# THE NON-DECREASING CHARACTER OF COMPLEXITY: A BIOLOGICAL APPROACH

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**Abstract:** The overall information processing capacity of an organism is proposed as a conceptual criterion for its complexity. The apparent tendency of complexity increase during the course of evolution is accounted for in terms of positive feedback mechanisms. Furthermore, the different modes of evolution of biological complexity are identified as: The ongoing appearance of more complex species in case of abundance of resources, pausing of the complexity increase when the limits of the resources are reached in a relatively isolated environment, and the extinction of some of the complex species due to lack of sufficient resources. All arguments concerning the definition of complexity and its non-decreasing character are based on concepts like information processing, maintenance of organisation and the related energy expenditures. As a result of these arguments it is concluded that complex adaptations have a teleonomic nature.

**Keywords:** Evolution, complexity, information, energy, teleonomy

## 1. Introduction

Within the last decades science has been dealing increasingly with the concept of complexity, which gave rise to controversial approaches and measures (Horgan, 1996). Particularly when viewed within the realm of biological evolution the controversy becomes even more obvious. In spite of all, there exists one intuitive consensus that indicates the somehow increasing character of complexity during the course of evolution. The main goal of this paper is to make a preference among the possible criteria of complexity such that a consistent argumentation for the non-decreasing character of complexity can be provided.

Before going into a discussion about biological complexity and its characteristics it is worth giving some basic concepts related to biological evolution.

Evolution is a process of becoming. It produces new designs not from scratch but by adding upon what is available at hand. Hence the same building blocks are used over and over again by newly emerging species. These building blocks refer not only to material structures but also to organisational ones. This kind of "build-upon-latest-version" principle is referred to as **tinkering** (Jacob, 1982).

In living organisms tinkering is realised as an emergent self-organisation, which eventually may create new higher order organisational levels. The creation of such an

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organisational level is referred to as a **meta-system transition** (Turchin and Joslyn, 1999). During the course of evolution complexity increases by successive meta-system transitions giving rise to nested **hierarchical** (organisational) **structures**. In spite of their nestedness each of the different meta-system levels has its own dynamics and rules, which emerge with the self-organisation process. Due to this very structure, when discussing some features of organisms, one has to pay special attention to be conscious and explicit about which meta-system levels of the organism are being referred to.

Tinkering brings forth a kind of inter-relatedness between different species. In fact, the so called "different" species are not so different, not only because they share common ancestry and building blocks as a result of evolutionary tinkering, but also because of their "**co-evolution**" even after they phylogenetically diverge. Having evolved by taking one another as reference, living (and even extinct) species together comprise the unity and wholeness of the phenomenon of life in space-time.

This unity, which is a consequence of co-evolution and tinkering, implies the **self-referentiality** of life from its simplest to its most complex level. The concept of self-referentiality seems in contradiction with the standard physicalist positivist epistemology. This contradiction can be resolved in view of the dual principle governing change as given in (Schwarz, 1997): "The first part of this (dual) principle is the general trend of the physical objects toward the more probable, which is formalised by the spontaneous increase of entropy of isolated systems; the second part (of the dual principle) is the existence of a relation obstacle to this trend, which is circular causality, i.e. operational closure and self-reference... A system, which is capable to resist the global physical trend toward disorder and uniformity must have in its logical organisation some feature, which enables it to compensate for the destructive effects of entropy's increase. This feature, to be found in the logical plane of relations, is operational closure: The existence of closed loops in the network of its organisation, loops that can be followed on and on, as time flows."

A self-referential phenomenon with weakening external causality, tends to become more and more authentic and ultimately an end in itself. This condition is closely associated with **teleonomy**. Jacques Monod, in his eminent work (Monod, 1971), has suggested teleonomy as a key feature that defines the living:

"Every artifact is a product made by a living being, which through it expresses, in a particularly conspicuous manner, one of the fundamental characteristics common to all living beings without exception: That of being objects endowed with a purpose or project, which at the same time they exhibit in their structure and carry out through their performances (such as, for instance, the making of artifacts)."

"Rather than reject this idea (as certain biologists have tried to do) it is indispensable to recognise that it is essential to the very definition of living beings. We shall maintain that the latter are distinct from all other structures or systems present in the universe through this characteristic property, which we shall call teleonomy."

