to use or to feed on other living systems) and/or to recycle matter/energy.
    (b) Increasing *efficiency* by reducing consumption is an alternative or addition to technology.
    (c) *Expansion* beyond a current niche is one option, when improvement within is not possible or not tried. Here, the long-term range of the niche is increased to exploit a larger region. Sensors systems (e.g. eyes) reaching beyond the niche (as indicated in Figure 1) can deliver data where to go.
    (d) *Symbiosis* (as called in biology) or *economy* (as called in human sciences) is another way to stick to a niche, by enhancing chances for viability across niches. Here, matter/energy is exchanged with other living systems in neighbouring niches.

    When technological improvement or expansion is not possible, further living in a scarce niche depends on establishing and maintaining such exchange relations. Let us mention at that point that most humans today seem to live in niches depending completely on such exchange relations. Here, the cybernetics of viability becomes a cybernetics of controlling flows in channels and networks. We say a few words on that in Section 9. Here, we just want to mention that development of far-reaching communication systems (as indicated in Figure 1), ranging from shouting via smoke signals to the internet, can ease that control.

The above options may be complicated and restricted, when living systems are bound to sheltering places, too, because the environment is scarce and unfavourable.

3. Finally, *migration* to another place or region is the last option, when all others do not work.

Now options 2(c) and 3 may lead and option 2(d) will lead to the next level phenomena: interactions of living systems. If expansion or migration leads into the niches of other living systems, we may get conflicts or hierarchies, while, respectively, technologies to support aggression or defence can enhance viability. On the other hand, maintaining a niche based on exchange requires cooperation, which will profit from any technologies to secure matter/energy flows in channels and networks. And all these interactions require regulations to control who has access to which resources. Here, we enter the world of social systems. We discuss their basic organizational options in Section 9, turning to the four modes of coexistence.

9. Interactions between living systems: social systems and the four modes of coexistence

So far, we have discussed necessities and options for the viability of single systems. Now, we move on to interacting living systems. Departing from Miller's notions, we do not speak of living systems any longer, but of social systems, which we understand as aggregates of two or more living systems.

We see this distinction as a very important to avoid errors of the logical type, which we think are contained in all theories not observing the set–subsets–elements character of social systems, with societies, subsystems like organizations or groups, and living systems as all their elements.

According to Russell and Whitehead (1910), logical types are constituted by a hierarchical order of the form set–subsets–elements. And errors of the logical type occur, whenever we try to draw any conclusions from the *properties* of the set to the *properties* of the subsets and/or the *properties* of the elements, or vice versa. Bateson (1956) showed how difficult errors of the logical type are to detect in communication, for very often the elements share *some* of the properties with the subsets and sets they belong to, but not all of them. So sometimes such conclusions seem right, while in other cases, they simply do not work.

Let us explain here, with three examples, why it is important to distinguish between properties of the elements and of the sets, i.e. here the living systems and the social systems they constitute.

Shared properties, which we can find in both living systems and social systems, are certain general *functions*, e.g. a highest level controller and lower level effectors. In an organism, we might call them a brain and e.g. a leg. In an organization we might call them, following Beer (1979, 1981), System 5 'policy' and a 'primary unit' of System 1, e.g. a man in charge of delivery. Or we might call them, taking an example from Miller and Miller (1990), 'top executives' and 'crew of the company jet'.

Yet, we find *totally different* properties *how exactly* such shared general properties are produced.

In the organism as well as in the organization, the highest level controller can order the lower level effector to act, e.g. to move. But in the living system, that is an *internal* data transmission of a trigger in an unequivocal data format. In the social system, that is an *external* communication, where the internal intentions of the man at the top have to be coded and sent as external data to the man at the lower level, where they have to be received, decoded, and understood. Accordingly, communication problems, impossible *within* living systems, prevail *between* them.

Second, in a functioning living system, the unequivocal internal trigger can have no other effect, but make the effector move. In the social system, the man in charge of the effector, even after having precisely understood the order, still has to make his *own decision* to actually trigger a movement.

Third, and most importantly, the effector as part of the organism shares with the brain the same *existential goal values* for the same existential conditions and needs. That definitely need not be the case with top management and the man at the lower level. But the existential goal values of that man will enter as his highest goal values into his decisions (Nechansky 2010b, and briefly discussed in Sections 6.3 and 7.3). So if the order does not sufficiently serve his goals, he will not follow.

