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# ENTROPY – OUR BEST FRIEND

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*We are the mirror as well as the face in it.*
*We are tasting the taste this minute*
*of eternity. We are pain*
*and what cures pain, both. We are*
*the sweet cold water and the jar that pours.*
Rumi

## SUMMARY

The paper tries to tackle the question of connection between entropy and the living. Definitions of life as the phenomenon that defies entropy are overviewed and the conclusion is reached that life is in a way dependant on entropy – it couldn't exist without it. Entropy is a sort of medium, a fertile soil, that gives life possibility to blossom. Paper ends with presenting some consequences for the field of artificial intelligence.

## KEY WORDS

entropy, autopoiesis, life, living systems

## CLASSIFICATION

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## WHAT IS LIFE?

The aim of the present paper is search for new understanding of the role of entropy in connection to life and showing some consequences that arise from this. If I want to reach this goal, I have to start by listing some of the most common answers to question “What is life?”

In searching for the principal, determining characteristic of life we normally tend to slip into the enumeration of its vital functions like metabolism, reproduction, growth etc. Karl von Frisch's book “Du und das Leben” from the year 1949 is an example of such an approach. The deficiencies, or at least borderline cases (crystals, viruses, the planet Earth…), of such definitions are not hard to find. Looking for the characteristic functions of living organisms is important for medical and some biological purposes, but it does not tell us enough about the phenomenon of life itself.

Maturana and Varela [1] characterise the prevailing attitude of contemporary biology to the question of life as a combination of the physical-chemical and evolutionary approach. The first one explains biological processes from the point of view of chemical reactions going on inside living organisms. It focuses on processes such as cellular respiration and metabolism, the synthesis of proteins and also the genetic code, which is supposed to contain all information necessary for the synthesis of proteins and for life and the development of the organism in general. The second approach explains the emergence of biological processes as the result of random variations of the genetic code and natural selection of the phenotypes in which the genetic information gets realised. The first line of thought considers its basic biological unit to be the gene, for the second one this is the species[1].

Maturana and Varela [1, 2] do not question the physical-chemical foundation of living systems nor their gradual development through continuous interactions with the environment. They only doubt that the units of research selected this way (genes, species) could present us with a basis for our understanding of what is life in its essence. They claim that the question: What do all living systems have in common that makes us classify them as living beings? remains unanswered and always tacitly present somewhere in the background, even if most biologists tend to avoid it [1; p.74].

It is interesting that one of the most influential works on the question of life had not been written by a biologist but by a physicist. In his book “What is Life?” Erwin Schrödinger [3] presents a view of life starting from an utterly different perspective from contemporary biology. He takes into account the uniform nature of living beings, by which he manages to avoid reduction. Schrödinger suggests the following answer to the question: When do we consider something to be alive?;

“When it ´feeds´ on negative entropy.” [3; ch.7].

The theory that living beings create negative entropy (the so-called syntropy or negentropy) has been picked up and developed in the last decades by the chemist Ilya Prigogine in his concept of *dissipative structures* (see e.g. [4]). A similar conception of the living can also be found in the work of one of the forefathers of cybernetics – Heinz von Förster, who compares living beings to the Maxwell demon in order to present the idea that living beings are actually entropy-retarders.

It is important to notice that in all the variants of the described theory the basic units of research are living beings in their entirety and not just one selected function or process (e.g. reproduction or metabolism). If the entropic definition of life is to appear plausible, we cannot consider living beings to be closed systems, as in such systems entropy can only grow or remain unchanged.

Living beings therefore must be open systems. But despite the fact that they are open, they are nevertheless also clearly separated from the environment in some way. This separation is, ontologically speaking, much stronger than for example the separation of the dewar (which can be considered to be an approximation of a closed system) from its environment. Thus, living systems are not closed in terms of the exchange of energy and matter, but they are "closed" in terms of preserving their identity. To emphasise these distinctions, Maturana and Varela distinguish between structurally and organisationally open or closed systems. Living organisms are thus structurally open and organisationally closed systems.

Schrödinger gave an expanded entropy equation for this kind of systems: $dS = d_eS + d_iS$, where $dS$ stands for the entire change of entropy of a living system, $d_eS$ stands for the flow of entropy through the system and $d_iS$ stands for the production of entropy inside the system due to irreversible changes occurring in it. While the diS member is always positive, the $d_eS$ member can also be negative and in its absolute value bigger than $d_iS$, meaning that the entire change of entropy in an open system can be less than zero. Thus, an open system can change in the direction of increased orderliness. Of course, this ordering in open systems feeds on the order of the (closed) wider system, which contains these open systems – namely, the environment. This containing system still change in the direction of lesser order according to the second law of thermodynamics. The increase of entropy represents the flow of entropy that has negative value from the point of view of the contained open systems and enables them to increase their inner order.