The word teleonomy, derived from the Greek word *teleo*: "to finish", "to bring to an end", refers to "the quality of apparent purposefulness in living organisms that derives from their evolutionary adaptation" (Online Webster Dictionary).

## 2. A Discussion of the Nature of Biological Complexity

Complexity, being used both in daily life and in scientific contexts in various ways, is a quite fuzzy concept. A distinction, which will reduce this fuzziness to some extent, is the one between the complex and the complicated.

We use complexity to denote the degree of organisational nestedness of a system. **Complexity** defined as such implies the existence of multiple meta-system levels within the system and the hierarchical relations among these levels. On the other hand, we use the term **complicatedness** to indicate the diversity of components at a single meta-system level. Consequently, these two terms are not easily comparable, although related. However, this relationship is not a simple linear one. As a matter of fact, it is quite common that the increase of complexity in a system gives rise to a simplification (reduction of complicatedness) in one or several meta-system levels.

Given these definitions, Shannon's information measure (Shannon, 1948) turns out to be more adequate for assessing complicatedness of a single meta-system level, whereas it is not suitable as a measure of complexity of an organism unless it is improved to account for different hierarchical levels.

### 2.1 Measures of Biological Complexity

In the literature there exists a variety of attempts to define biological complexity. Among them there is a widely accepted one that considers complexity as a property confined to physical structure of the organism alone. This opinion that complexity must be divorced from behaviour is a fruitless one. Just the contrary, the only favour that complexity can do to its possessor (speaking in terms of Darwinian fitness) can be through behaviour. To establish a more versatile approach, let us consider the rather fuzzy concept of complexity both from a structural (material) and a functional (behavioural) point of view:

**i) Structural Complexity:**

The common reductionist approach in biology tends to measure the complexity of an organism in terms of criteria like body size, the number of cell types (Bonner, 1988) or the number of genes. In this article the term "structural complexity" will be reserved for such physical measures. It should, however, be kept in mind that these measures, although they give a rough idea about complexity, miss the actual hierarchical organisation, which makes up the real complexity of the organism. In other words, using such structure-based measures one is exposed to the risk of confusing complexity and complicatedness. For example, it is well possible that a less complex organism has the same number of genes or cell types as a more complex one.

On the other hand, the analysis of the hierarchical organisation becomes impossible as the organism gets more complex. Nevertheless, such an organisation carries the potential to manifest itself functionally, which in turn can bring the behavioural selective advantage mentioned above.

**ii) Information Processing Capacity:**

Information processing capacity is a product of the hierarchical organisation, the complexity of which we are interested in. Since it is impossible to measure a potential as such, one can only hope to be able to observe its functional manifestation. This hope is of course based on the assumption that the observation is being made within some context, where the capacity is sufficiently exploited. After all one would not try to measure someone's intelligence when he is sleeping; rather than that one would try to create a competitive environment (like an examination), which will urge him to explore the limits of his potential.

Such a functional manifestation is a behavioural feature, which includes the extent/capacity/ability of the organism to interact and form links with the environment.

Considering the difficulty of analysing the underlying hierarchical organisation that provides such a behavioural potential, it seems to be a more appropriate approach to search for a criterion for complexity in the domain of the behavioural potential itself, i.e. in the information processing capacity.

It should be added that structure based criteria (body size, number of cell types, number of genes etc.) not only miss the hierarchical organisation in its wholeness, but are also misleading because they rely on what can be referred to as a "false boundary" for the organism. All these criteria are limited to the physical body alone. However, if we want to be more realistic in our models of organisms (especially when more complex ones are considered), we should try not to isolate them from their environment and their cross-relations therein, thus avoid the historic mistake of considering an organism as a "per se" existing (totally autonomous) entity. In fact, this line of thought is consistent with the idea of an "extended phenotype" as introduced in (Dawkins, 1999).

## 2.2 Energy and Information in Biology

Energy and information (as defined by Shannon (Shannon, 1948)) are related concepts. The storage or transmission of information requires coding, i.e. the creation and maintenance of some patterns. In order to create and protect these patterns against the increase of entropy some energy has to be spent.