Theories ignoring the aggregate character of social systems may have some explanative power, but will somewhere show errors of the logical type. Accordingly, neither communication nor decision problems nor goal conflicts can be derived from Beer's (1979, 1981) or Miller's (1978) approaches (and, as we can only suggest in passing, from many sociological theories in the Durkheimian, systemic tradition).

But a mismatch of the goal values of living systems is the point where all struggles in social systems come from. We showed elsewhere (Nechansky 2007) that there are just four ways in which two or more goal-orientated system can act to pursue their goal values – alone, or against each other in conflict, or in hierarchies, or with each other. We called them the four modes of coexistence.

1. Two (or more) living systems may live side aside, each one in its own *niche*.
2. Two (or more) living systems may pursue different goal values in one niche, entering a *conflict striving for the upper position in a hierarchy*.
3. A *hierarchy* results, if at least one living system has the power and/or variety of behaviour to force at least one other system to pursue certain goal values in its niche.
4. Two (or more) living systems may establish a *cooperation* by compromising on mutual goal values and sharing effort and results.

Above we discussed the options of single systems in their niches. Here, we just add that a living system need not interact with any of its neighbours, only if it lives in a 'paradise', i.e. an abundant and favourable environment offering all it needs. Only this is the base for complete individual 'freedom'. The living system may interact for other reasons, like reproduction or just fun, but on its own discretion and not for any reasons of dependence. Rousseau's (2009) 'noble savage' seemingly was able to live such a life. Any change from 'paradise' to scarcity or unfavourable conditions requires the efforts and/or interactions discussed in Section 7.2. This is the point of departure where all the technical, economical, organizational, legal, and political measures to maintain niches come from. And here, the cybernetics of viability meets the mythological metaphor of the 'expulsion from paradise'.

For the cybernetic foundations of the four modes of coexistence, we have to refer to Nechansky (2007). Let us discuss here how they come about and how the organization of a social system may finally show one mode.

The starting point is always the *individual decision* of a *single* living system how to pursue its existential goal values. It may try that (1) alone, as far as the resources in its niche allow that. It may try that (2) against others, to gain more resources. It may do it (3) subordinated to powerful others to gain something from the powerful or to avoid greater losses, defeat or death. Or it may try it (4) together with others. The resulting pattern in the social system depends on the *individual decisions* of all the *neighbouring* living systems.

1. All neighbours may stick to their niches, provided they find abundant resources there.
2. If just one of the neighbours decides for conflict, there will be conflict involving one or some others. This conflict may never end, may end undecided with all conflicting parties returning to their niches, or may end in a hierarchy.
3. An *authoritarian* hierarchy results if one individual is powerful enough to force one or more neighbours to pursue its goal values, and these are bound to a place or region for some reasons.
4. Finally, cooperation can only show as long as all individuals involved decide to compromise on mutual goal values, resources, efforts, and results.

This basic pattern is complicated by the fact that large numbers of cooperating individuals will reach a point where direct communication between them becomes impossible, because it starts to exceed their free channel capacity. Then, they will not be able any longer to coordinate and control their mutual efforts by themselves. Here a *coordinating hierarchy* with one or some leaders emerges as a cybernetic necessity (Nechansky 2008a). Now Lenski (1977) explicitly stated the easily overlooked obvious, that we always face a *scarcity of positions* at the top of hierarchies. So successful cooperation, which primarily avoids conflicts about favourable conditions and scarce resources in niches, can lead secondarily to conflicts about scarce leadership positions in a coordinating hierarchy. These positions in turn may again open the door to preferred access to exactly these favourable conditions and scarce resources. So successful cooperation can directly lead to the next conflicts, which, of course, depend again only on *individual decisions*, now of leaders and followers. These individual decisions, e.g. if and when a leader switches to conflict by deciding to use his privileges to pursue his personal goals against the interests of his subordinates, or if and when these stop to follow, are in no way predetermined. These individual decisions make the overall process unpredictable.

