*Interdisciplinary Description of Complex Systems* 11(1), 37-50, 2013

# EXTENDING LIFE CONCEPTS TO COMPLEX SYSTEMS*

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DOI: 10.7906/indecs.11.1.4
Regular article

*Received:* 5 July 2012.
*Accepted*: 22 January 2013.

## ABSTRACT

There is still no consensus definition of complex systems. This article explores, as a heuristic approach, the possibility of using notions associated with life as transversal concepts for defining complex systems. This approach is developed within a general classification of systems, with complex systems considered as a general 'living things' category and living organisms as a specialised class within this category. Concepts associated with life are first explored in the context of complex systems: birth, death and lifetime, adaptation, ontogeny and growth, reproduction. Thereafter, a refutation approach is used to test the proposed classification against a set of diverse systems, including a reference case, edge cases and immaterial complex systems. The summary of this analysis is then used to generate a definition of complex systems, based on the proposal, and within the background of cybernetics, complex adaptive systems and biology. Using notions such as 'birth' or 'lifespan' as transversal concepts may be of heuristic value for the generic characterization of complex systems, opening up new lines of research for improving their definition.

## KEY WORDS

complex systems, life concepts, refutation approach, heuristic

## CLASSIFICATION

JEL: Z13

PACS: 87.18.-h, 89.75.-k

*A preliminary version of this work was presented at the European Conference on Complex Systems, Lisbon, Portugal, 11-15 Sept. 2010.

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## INTRODUCTION

Since the pioneering studies on cybernetics [1, 2] general systems theory [3, 4] and systems science [5] and the advent of computers, researchers in the field of complex systems science have developed a dense and diverse body of knowledge concerning the characteristics, structures, processes and behaviours associated with the notion of 'complex systems' [6, 7]. Many avenues have been explored, but there is still no consensus definition of complex systems [8-10] or of some of their kernel concepts, such as emergence [6, 11]. However, even very diverse complex systems can be seen to have features in common [12].

Within 'complex systems' research, increasing numbers of relationships are being established between complex systems and life sciences concepts [12]. Relationships are commonly established such that living organisms are considered to be the archetypes of elaborate *complex systems*, e.g., [13, 14]. However, attempts to qualify complex non-living systems as living or life-like [15] entities are less frequent and concern few examples such as rivers [16], social [17] or cultural [18] structures. Moreover, in such situations, authors generally refer to complex adaptive systems [19, 20], which are particularly sophisticated instances of complex systems (great diversity, organisation, long history).

This contribution lies within the framework of complex system definition and, in some ways follows on from the work of Kauffman [21], who suggested that life, as a probable consequence of random chemical processes, is an almost common fundamental process of Nature. We explore the proposition of using some life definitions as unifying properties of complex systems, whether sophisticated complex adaptive systems or simple non-linear entities [22]. Examination of the correspondence between complex systems in general and concepts associated with 'living systems' fits into the framework of analogies [23]. It may lead to the controlled generalization of basic characteristics of 'living things' and the establishment of a kernel for the definition of complex systems [24]. The advantage of this approach is its heuristic value for **exploring and examining the uniqueness of complex systems**. It does not call into question established knowledge about life, generated through biology, a key branch of science, by seminal authors such as Buffon, Lamarck, Darwin, Haldane [25], Ruffié [26] or Maturana and Varela [27].

We first describe this proposal within a general classification of composite systems. We then explore its consequences, by focusing on a subset of distinctive properties bound to living and complex systems science. We then initiate a stepwise validation/refutation process, in which we consider complex systems at the edges of the definition and their status as "living entities" within the terms of the proposal. A synthetic overview is then presented, with a discussion of the consequences of this proposal.