Most life processes occur under isothermal conditions. This is also valid for the information-related processes at the molecular level (e.g. synaptic transmission, DNA-protein binding reactions etc.). The amount of energy needed to create the patterns that encode a certain amount of information under isothermal conditions has a lower bound (eq. 2), as explained for DNA-protein binding reactions in (Schneider, 1997):

"The second law of thermodynamics shows that information (*R*) and energy (heat, *q*) are related, but by an inequality (eq. 1):

$$k_B T \ln 2 \leq -q/R \text{ (joules per bit)} \qquad (1)$$

where $k_B$ denotes the Boltzmann constant, T the temperature (°K), q the heat energy (Joules) and R the information (bits).

The interpretation of this equation is straightforward. There is a minimum amount of heat energy:

$$E_{min} = k_B T \ln 2 \text{ (joules per bit)} \qquad (2)$$

that must be dissipated (*negative q*) by a molecular machine in order for it to gain $R = 1$ bit of information. More energy than $E_{min}$ could be dissipated for each bit gained, but that would be wasteful. This derivation, which consists of definitions and simple rearrangements, shows that eq. 1 and 2 are just restatements of the Second Law under isothermal conditions."

This relationship between the amount of processed information and the minimum amount of energy required for such a processing is not only valid for the molecular level but can also be applied to any meta-system level and eventually to the whole of an organism. It should be noted that the minimum amount of energy necessary for a given organism to process a certain amount of information would also contain the energy necessary to maintain its organisation and material structure at all existing meta-system levels.

Although it is practically impossible to calculate such a value, one can conclude that given an organism (together with its structure and organisation) there exists a lower bound for the energy it has to expend in order to maintain the capacity of processing a certain amount of information.

### 2.3 Changes in the Energy Expenditure During a Meta-System Transition

The maintenance and survival of any organism depends critically on its energy budget and the energy resources available. As already mentioned in Section 1, during the course of evolution complexity increases by means of meta-system transitions. In order to be able to account for the non-decreasing character of biological complexity the changes in the energy budget of an organism during a meta-system transition must be investigated.

The increase of complexity and complicatedness during a meta-system transition can be analysed through certain stages. According to Turchin (Turchin, 1977), a meta-system transition requires the following 2 steps:

1. **Duplication** of the original system, and
2. Establishment of **control** over multiple copies.

The duplicated parts are subject to variation and hence the first stage gives rise to an increase of complicatedness. The mathematical model of an ecological system as presented in (Dubois, 1998), where the diversity (complicatedness of the ecosystem) increases with the emergence and stabilisation of new species, demonstrates this stage. In this example the ecosystem corresponds to the whole, which makes the first step towards a meta-system transition.

The next stage involves a self-organisation of the duplicated/varied part(s) and the original system. From the point of view of an external observer this can be described as the establishment of control over multiple copies. However, it must be pointed out that it is not the original system that controls the copies, rather than that the newly emerging whole (an entity at the newly emerging meta-system level) controls the original and the copies all together.

This can be best explained with the aid of a specific example, namely the increase in genome size and its relation to abundance as mentioned in (Schuster, 1996):

The complicatedness of an organism with a certain genome length can increase due to the duplication of some parts of the genome. The duplicated parts most probably will not serve any function at the beginning, hence there will be no increase in the functional complexity (the information processing capacity) of the organism. According to some structural complexity measure the organism might appear as having become more complex, although actually its complexity remains the same. Even though these duplicated parts do not serve any function they will contribute to the maintenance cost.

Later on such a duplicated, thus extra, part may happen to encode a useful and novel function, which gives rise to a selective advantage for the organism. Such a transition increases the functional complexity, hence the information processing capacity of the organism and in this case will be referred to as a **complex adaptation**.

An important point is that actually the extra part constitutes a burden for the organism until it attains a novel function, which may lead to a selective advantage. The accommodation of this extra part until it becomes useful is of course easier in times of abundance when the extra maintenance costs do not constitute a serious burden for the organism.

If we analyse the scenario described above from the point of the complexity and energy expenditure of the organism we end up with Table 1, where the "long genome phase prior to complex adaptation" corresponds to step 1 according to Turchin, and the "long genome phase after the complex adaptation" corresponds to step 2.