Finally, authoritarian and coordinating hierarchies can lead to ever larger social units, such as organizations, communities and states. All these social units face again the same possibilities of interaction, to pursue their goals alone, against others, subordinated to others, or together. Now an emerging pattern or a prevailing mode of coexistence between social units depends again on *individual decisions*, here on the decisions made within all the neighbouring units. But the power to decide tends to shift from the members to the leaders of these units. Anyway, these individual decisions remain unpredictable.

And now we have a dense, but quite complete overview on the cybernetics of viability.

Let us finally say that with this cybernetic view emphasizing individual goal orientation and decision making, we tend towards a Weberian (Weber 2008), individualistic and against a Durkheimian (von Beyme 2007), systemic view of society. And we contradict the view that social systems would be ‘self-organized’ or even ‘autopoietic’ in Luhmann’s (1987) sense, where communication systems stripped of any individual goal-orientated intentions should have any shaping effect.

We see the emerging organization of social systems (Nechansky 2008b) as the result of the sum total of the individual decisions of all involved livings systems, how they pursue their individual existential goal values. If their niches are not favourable and abundant, interactions become a must. If interactions do not lead to cooperation, Ashby’s law will prevail shortly. If cooperation is pursued, Ashby’s law will prevail later. Ashby’s (1957) fundamental *law of control*, that the system with the most power and variety of behaviour will dominate all other systems, determines social systems, too. Calling that 'self-organized' or 'autopoietic' either naively overlooks or intentionally veils the *goal-orientated* power struggles *to control* favourable conditions, scarce resources, and/or scarce positions, leading to the pecking orders of animal species and the social stratification of human societies.

10. Discussion and summary

10.1 *A second look at the systems theories dealing with viability*

After developing our approach, let us have a second look on the theories we briefly introduced in Section 2.

1. We agree in principle with Bunge's (1979, 1985) 'Biosystemism', that all phenomena of life must finally be related to chemical processes, even if we did not get down to chemistry in this paper. We relied here on Miller's (1978) approach and on its grounding in biochemistry.

   But we have to reject two of Bunge's (1979) postulates for biosystems, namely that adjustment to the environment and competition or cooperation would be constituting principles of life. We suggest that early forms of life basically can just feed or not feed, while adaptation emerges later, demanding on already quite complex cybernetic structures (see Section 7.3). And we see competition or cooperation only then as necessities, when there is scarcity in niches and migration is impossible (see Section 8.2). They are not necessary in any 'paradise', which we see as a precondition for the emergence of life (see Sections 5.1 and 7.1).
2. We can only sketch here the differences between cognitive autopoietic theory and our cybernetic approach, which still require detailed elaboration:

   We doubt the basic assumption of cognitive autopoietic theory (Maturana 1970, 2002, Maturana and Varela 1980), that considering just single nerve cells and ignoring the structural and functional interaction of more such cells, allows us to draw valid conclusions about the cognitive power of whole living systems. We think that approach just leads, too, to errors of the logical type. But here, we can illustrate our objection only with simple examples: a single sensor cell can just observe a punctual phenomenon, but already two can observe a basic 'left–right' distribution (e.g. 'light–dark'). And a single nerve cell can never register and store a development in space and time, but already two can, when the first is excited before the second and they develop a directed synaptic connection leading from the first to the second; this can map a development in space ('left–right') and in time ('first–second'). So already with these abilities emerging with the combination of just two cells, we leave behind the limiting chemical determination of the single cell, which is the base of Maturana's approach to cognition.

   At the core, our approach is precisely the investigation of such combinations. But we start with certain functional elements (sensors, channels, memory, etc.) which may but need not be biological cells. The appropriate combination of such functional elements can lead to feedback systems, the simplest cybernetic structures (Nechansky 2006), which already can carry out processes going beyond the limited abilities of their components. Feedback systems can be expanded to give ever larger controller structures, provided certain design rules are met (Nechansky 2009). So we get to increasingly complex structures with emerging cognitive abilities (see Section 7.3 and the references therein), which can neither be explained by the abilities of their functional elements nor their mutual structure, but only by (1) the processes the structure enables and (2) how these are actually individually realized in interaction with a niche. We emphasize that these different emergent abilities are the first main differences to cognitive autopoietic theory.

The second differences concern that we maintain that the decisive activities of controller structures, i.e. making situation-specific decisions for goal-orientated actions, require *representations* of observed objects, fulfilling certain criteria of correspondence (Nechansky 2009, 2010c).