Under certain circumstances open systems can continuously perform work. For a system to be able to do that, it must not be in the state of stable equilibrium, rather, it has to "search" for such equilibrium [5]. Let us consider Bertalanffy's example of the water reservoir with high potential energy: one might open the reservoir and the water would start flowing from it in the direction of lower potential energy until it would reach a state in which its potential energy could go no lower (the state of stable or at least local equilibrium). In the meantime, it could perform some work, for example, it could make a turbine go. But it is obvious that this performing could only last for a limited period of time.

## IN WHAT STATE SHOULD A SYSTEM BE IN ORDER TO PERFORM WORK CONTINUOUSLY?

That is the key question. Let me explain why: In the second part of his autobiography Karl Popper included a chapter entitled "Conversations with Schrödinger" [6]. In this chapter Popper challenges Schrödinger's definition of life (that which "feeds" on negative entropy) with the claim that also a common oil stove or a self-winding watch can do that. Therefore, that cannot be the defining characteristic of life. Schrödinger answers that living beings remain in the stationary state of relatively high orderliness (i.e. low entropy) by continuously extracting order from the environment (and are thus continuously capable of performing work).

The realisation that living beings are structurally open systems that can lower their inner entropy on the credit of the environment is important, but it is even more important to find out how they (we) manage to do that *continuously*.

The answer is: Structurally open systems have to search for the state of stable equilibrium, but in order to do that they must constantly remain outside that state. The systems succeeding in this are far from the so-called thermal equilibrium. The imperfective aspect of the verb "to search" implies a major change in our line of thought. We are dealing with systems whose goal is not to reach a given state, but to continue *searching for such a state*. The most appropriate way of describing them is perhaps the Zen saying: *the path is the goal*. In the rest of the paper I will reflect upon such searching systems.

## NEGOTIATING

The state in which we find structurally open systems capable of continuously performing work is called the stationary state. The term “stationary” is perhaps not the most appropriate, since the described systems are actually constantly in motion. Stagnation would mark the change of their organisation and thus their identity. Naturally, their mobility cannot be of just any kind – it has to be *regulatory*. The characteristic variable (variables) of the system has to be maintained inside of given delimitations. Like a rope-walker, who has to keep balancing herself. The rope-walker “functions” far from the state of balance – the finding of a balanced position for her would mean certain death (or at least unspectacular messing around in the safety net).

Exactly the same goes for living beings. They need to balance fixation and flexibility. Just as adaptation to a given life-space is essential, so is the permanent fluidity. If the system became completely fixed, it would not only lose its “stationary” organisation, but it would also become unable to preserve its dynamic stability with the environment. The importance of this conclusion cannot be overemphasised. I believe that here we touch upon the principal pattern, characteristic of living systems. As we can see, the decrease of entropy or the preservation of available energy inside the system is not a finite task (one that has a reachable goal). It is vital that the system *persists in doing this*.

The linear way of thinking that we are used to cannot handle the imperfective aspect of the described process very well. If we take it, for example, that “searching” is the essence of the described systems, one would imagine a system searching for something and once it finds that thing, its task is done. Searching (like all other processes which can be described reasonably well) is a linear thing. It is a process with a beginning and an end and a transitory function: from *x* to *y*, from the problem to the solution. This roughly depicts the view on life (and cognition) held by prevailing approaches in artificial intelligence: living beings are supposed to be a type of so-called autonomous agents (entities that can solve problems in changing environment).

But the “searching”[2] as described here is intrinsically imperfective. We do not search to find, but *to keep searching*. Once we find it, we are lost. Obviously, the process in question is recursive and circular. We seem to have problems with describing it. (Zen koans appear to be the most appropriate way of doing this).

### “A MISTAKE IS NOT AN ERROR” [7]

Before I go on, let me indicate one of the consequences of the described pattern. Pask characterises it with the sentence: “A mistake is not an error.” [7]. Continuous, self-centred “searching” (or “testing”) which enables us (living systems) to survive is also reflected in our experiential world. In this perspective, the “imperfections” found in any performing or concept (if we only delve deep enough analytically) prove to be necessary. The “fuzziness” of borders, indeterminacy and similar “bugs” are not just signs of a momentary incapability or lack of precision of the observer (or deficiencies of the theory), but a reflection of the amazing property of living (in this case also conscious) beings, which allows them to continuously adapt to a changing (entropic!) environment.