**Table 1.** Different stages during complex adaptation and the associated energy expenditures.

| | Short genome | Long genome Prior to complex adaptation | Long genome after complex adaptation |
|---|---|---|---|
| Structural complexity | Low | High | High |
| Information processing capacity | Low | Low | High |
| Material maintenance cost | Low | High | High |
| Additional search cost | - | High | Low |
| Cost of additional control loops | - | - | High |

Increase in structural complexity refers to an increase of the potential of the material substructure to support some additional information processing capacity, e.g. a longer genome in the above example. A complex adaptation is the realisation of this potential. In the example above this corresponds to the actual encoding of a novel function that gives rise to a selective advantage for the organism.

**Material maintenance cost:** The material maintenance cost is the energy necessary for sustaining the material substructure. For this particular example, the material substructure obviously refers to the nucleotides that make up the genome. Thus the maintenance cost consists of the energy used for the biosynthesis of the constituent nucleotides and the replication of the genome at a certain level of fidelity.

**Additional search cost:** As a prerequisite of adaptivity, every organism exhibits a search behaviour to a certain extent; e.g. mutations in a genetic system accompanied by selective forces can be considered as a search within the genome space for fitter phenotypic properties. Such a search is always associated with some energy expenditure. The increase of structural complexity expands the search space and consequently increases the search costs. In that sense, a complex adaptation corresponds to the discovery of an advantageous site in the expanded search space. It should be noted that the selective mechanism favours higher search rate before the complex adaptation (this can be best demonstrated by the example given above where the duplicated part of the genome is being used as a scratch-board without endangering the organism). On the other hand, after the complex adaptation those organisms, which by random mutations and natural selection develop a mechanism that limits the search space in order to protect the essential functions, have higher chances to survive. It should be noted that the part of the genome, that was being used as a scratch-board before, is now registered for novel and essential functions, and variations in it are less likely to be favourable. Such a limitation of the search space is accompanied by the economic benefit of reduced search cost.

**Cost of additional control loops:** A related energy item that increases with complex adaptations is associated with the control loops. As the search space expands, the search process gradually becomes impossible to conduct as freely as before (e.g. by simple mutations). On the other hand, cessation of the search process will render the organism incompetent. The way out is the development of control mechanisms that guide the search (e.g. more complex genomic organisation of eukaryotes with multiple chromosomes, introns, exons etc. compared with simple prokaryotic genomes). The control mechanisms that determine and guide the search pattern dictate their own mechanistic implications upon the forthcoming results; thus the system becomes more and more authentic. (A nice example is the phenomenon of the exon shuffling observed in higher eukaryotes. Many proteins that may have different functions and even belong to different species share common structural motifs.) This is actually saying in other words that biological organisation is inherently self-referential and moreover this self-referentiality tends to increase together with the complexity of the control loops. In spite of their additional cost, the control loops constitute a preventive system against the growing risk of running out of resources during the search process within an expanded search space.

Although Table 1 gives only a qualitative description of the changes in the energy budget, one can observe that there is a relative increase in the overall energy expenditure after the complex adaptation. This statement immediately gives rise to the question of how complex adaptations are viable in spite of this economic disadvantage. When answering this question one has to keep in mind that an economic disadvantage is a matter of the balance between the demand and the supply. Table 1 only indicates that the demand has increased. However, a complex adaptation is likely to give rise to an increase in the energy supply, too, due to the following reasons:

1. The complex adaptation can provide access to new resources.
2. Thanks to the increased information processing capacity the organism may improve the efficiency, at which it exploits the old resources.

This argumentation will be expanded in the subsequent sections.

Another issue of critical importance is the discussion of the energy expenditure from the point of view of information processing capacity. As indicated at the end of Section 2.2, there exists a lower bound for the energy necessary for a given organism to process a certain amount of information and this amount also includes the maintenance cost of the substructure, which provides the information processing capacity. The information processing capacity, hence the associated minimum necessary energy of a complex organism is higher than that of the less complex one.