## ESSENTIAL FEATURES OF THE PROPOSAL

The approach adopted here is based on the description of composite systems, one of the foundations of complex systems theories [28]. Multiple criteria have been proposed for the classification of systems into levels [29], e.g., the intuitive classification, on nine levels, of complexity from static to symbolic established by Boulding [3] and revised by Von Bertalanffy [4]. Each of these classifications includes parts accounting for living and non-living systems. These attempts to classify systems have provided different viewpoints on systems but none has emerged as a clear reference for further construction [30]. For the sake of simplicity, we illustrate our proposal with a simplified, four-level scheme. The illustration in Figure 1 establishes a hierarchy of composite systems beginning from mere collections of entities (e.g., books on a shelf or pebbles on a beach), to cybernetic systems (e.g., manufactured machines) and complex systems, of which living organisms are a specific case (Figure 1a). In the proposal discussed here (Figure 1b), complex systems are considered to have the basic properties of living organisms, which they are therefore considered to resemble. This modifies the top level of the hierarchy, with the concept of ‘life’ extended to the more general complex systems category, which we hereby arbitrarily name ‘living things’. Within the proposal, organisms become a special case of ‘living things’. For the purposes of discussion, they could be described as ‘real living’ or ‘eu-living’ organisms (the prefix “eu” here indicates “true” or “genuine”).

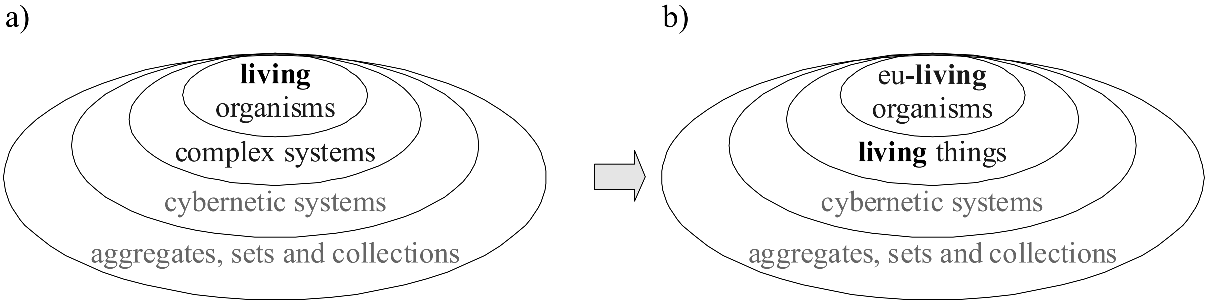


**Figure 1.** Illustration of the proposal considered here, within a possible classification of composite items. The successive concentric circles formalise the progressive specialisation of each category. Each smaller circle is included within a larger circle and represents a specialisation of that larger circle. Classifications: a) the common sense, b) the proposed modification to the common sense classification.

## METHOD

This proposal will be examined in three steps. The first is based on the notion that ‘living systems’, like ‘complex systems’ [31], are not clearly defined [32] and are usually based on a set of properties and concepts [33]. It is therefore possible that some of the concepts and properties commonly attributed to living organisms (e.g., birth, death, lifespan) could be extended to complex systems and included in the definition of these systems, whereas other notions are specific and be reserved for the definition of living organisms (e.g., reproduction).

We therefore need to consider the concepts associated with life and complex systems. We will thus explore a subset of emblematic concepts pertaining to the definition of life or complex systems and determine (i) the status of these concepts in the framework of the proposal and (ii) the validity of the change proposed given the particular meaning of these concepts.

The second step relates to the highly diverse nature of existing complex systems. If the change in classification is considered acceptable, it would imply that each and every complex systems fulfils the change proposed and could therefore be considered a ‘living thing’. Moreover, most instances of complex systems (macromolecule, river delta, market, etc.) seem to constitute a unique case with a particular combination of complex systems features. **Each should therefore be considered as a particular potential objection to the proposal**. We have taken the considerable diversity of specific cases into account, by examining the validity of the proposal in a stepwise refutation approach based on the search for counter-examples. In this approach, a diverse set of systems is progressively compared with the ‘living things’ paradigm proposed. For each instance, we use a back and forth process in which we simultaneously (i) determine the “composite item” category (collections, cybernetic systems, 'living things', complex adaptive systems or organisms) to which each example belongs and (ii) incrementally refine the distinctive features of each category within the set of concepts characterising living organisms, including those discussed in the preceding step.