This ability of constant manoeuvring, this continuous search for equilibrium that is an aim in itself (I hope that the recursion here is obvious) is called *negotiating* by Varela, Thompson and Rosch [8]. The authors believe that this ability of living beings *to negotiate their way through a world*, which is “not pre-given and determined, but *constantly formed by a series of actions, which we engage in*, is a necessary condition for a richly interlaced and independent experiential world” [8].

## LIFE IS A SYSTEM-PROCESS (SYSTEM-PHENOMENON)

An aeroplane is an aeroplane whether it happens to be flying at the moment of observation or not. Similarly, a computer remains a computer also when turned off. The organisation of its components, that is, the network of its internal relationships due to which we classify such a system as a computer (the identity of the system) is independent of whether the entire system is operational (performs certain operations) in a given moment or not. In living systems, the situation is completely different[3]. They must function constantly in order to exist. Their identity is therefore determined by their functioning or dynamics and not their structure. We can thus conclude that *existence is the only really important product of the functioning of living beings*.

In order to understand the nature of living systems, we must establish *a double view* [9], which allows us to see the pattern and the components through which it is embodied at the same time. Besides, this living system cannot be observed non-temporally – a frozen picture (i.e. only by exploring its structure) cannot tell us whether the system in question is indeed alive or not.

At this point we could ask ourselves: Is life a phenomenon? Is it perhaps a characteristic of a system? Or is it a particular kind of dynamics, which can "happen" to a particular type of systems? The answer is hard to find, since (in scientific language) there exist no appropriate categories for describing such phenomena. Life is a combination of dynamics and entity (structure) that changes. It is neither structure nor process, it is structure-process. Consciousness is neither body nor mind, it is body-mind. We are dealing here with indivisible wholes, composed of two levels: dynamics and structure that gets realised through it. More accurately: if we divide them, their essence is lost.

The scientific language endeavouring to follow as much as possible the ideal of the mathematical-logical language, does not include any appropriate structure for dealing with that. In logic there exist entities (logical variables), their properties and relations between them. In mathematics we find mathematical structures, their properties, relations between these structures and an active part in the form of functions. But there is no possibility of describing a structure-process. Because of that, the scientific language must necessarily objectify living beings (and from here the next step of trivialization is just around the corner). Now we can understand why Maturana and Varela felt a need to create a new language [1], which would be capable of dealing with circular phenomena (or better structure-phenomena) of the living world.

Exploring the properties of the living is not the only area affected by the deficiencies of the existing scientific language and concepts. A widely known example is also the problem of quantum physics undecided about how to classify quantum entities. These manifest a "double" nature: they have some properties of "proper", "normal" particles, but on the other hand they also show wave properties (a wave is *a pattern* of dynamics, a non-material thing). The problem was solved by de Brogli through coining the term *wave-particle* (and an appropriate mathematical formalisation – the de Brogli wave equation). Thus physics was forced to accept a completely new type of system – *a system which remains what it is only so far as it keeps doing what it is doing*[4]. A similar problem was encountered by computer experts who solved it in a pragmatic way, by introducing the so-called object-oriented languages in which the definition of some of the variables includes also their properties and functions.

*Thus, life is a wave-particle, or rather, a structure-process*. A living system remains alive as long as it has this double nature – "double" only from the point of view of the linear analytical-reductionist thinking. From a cybernetic point of view, the structure-process is a basic unit. And the conclusion from chapter two applies to it: if we "cut" it, the creative circle is broken and with that the domain it used to create is lost.

The above insight also suggests that life is a continuous process that cannot be interrupted. Thus, "turned off" living systems are the impossibility.

## AUTOPOIESIS

It is quite obvious that the standard (scientific) vocabulary does not include an appropriate term for describing the imperfective process of searching for equilibrium or negotiating. There is also no model available to account for such processes. Let us take a look at what can actually be stated about them:

Since we are dealing with a repetitive process "curved on itself" it is safe to assume that there is recursion involved at some point. In the language of cybernetics, one could say that we are dealing with a self-regulatory system with a feedback mechanism. The big question is, of course, what are the elements of this mechanism and mostly – what is the essential variable preserved by the system. In the case of living beings, this feedback mechanism cannot be considered to have been "programmed" from the outside in order to regulate a certain variable (as in the case of the thermostat – heater system), but a loop functioning autonomously. This means it is also independent in "selecting" its manner of functioning.