Let us illustrate all that with our simple example: we maintain that two sensors can deliver a *representation* of the basic 'left–right' (e.g. 'light–dark') order of an observed object. If this representation is persevered with during data processing, it can be used for control, i.e. decisions for goal-orientated actions. Maturana himself was involved in showing that the nerves leading from a frog's eye to its brain, thought twisted on the way, deliver to the brain an exact topical mapping, including the 'left–right' order (Lettvin *et al.* 1959). Luria (1992) discusses the corresponding 'somatotopical' data processing in the lower levels of the brain. Now we need such representations for successful decisions for actions: e.g. to hit an observed *external* object on the 'right' side with a chance of 100%, the *internal representation* of 'right' used to *internally* trigger the action to hit the 'right' side must correspond to the actual *external* 'right' position. Without such an internal representation corresponding to external facts, the chance to actually hit the 'right' side (and not the 'left' one) could not be higher than 50%. That would be a weak base for viability.

This short argument has to suffice here to highlight the theoretical and particularly the epistemological differences between our cybernetic approach and cognitive autopoietic theory. We already mentioned above our objections to Luhmann's (1987) application of autopoietic theory to sociology.

3. We see Miller's (1978) approach as an excellent base to comprehend living systems understood as *organisms*. Our approach is indebted to it and builds on it by adding how Miller's minimal controller structure may evolve.

   We think Miller's approach looses accuracy on the lower levels of living systems as well as on the levels of social systems, because of the element–subset–set problem discussed above.

4. We think Beer (1979, 1981) provides an excellent general systems approach to organizations, making explicit important issues of management. But we suggest its proved success in this field has to be clearly separated from its claim to show cybernetic necessities of viability.

   Viability presupposes sufficient conditions and resources for matter/energy processing systems in niches. Based on that, different controller structures can emerge and evolve. Beer's complex structures may be a form of them, but viability neither presupposes nor needs them.

5. In Aubin's (1991) approach, we cannot find many crucial aspects of viability.

Aubin does not address the necessity of matter/energy supply for his controller. In a living system with a controller, the controller has to maintain a constant energy supply in the matter/energy supply part, by acting on a niche within an environment. This is a four-system problem, with the first acting on the third within the fourth, to maintain flows of matter/energy into the second and from their to itself (!). Even in Aubin's more advanced approach we find only three systems (controller, controlled system, and environment), and no such flows. So Aubin seems to provide more of a generalized theory of technical control, but less of viability.

10.2 *The cybernetics of viability*

In this paper, we introduced the following additions to the existing theories of viability.

(1) We introduced the notion of the niche, understood as the region within the environment that is within the reach of the *actions* of a certain living system. The niche has to provide sufficient conditions and resources to maintain certain matter/energy processing systems.
(2) We showed that matter/energy processing systems producing more matter/energy than necessary to maintain themselves are a prerequisite for any addition of controller structures.
(3) We showed that a controller structure with three different sensors is prerequisite for behaviour actively searching for favourable conditions and appropriate matter/energy supply in niches.
(4) We briefly discussed how the evolution of controller structures can improve such behaviour, suggesting that sequence learning is the prerequisite for any goal-orientated change of niches.
(5) We discussed how living systems can enhance their viability when facing scarce environments. This led us to the phenomena of technology, expansion, economy, and migration.
(6) When these phenomena lead to interactions with other living systems, social systems emerge, which we understand as aggregates of living systems.
(7) The emerging organization of social systems results from the sum total of the individual decisions of all involved livings systems, how they pursue their individual existential goal values. These decisions lead to a prevailing mode of coexistence, i.e. retreat in niches, conflict, hierarchy, or cooperation.
(8) Emphasizing that individual decisions determine the prevailing mode of coexistence in a social system, we explained the unpredictability of societal organization.

What we did not discuss here is the *emergence* of living systems and particularly of the matter/energy processing systems, which is a prerequisite for controller structures and therefore for the cybernetics of viability. And we did not address the *reproduction* of any emerged structures. So we did not deal here with two further important aspects of viability. But we do hope that we could clarify some important aspects, what existing living systems with certain controller structures can do and have to do to maintain their viability.

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