Finally, we attempt to bring together the results obtained in the first two steps in a summary, with the aim of supporting, invalidating or refining the limits of validity of the proposal and its heuristic value for clarifying either the essential nature of complex and living systems or the distinction between the two classes.

## POSITIONING CONCEPTS WITHIN THE CLASSIFICATION PROPOSED

Life is usually defined by a set of properties but different authors make use of different sets of properties, e.g. [15, 26, 34, 35]. Nevertheless, within the existing definitions, a common set of life traits can be identified that are either self-evident or form a consensus. We will consider these prominent concepts in the light of the proposal and focus particularly on those concepts that could separate 'life' from the biological concept of 'an organism': emergence, birth, death and lifespan, adaptation, ontogeny and growth, history and evolution, reproduction, diversity, input and organisation, adaptation and self, homeostasis and autopoiesis.

**Emergence** has often been described in complex systems sciences [6, 33] but it has not been specified whether this property is identical in nature in living organisms and complex systems. In the proposal, the emergence of an entity, or monad (Plato in [36]), from a set of interacting components equates to bringing a recognisable 'living thing' into existence (essentially, a phenomenon of 'birth'). The acquisition of an identity through emergence thus becomes one of the cornerstones of the equivalence between complex systems and 'living things'. It may follow that the whole hierarchy of Nature, from quarks to animals [19], ecosystems [37-39] and galactic filaments [40], could be unified into a full hierarchy of 'living things'. With some justification, the concept of birth is identified as an essential feature of living organisms. If the proposal is consistent, birth should be transferable to the definition of complex systems ('living things'), which is a much broader set than that of 'eu-living' organisms. The status of the 'death' concept is more questionable as it may rely on a relative viewpoint, as in the case of transformation, metamorphosis or reproduction. The difficulties associated with this particular concept are discussed below.

**Ontogeny**, **morphogenesis**, **maturation**, **learning**, **history**, **growth** or **evolution** refer to processes resembling the irreversible stepwise construction of the system over a given time period (a 'lifespan' in the proposal). This notably places these systems in opposition to engineered systems, which can be planned from the outset by human work and this distinction may constitute a frontier between cybernetic systems and complex systems/'living things'. Any emerging system capable of evolution, ontogeny or history (a 'lifespan') would thus belong to the 'living things'/complex systems category. This 'lifespan' central notion is bound to the distinction between a system and its environment [41, 42]. A system emerges in a changing environment, with which it establishes relationships with **irreversible** effects.

Two levels of irreversible dynamics may be considered: a 'light' level in which successive changes are not memorised (river water irreversibly becomes lake water and then waterfalls etc.) and real adaptation, corresponding to ontogenetic growth in which change and adaptation to change leave an imprint on the living system, affecting its future behaviour and fate (a community becomes a society, a civilisation, etc.).

Autonomous **adaptation** is a key concept used to describe living organisms [43, 44]. In complex systems science, it is usually associated with the particular category of complex adaptive systems [19-20]. The range of complex adaptive systems extends well beyond the subset of biological organisms. It includes biological substructures such as the immune system [45] as well as non-living (in the strict classical sense of the term) items, such as markets [46], fisheries [47], industry [48], language [49], groups (Smith in [17, 50]) or the Internet [51]. This property cannot therefore be considered to characterise living organisms. Instead, it may relate to a less specialised 'complex adaptive systems' category close to the living organisms category. This raises questions about the true nature of the distinction between complex adaptive systems and organisms. For example, more often than not, as in the above examples, non-biological complex adaptive systems are supersets of biological items (e.g., an ant colony) or are driven by biological items (e.g., stock market, industry). This distinction therefore requires clarification as far as the property of adaptation is concerned.

Together with adaptation, organisation, birth and lifespan, reproduction is a fundamental feature, and possibly the essential characteristic of living organisms. It allows a species to adapt to change through Darwinian evolution and to perpetuate itself after the death of a given organism. Within the specific context of this proposal, reproduction would be interpreted as a specific instantiation of processes enabling living organisms (i) to prolong lifespan (e.g., of a species), (ii) to develop and to conserve adaptive features. This specificity may constitute one of the threshold properties characterising the uppermost organisms or 'eu-living organisms' level.