This is exactly what Maturana and Varela had in mind when coining the term autopoiesis to describe the essential characteristic of the living. Autopoietic systems are those (auto-regulatory) systems, which preserve their own auto-regulatory nature. Thus, they do not preserve some externally prescribed parameter (e.g. the temperature in a room), but their very own manner of functioning. Notions such as "nature" or "manner of functioning" are mere approximations and do not describe the essence of autopoietic systems too well. That is why Maturana and Varela used the notion of organisation. Autopoietic systems are those, whose organisation has the property of preserving itself (*auto-poiesis*: self-production).

According to Maturana and Varela, the organisation of the system determines its class identity and must remain unchanged if this identity is to be preserved. From the point of view of organisation the concrete realisation of the components of the system is of no importance. What matters are only the abstract characteristics of the system and relations between them, which make this system belongs to a particular class. We can see that for most systems organisation is determined from the "outside", i.e., by the observer. But there is an exception, autopoietic systems determining their identity (organisation) by themselves. And this self-defining is the source of their autonomy, according to Maturana and Varela.

### BACK TO THE CONNECTION BETWEEN ENTROPY AND THE LIVING

The autopoietic theory is consistent with Schrödinger's thesis of life as that which defies entropy. Both theories discuss the living system as a closed system separated from the environment by its activity. This activity is self-preservation. While Maturana and Varela determine the meaning of this term, they do not explain how the emergence of such a system comes about nor what are the elements of the feedback mechanism that keeps living beings going in a state far from thermal equilibrium (i.e. maintains their flexibility – openness – while at the same time fixes them). I am afraid that also the present article will not solve these problems. But it can at least give it a try.

When talking about the autonomy of living systems that does not mean that a living (autopoietic) system could function without the environment. An autopoietic system is *structurally open and organisationally closed*. The above connection between the Schrödinger's definition and the autopoietic one renders another essential bond between the system and environment: the (entropic) dynamics of the environment allows for the autopoietic dynamics of the living system. If we "turn off" entropy, we also turn off the conditions for life.

The state of continuous searching (negotiating) can be reached only through the co-operation of two opposing forces. At this point we can think of the numerous examples of "self-propelled" feedback systems offered by cyberneticists.

## ARTIFICIAL LIVING SYSTEMS?

Černigoj [10] defines autopoietic systems as

"any form of auto-regulation based on auto-regulatory systems, the recursive parameter of which is the organisation of the system inside which this auto-regulation takes place".

This definition emphasises the ability of the systems in question to dynamically change their own structure and with it also the auto-regulatory *mechanisms* (which are considered to be something static, what in the language of cognitive science would be designated as hard-wired). According to Černigoj, auto-regulatory processes allow for the self-organisation of the system and with this also for its non-trivial adaptation to the environment. This implies that the system is capable of *creating novelties* through which it can adapt even to unpredicted changes in the environment (which is non-trivial itself!). An auto-regulatory system that could balance the states of its recursive parameters exclusively by auto-regulatory *mechanisms* would be, by definition, incapable of such adaptation, since the essence of auto-regulatory mechanisms lies in the fact that they are based on pre-existing arrangements. Auto-regulatory mechanisms can compensate only for the disturbances the compensating of which they were intended for (when speaking of man-made auto-regulatory mechanisms) or those to which they are adapted (when speaking of naturally evolved auto-regulatory mechanisms). But we should keep in mind that from the point of view of an individual organism these adaptations exist as predetermined biological facts, whose philogenetic development is possible only due to the auto-regulatory processes working in the background.

In other words, the autopoietic organisation enables the system to change the strategies of its functioning. This is possible because the only constant in an autopoietic system is its organisation (i.e. its capability for preserving its capability of preserving its capability of preserving…). As long as this goes on, the system can change its structure and manners of functioning. An autopoietic system has no other "task" but to preserve its organisation. Its behaviour is of a negotiating character; one could say that given segments (bodily or temporal) of its being perform certain tasks, but if we look at it as a whole, we see that their only "task" is to endure. There is no way of telling if autopoietic systems have any other task (or if they are saving particular "problems", as can often be heard in the field of artificial intelligence).

This fact has far-reaching implications. Understood this way, the notion of autopoiesis implies that it is impossible to artificially create a system embodying this type of organisation! How are we supposed to design a robot or a computer programme whose only duty is the preservation of its preservation of its preservation…? (The task of a robot is always to fulfil the orders of its programmer.) It is a big mistake on the part of the researchers of artificial intelligence and artificial life *to set their systems inside a trivial environment*[5], *an entropy-free environment* (usually, that is some sort of a virtual world in a computer). As we have seen, entropy is not an enemy to life but rather a stimulus allowing for its constant battle, constant search for new forms of auto-regulation and adaptation (the task of which is again searching for new ways…). Entropy would represent an "enemy" or a problem to be "solved" only in case if life were a perfectly linear thing (in which case the solution would be quite simple. We could, for example, make a simple vacuum container, put a stone inside it and we would thus have made a system capable of defying entropy changes for a very long time). Fortunately, it is not so. Entropy or the imminent danger of decomposition, of death, of the termination of the autopoietic organisation is, so to speak, a necessary condition for the preservation of life.