On the other hand, it should be noted that practically all organisms expend more energy than this minimum necessary amount. The difference between the actual expenditure of an organism and the minimum necessary amount can be considered as a “waste of energy”. Following the second argument above, it is even possible that a more complex organism expends less energy than its simpler counter-part by reducing the “waste of energy” thanks to its higher information processing capacity.

## 3. Positive Feedback Mechanisms Supporting the Increase of Complexity

There is an apparent tendency in biological evolution towards increasing complexity (in the sense of information processing capacity). A possible reason for this tendency is the positive feedback effect, which shall be analysed below from different points of view:

**i)** A possible way of interpreting the positive feedback loop is from the point of view of the mutual interaction between the organism and its environment. It is a well-known fact that the fitness of an organism is the product of the interplay of the phenotype and the environmental responses to the actions of the organism. This makes the fitness a contextual property. As a consequence, changes in the environmental conditions as well as in the phenotype affect the fitness. All organisms have models of their environment and of their own. Based on these they **anticipate** the results of their actions and act accordingly. The prediction power of these models is essential for their fitness and survival. A more complex organism, thanks to its higher information processing capacity, has more influence on its environment compared to a less complex one. The resulting change and destabilisation in the environment affects all organisms in the same environment. The simpler ones, since their organisations are structurally more robust (e.g. bacteria), can cope with these changes by adapting themselves to a great extent. The more complex ones do not have the same degree of freedom for organisational restructuring, hence they try to cope with the changes by adopting more sophisticated anticipatory models, which require higher information processing capacity on behalf of these organisms.

In summary a more complex organism follows the “change the world rather than myself” strategy more strongly than a less complex one. However, in order to cope with these self-induced changes it needs more complex models for subsequent anticipation, which necessitate a still higher information processing capacity. Under this pressure the further increase of complexity is favoured, which completes the positive feedback loop (fig. 1).

The most striking example of this phenomenon is of course our own species. The highly developed central nervous system that our ancestors attained allowed the creation of an ever increasing technology that changed the world towards a more unpredictable environment where more and more complex adaptations are necessary to survive. The most drastic changes are induced in the ecosystem, e.g. climate changes, weakening of the ozone layer etc. These are accompanied by the adaptations of other species (especially viruses, bacteria) that render the environment even more unpredictable. And to cope with an unpredictable environment we obviously need higher technology, which actually seems to be the current trend.

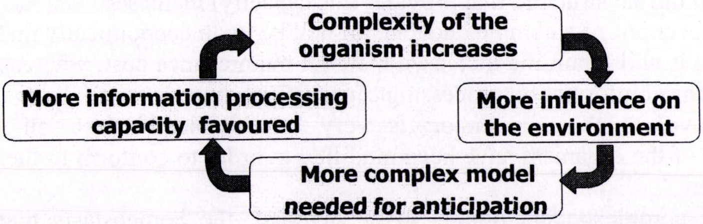

**Figure 1.** The environmental positive feedback loop supporting the increase of complexity

**ii)** Another way of looking at the positive feedback effect is from the economical point of view. The organism, which undergoes a complex adaptation and attains a higher information processing capacity, creates a new niche, where there are no competitors to share the resources. The creation of a new niche can correspond to access to new resources or to more efficient usage of old ones. Hence in effect, complex adaptations increase the abundance of resources available to the organism under consideration as already mentioned at the end of Section 2.3.

On the other hand, we know that the substructure (e.g. increased genome length) necessary for the increase of complexity can be attained more readily in times of abundance (Schuster, 1996). The abundance attained in the new niche will favour the emergence of such substructures that can eventually lead to even further increase of complexity. This gives an internal positive feedback mechanism for the increase of complexity (fig. 2).