**Homeostasis**, like **autopoiesis** [27, 52], is often identified as a characteristic of living systems [53]. These two properties play different roles in the existence of a system. Homeostasis relates to the cybernetic feedback mechanisms involved in maintaining the stationary state of a structure, within a flow of input and output, whereas autopoiesis refers to the closure of the system and is an essential element completing the existence of living organisms. Homeostasis and autopoiesis may constitute two facets of a general unity or identity conservation property characterising life. Within this definition relating to the conservation of systems as existing things, homeostasis and autopoiesis would ensure the conservation of a unit identity over a given time (i.e., as long as efficient homeostatic and autopoietic processes are possible). These notions would therefore lead to and be associated with the 'lifespan' feature of 'living things'.

Other important properties or concepts would have to be reconsidered in the light of this proposal. **Input** for example is a characteristic feature of living organisms (e.g., intake, information coming from the environment, sense organs). However, this property is also a characteristic of cybernetics systems [2]. The 'input' property is therefore a feature pertaining to the lower level cybernetic systems category and should not be considered for evaluating the distinction between proposed 'living things' and organisms. **Organisation** and **self-organisation** are widely perceived as properties of both complex systems and life; they may take very diverse forms, from physics to chemistry to biology; from organs to hierarchies of structures. Kauffman [54] established that self-organisation was a necessary property for the emergence of life. However, Ashby [55] described self-organisation in simple composite machines long ago. Organisation thus remains a concept that is difficult to classify. It seems to be common to all composite systems, from simple collections to living beings (e.g., Figure 1a can be considered a representation of the different levels of organisation).

Finally, in this incomplete overview of life and complex systems features, several major contributions in the field of complex systems have identified **diversity** as an important **property** for the control [56], development [15] or viability [57] of complex systems. The concept of 'diversity', or 'polymorphism' in biological contexts, has also been identified as a fundamental property of life (see e.g., [26]). Within the context of the proposal, it remains unclear whether diversity is an integral part of 'living things' or whether it is required only for certain upper-level functions, such as differentiation, variation and selection.

## CLASSIFYING COMPLEX SYSTEMS ITEMS

The second major change implied by this proposal is the need to apply the ‘living things” concept to the highly diverse set of complex systems. In the framework of a refutation approach, the validity or limitations of the proposal are explored incrementally by studying the properties and classification of archetypal examples of composite systems. We select, with arbitrary illustrations, various archetypal situations, ranging from obvious complex systems, to complex systems at the edges of the definition (undiversified, transforming systems), to immaterial systems and manufactured complex systems. In the words of [58], the examples selected have been chosen arbitrarily from thousands of possibilities and may not be the best to appeal to a reader. However they provide an illustration of the approach used to examine the proposal and its characteristic stepwise nature. This approach is summarised in Table 1.

As a reference, we first consider the example of a vertebrate, located at the ‘living organism’ level of the hierarchical classification. A vertebrate is characterised by the set of all features and properties to be discussed: indeed, it is composed of diverse elements; it emerges as a recognisable entity within its environment (wholeness); it is organised, autopoietic, homeostatic (transducing an equilibrium between input and output); it has organs and a metabolism, comes to life, dies, grows, changes form through ontogenic processes, matures and evolves with irreversible dynamics. It can reproduce, move, take up and supply energy and information to and from its environment and adapt to inner and outer changes. This establishes the framework within which ‘living things’ could be identified and potentially distinguished from ‘eu-living’ organisms.