It would appear that entropy in some way exists on a similar level as life itself – on the level of gestalt. Let us consider the following: (just like life) entropy as such cannot be modelled. We can model, for example, gas diffusion, we can model random increase of disorder etc. But the very essence of entropy is impossible to grasp. From this point of view, it would appear that life and entropy go hand in hand at some invisible level, only the reflections of which are visible to the scientific eye.

Thus, artificial systems are not located in an entropic environment. The first thing that comes to mind is, of course: then let us build an entropic environment and set our "living" software inside it. But as mentioned above, it is not as simple as that. It seems that building an artificial entropic system is just as complicated as building an artificial living system. As I mentioned before: we are able to model some of the effects of entropy, just as we are able to model certain processes of life. Thus, we are able to counterfeit *the appearance*, but not the autopoietic organisation itself. This mistaking of the appearance (of the structure) for its organisation (identity) is called the "PacMan sindrome" by Riegler [11]. Programmers, who want to create conditions as "natural" as possible for their artificial agents, tend to build *a priori* determined concepts into them. Artificial agents thus enter into interactions with man-determined entities such as "food" and "enemy", who make sense only to the programmer of the system. Doing so, they ignore questions like: How did the organisms get the idea that a given type of entity represents food? How can they "know" that some other being is a dangerous opponent? Beasts do not come equipped with little signs saying "I am your enemy". And even if they did – how could cognitive beings manage to learn to understand the meanings of such signs? Autopoietic systems create system-independent inner states or "meanings". But artificial systems are unable to create their meanings.

Another possible solution would be to expose our programme (or robot) to real/natural entropy. And here is where we notice the disadvantages of Schrödinger's definition and the advantages of the one formulated by Maturana and Varela. Maybe we could create an autonomous agent capable of changing its parts once they malfunctioned. But this would still not mean that we are dealing with a living system. It would still be a robot given a particular task (set by the programmer!). By its functioning it would not constitute itself as an ontologically separate unit. Living systems are autopoietic, meaning that they keep constituting themselves – not only in the physical sense but also in the sense of constituting themselves as ontological categories which get separated from the rest of the world exactly because of this self-constitution. Living systems preserve their organisation, but organisation cannot exist without a structure to be embodied in (this is what I was trying to point out when mentioning the "double view"). Entropy presents a constant threat to this structure and thus provides an opportunity for the autopoietic organisation to get realised.

## CONCLUSION

Let me try to give a conclusion based on what was said previously:

*Living systems must function in a non-trivial (entropic) environment. Non-triviality of the environment is a necessary condition for preserving the negotiating nature of living/autopoietic systems.*

Entropy allows for a constant dynamics of living systems, the existence of which is obvious just as long as they remain active. A constant threat of decomposition, chaos and destruction is what keeps us going. We fight against them all our lives, but nevertheless they are our best friends. They are our allies making our existence possible, for this never-ending battle is just what life actually is.

## REMARKS

[1]One of exceptions is perhaps Dawkins who tries to combine both aspects in his theory of the selfish gene and severe criticism of non-evolutionary conceptions.

[2]An alternative term would also be „striving“.

[3]Let us consider the possibility that what was said in the above paragraph is wrong and we could make an artificial living being. Can you imagine switching such a creature off (just for the night, not to spend too much energy)?

[4]Whenever they can, physicists still talk about the “double” nature of “particles” and they are still irritated by the fact that they are unable to determine exactly both the position (a quantity defining the physical component) and the speed (defining the “kinetic” component) of such particles.

[5]A mistake also made by Varela who claimed that his cellular automata programmes, that simulated the organisational closure, were autopoietic systems.

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# ENTROPIJA – NAŠ NAJBOLJI PRIJATELJ

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## SAŽETAK

U radu je naznačeno pitanje povezanosti entropije i života. Definicije života kao pojave koja proturiječi entropiji su analizirane. Zaključeno je da je život na određeni način ovisan o entropiji – jer bez nje ne bi mogao postaojati. Entropija poprima značenje vrste medija, plodnog tla, koje omogućuje razvoj života. Članak završava prezentiranjem dijela posljedica za područje umjetne inteligencije.

## KLJUČNE RIJEČI

entropija, autopoiesis, život, živi sustavi