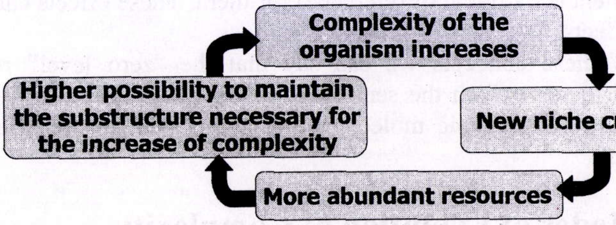

**Figure 2.** The energy feedback loop supporting the increase of complexity

## 4. Why Complexity is Unlikely to Decrease Gradually

Complex adaptations bring forth an advantage and a disadvantage to their possessors. The disadvantage is that becoming more complex means to need more resources in order to survive. The advantage is that, having been endowed with a higher information processing capacity, the access to newer resources and the more efficient exploitation of the old ones is possible. Actually the evolution of complexity seems to be a trade-off between these two aspects. When an organism undergoes a complex adaptation, the minimum energy it needs to maintain its information processing capacity (together with the substructure that provides this capacity) increases.

Any revertant of a complex adaptation will be in an economically disadvantaged position since it will retain the increased material maintenance cost, whereas it will not have the increased information processing capacity any more.

Moreover, such a reversion is very improbable because all constituent substructures of the organism have been modified in order to conform to the new, more complex order.

If the complex adaptation is to be reverted, the homeostasis that has been achieved will most probably be lost and this will in turn affect all of the co-existing substructures. Such a destabilisation is likely to cause a catastrophic consequence, which means that a total disintegration of the organism will follow. The next stable point, when this disorganisation process will stop, is when the "zero level" is reached.

In order to explain what is meant by the "zero level" it is worth remembering the dynamics of hierarchical self-organised structures, such as organisms or even ecosystems:

Such a system consists of many meta-system levels (e.g. an organism can consist of levels such as subcellular organelles, cells, tissues, organs and organ systems). The components at a given level organise themselves to form an entity at the next higher meta-system level, i.e. components at the lower level constitute "building blocks" for the next level. In such a multi-level system the dynamics at different levels influence and modify each other such that eventually a homeostasis is reached throughout the whole hierarchical structure.

Phenomena at lower levels influence higher levels by means of successive self-organisations, hence this "bottom-up" influence is a collective one. On the other hand, phenomena at higher levels impose conditions upon lower levels by creating some kind of a stable environment (or a frame of reference) for them. These effects can be referred to as "top-down" effects.

In terms of these concepts we can say that the "zero level" refers to the organisational level, below which the sensitivity to top-down effects is very low. For example the structure of inorganic molecules and atoms will not be affected by the death of an organism.

## 5. Different Modes of Evolution of Complexity

The discussions up to here indicate that the complexity of organisms tends to increase if sufficient resources are available. However, this should not be interpreted as each and every species becoming more and more complex in the course of time. We can summarise the general tendency of complexity increase and the exceptions of this tendency as follows:

In general, as far as complexity is concerned, there appear three modes of the evolutionary process at a given geographical location and an era:

**1. More complex species keep on appearing** and sometimes they compete out some of the previously existing ones. For this mode to operate, a wealth of resources is necessary. This mode of evolutionary process is the one accounted for by the arguments in the previous sections of this article.

**2. More complex species cease to appear** and the evolutionary tendency of increasing complexity seems to "pause". This mode of evolution is likely to occur in relatively isolated environments with limited resources. Since this mode has not been mentioned so far within this article it is worth giving an example:

The so-called Komodo Dragons are giant carnivorous reptiles that inhabit the Komodo islands. These islands are rather small and the resources (the number of animals the dragons prey upon) are relatively limited compared to the mainland. These reptiles, thanks to their slower metabolism (for instance, than that of a tiger, which occupies a similar niche in the mainland ecology at the same latitude), can survive for weeks without food. Additionally, when they catch a prey they consume virtually all of it, which is much more efficient, compared to the consumption strategies of most mammalian carnivores. It seems to be more than a coincidence that the Komodo islands constitute the only habitat where these rather ancient predators have taken rule and no mammalian predators (which are presumably more complex) exist and probably never have evolved (Ciofi, 1999).

**3. More complex species become extinct** catastrophically if they cannot afford the relatively high minimum energy level necessary to maintain the species due to lack of resources. Such a lack of resources can arise

**i)** as a result of an external disaster, or

**ii)** due to the destructive competition of other species of comparable complexity, yet more efficient in their energy consumption.

The most common example of this mode is the extinction of dinosaurs, although there is still an ongoing debate about which of the two reasons cited above (external reasons like meteor impact or climate change, or emergence of more advantageous competitors) gave rise to the lack of resources.