At the edge of the proposal, a breaking wave of water is a complex physical set of interacting identical elements. Its fluidity and liquidity emerge from the interaction of its particles in an appropriate environment. It is unusual in that it persists for only a short time, but it could nonetheless be considered to have a ‘birth’, ‘death’ and ‘lifespan’. It is organised by the constraints of the surrounding masses of water and air within which it evolves (irreversible

**Table 1.** Classifying example systems (columns) relative to the notions associated with life (rows). The blocks refer to properties which would be a) specific to living organisms, b) related to ‘lifespan’ and c) related to ‘birth’. For each comparison, the property is observable, not observable or questionable.

| | | archetype | at the edge of the definition | | | immaterial | | manufactured |
|---|---|---|---|---|---|---|---|---|
| | | VERTEBRATE | Breaking water WAVE | ROCK (human time scale) | ROCK (geological time scale) | IDEA | FIRE | Conway's game of life GLIDER |
| a) | metabolism | * | | | | | * | * |
| | reproduction | * | | | | * | * | * |
| | functional organisation | * | | | | * | * | * |
| | dispersal, motion | * | * | | * | * | * | * |
| | diversity of composing items | * | | * | * | * | | |
| b) | ontogenesis, evolution, growth (1) | * | | | * | * | ? | |
| | irreversible dynamics, history | * | * | * | * | * | * | |
| | transformation, tipping, adaptation | * | * | * | * | * | * | * |
| | openness - homeostasis | * | * | | * | * | * | * |
| | autopoiesis | * | * | * | ? | * | ? | |
| | death | * | * | * | ? | ? | * | * |
| | 'lifespan' | * | * | * | ? | ? | * | * |
| c) | identity, unity, wholeness | * | * | * | ? | ? | * | * |
| | emergence | * | * | * | * | * | * | * |
| | 'birth' | * | * | * | ? | * | * | * |

(1) with imprinting of change and self

| legend: | * | ? | |
|---|---|---|---|
| | YES | QUESTIONABLE | NO |

tipping) and, once it achieves the status of a wave, its structure is maintained by molecular cohesion (simple autopoiesis) although the wave exists for only a short period of time. During this time, the wave also conserves its dynamic cohesion and homeostasis through the incorporation and release of water molecules. If considered as a living thing, these properties would constitute a first kernel for establishing a definition of ‘living things’/complex systems. However, a wave does not display ontogenic growth or maturation and has no reproductive mechanism. Furthermore, the molecules constituting a wave are not diversified and do not give the wave the necessary creativity for self-adaptation [59]. In the framework of this incremental refutation approach, and as previously proposed, diversity and ontogeny would therefore need to be considered as non-essential properties of ‘living things’.

At another edge of the classification proposed, the status of a rock is also debatable. As long as it is recognisable by its shape, it is an existing entity emerging from a diversified set of interacting minerals. It may be structured (e.g., geode) and may thus react specifically to shocks, given its particular structure (e.g., as described by sculptors). Nevertheless, its main characteristic is its stability, mostly linked to its being an orderly [51] and closed system, that is, an inanimate object. This distinctive feature excludes rocks from even the cybernetic system category.

However, over the geological time scale, a rock is not static and may irreversibly tip into new forms (e.g., transformation into lava, river sand, silt, etc.) depending on the successive environmental events to which it is subjected. Over a long time scale, a stable rock could be considered analogous to the diapause, hibernation or dormancy (such as ticks remaining dormant for 18 years before finding a mammal on which to settle [60]) phase subsystem of a larger complex system/‘living thing’ involved in a perpetual life cycle. This definition pushes to the limits of the lifespan concept, but without actually refuting it: At a geological time scale, the very different possible shape of the rock resembles the pupa-butterfly classification problem. It follows from the transformation or tipping perspective, common to both complex systems [59] and living organisms, that the ‘death’ concept is somewhat problematic in this case (as also seen in the examples below).

Various immaterial items, such as languages [49], meetings [15], innovation [61], and culture [18], are also considered to be complex systems. For the proposed classification to be valid, it would also be necessary to include these items in the ‘living things’ category. The example selected here for this category is that of an idea or a meme [18] developed by a single person or spread throughout a population. An idea can reproduce by dissemination between the individuals of a population and is organised into several different components (premises, references, arguments etc.). An idea continually adapts to successive inputs. However, it is also questionable whether the notion of ‘death’ can be applied to an idea, as ideas are again more likely to undergo transformation. The property of motion depends on the context. It may characterise an idea disseminating within a population or society, but not an idea as a living thing within a single individual developing it.

A fire is another type of immaterial system. It is also clearly an emerging item, living, dying, changing form and irreversibly evolving in close relation to its environment. An observer may perceive it as feeding on the environment and adapting its strength to the outer temperature and oxygen. It establishes a hot environment maximising the combustion of its fuel. It can disseminate, grow and mature to an established fire before being extinguished. Within the classification system proposed, a fire thus appears to reach the benchmark of the most sophisticated ‘living things’. As in the example of an ‘idea’, fire remains an immaterial item, the simple result of the highly exothermic oxidation of a fuel by the ambient air, with energy released as heat and light, giving ‘birth’ to a visible fire.

Computers are cybernetic machines, but their output may take the form of complex systems [62]. They therefore provide a useful model for exploring the 'vitality' of complex manufactured systems. A dynamic glider cellular automaton [63] moving and reproducing in a grid may be considered a parsimonious example for this comparison. Indeed, as soon as it has a sufficient lifespan, this entity emerges as a recognisable item to the observer. A glider thus 'comes to life', can 'mate' with 'another' and 'produce' 'offspring' (e.g., the Gosper Glider Gun p30 [63]). It 'dies' by dissolution if the environment (the grid) is not isotropic (i.e., when the glider 'meets' other black cells). It takes input from its environment as it depends on the state of its neighbouring cells. The rules of the glider resemble metabolic function (cells are metaphors for a localised organism or population) and its topology, crucial for its survival, resembles functional organisation. A glider could not be considered autopoietic: even if the only reason for its existence is to maintain itself as a 'living' glider, no mechanisms are implemented within the model to ensure this property. Moreover, the glider does not display growth or ontogeny. In an isotropic environment, some gliders would not 'die' (within the software run). Therefore, if the glider is to be considered as a living thing, within the framework of the proposed classification, autopoiesis and irreversible growth or ontogeny could not be considered essential properties of 'living things'. We suggest the following alternative, that a glider, as an artefact, cannot be considered to be a living thing despite its unsettling behaviour.

## SUMMARY AND DISCUSSION

The items used to decipher the limits of each composite system category are indicative and remain a preliminary illustration of possible ways to evaluate this proposed classification. Further testing of this proposal will require the accumulation of additional complex systems examples for exploration. Given this limitation, and in the light of the concepts and items examined, we can try to outline the distinctive features of composite items based on the arguments set out above. In summary, 'living things' (*i.e.*, all complex systems):

> *Simultaneously come into existence (life) through an emergent process, acquire the status of a recognisable entity (a monad), which is inseparable, and enters into a relationship with a surrounding environment. The existence, wholeness or identity of the unit is maintained throughout its 'lifespan' by conservation forces (of which autopoiesis and homeostasis would be particular instances). 'Living things' have an irreversible history/evolution/fate within a changing environment during their 'lifespan' without the compulsory need for memorisation and self-elaboration. Adaptation is therefore not a necessary element of the definition and a changing environment may be sufficient to produce irreversible changes in a given complex system. 'Living things' die by losing their integrity (their existence), although this is not an absolute condition. Indeed, transformation is a limiting but frequent case that must also be considered (rock to sand or lava, caterpillar to butterfly). Finally, the status of 'living things' is scale-dependent (as in the rock example) and observer-dependent (as in the cases of fire and memes).*

This viewpoint leads to the refined representation proposed in Fig. 2.