It is remarkable that in none of these three evolutionary modes less complex species are seriously affected. Moreover, except for the case in 3.i, the highest level of complexity attained in the environment under consideration is never lowered though its carriers may change (as in 3.ii).

All three modes of evolution of complexity are closely related to the scarcity/abundance of the resources.

## 6. Conclusion

In this article the information processing capacity is proposed as an adequate criterion for the complexity of organisms. This criterion is capable of accounting for the functional manifestation of the nested hierarchical organisation of living beings as opposed to the common complexity criteria like number of genes, number of cell types, body size etc.

The intuitive observation of complexity increase in the course of biological evolution is accounted for by two novel positive feedback mechanisms, which support and drive this increase. These mechanisms are based on energy consumption strategies and the interactions with the environment.

In evolution complexity increases, i.e. more complex species appear as time flows. Species themselves do not become more complex, since the ones that have done so are considered as different species. Consequently, speciation is the way, how complexity can increase in evolution, although not every newly emerging species has to be necessarily more complex. According to our criterion of complexity (information processing capacity), increasing complexity brings forth an increase in the energy consumption. The energy consumption, which increases parallel to the complexity, corresponds to the minimum necessary energy and does not account for the wastefulness of the organism.

Moreover, some barriers seem to exist, which make a decrease of biological complexity in a smooth manner very improbable. For one thing, increasing complexity brings forth a selective advantage that shall be lost upon any reversion; besides, the intricate homeostatic balance of the whole organisation will also be lost leading to the total disintegration of the organism.

Depending on the spatio-temporal conditions there are three general modes of the evolution regarding biological complexity: The ongoing appearance of more complex species in case of abundance of resources, pausing of the complexity increase when the limits of the resources are reached in a relatively isolated environment, and the extinction of a complex species due to lack of sufficient resources. Although the last mode corresponds to a decrease of complexity this does not contradict the improbability of a smooth decrease. Moreover, a complex species, which goes extinct in this manner, will most probably be replaced by another comparably complex one, which, however, uses the energy resources more efficiently.

If we have a closer look at the nested organisation of complex species, we can conclude that together with complexity also the self-referentiality of the organism increases, hence it becomes more authentic. Such an organism is structurally more fragile than a less complex one, hence has to make use of the "change the world rather than myself" strategy in order to survive.

Although complex adaptations often work for the behalf of their possessors, this is a consequence rather than a cause. The main reason for the increase of complexity is its own drive to increase itself and not the survival of the organism. The still existing species are the lucky ones who have met both conditions at the same time. At this point we deviate from the view that evolution is purely contingent and without direction ("The Blind Watchmaker"). Rather than that we suppose there is a causality, thus a directionality, as far as the increase of complexity is concerned. This causality, namely the own drive of complexity to increase itself, is a circular (self-referential) one. This is closely related to the purposefulness, which underlies the philosophy of the living as suggested by Monod (Monod, 1971). To comprehend the logic of life one has to lay the Newtonian-Cartesian paradigm aside and allow the existence of a final cause in the Aristotelian sense as extensively discussed by Rosen (Rosen, 1985). The circular logic of life allows a final cause in the form of anticipation, which involves emergent goals. In that sense, these goals are both results and causes of the evolutionary dynamics. It can be thus concluded that complex adaptations, which lead to further increase of biological complexity, have teleonomic nature.

Our main concern in this article was to point out some properties underlying the increasing nature of complexity in biological evolution. Any extension of the arguments presented herewith to other evolutionary dynamics, such as the social or the technological one, should be done with extensive care.

Keeping this warning in mind, we still can allow ourselves to draw some analogies to systems at social or technological level, especially concerning the issues involving energy consumption. For example, one can clearly observe the increase in energy consumption throughout the technological history, which is in accordance with the increase of complexity. On the other hand, the construction of less energy-consuming devices compared to their early counter-parts is also a common fact, which can be explained on basis of the reduction of "wasted" energy in their operation. Nevertheless, there exists a lower bound for the energy necessary to fulfil the high information processing capacity these devices have attained. In that respect, the research towards quantum computers can be considered a result of the endeavour for approaching the minimum energy bound.

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