Organisms ('eu-living' organisms) could be distinguished from other 'living things' by being organised (self-organised) into subsystems (organs), some of which are dedicated to reproduction. Any complex system endowed with reproductive machinery mechanisms making it possible (i) to perpetuate and (ii) to generate variety and Darwinian selection would be classified as an organism. This is the case for living beings with genes and for culture with memes [18]. Complex adaptive systems are not necessarily capable of reproduction (e.g., a brain)

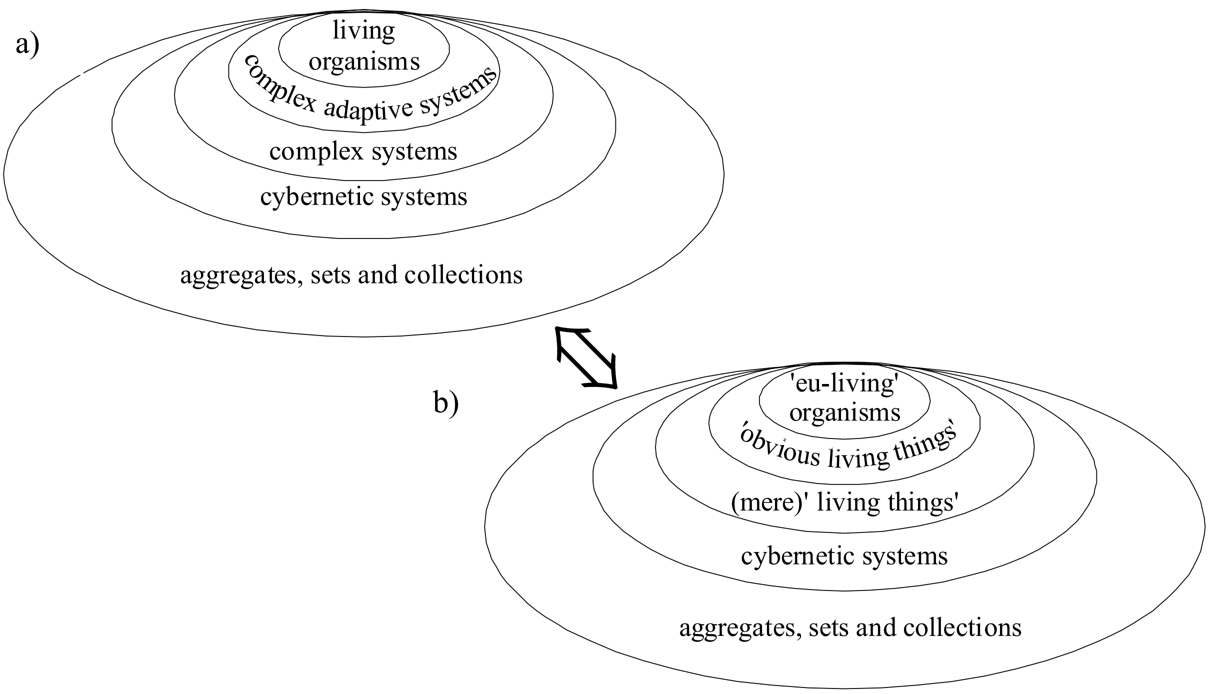


**Figure 1.** Refining the proposal: a) diagram similar to that presented in Figure 1, except that it distinguishes the complex adaptive systems category within the classification proposed, b) complex adaptive systems (‘obvious living things’) become a specialised category of complex systems (‘mere living things’).

and should therefore be distinguished from organisms. They may be considered to constitute a specialised category of ‘living things’ with the property of ontogenic adaptation. Systems such as stock markets, cities, forests, organs and cells display clear life-like behaviour [15]. These systems of the complex adaptive system type could be called ‘obvious living things’.

Within this perspective, living would then be distinguished from cybernetics systems, which would encompass manufactured things designed for a purpose. Going upward in the hierarchical classification, organisms (‘eu-living’ organisms) would become a specialised category of complex adaptive systems with the property of a prolonged ‘lifespan’ through reproduction or dissemination and the archetypal case of Darwinian evolution. Finally, as this proposed classification aims to encompass all complex systems, it should also account for abstract or immaterial systems, which may be considered either as ‘mere living things’ (e.g., project), ‘obvious living things’ (e.g., idea, theory) or possibly ‘eu-living’ organisms (e.g., discipline, culture). In this sense, materiality would not be a criterion for the characterisation of complex ‘living’ entities.

## CONCLUSIONS

This work does not aim to provide a canonical definition for complex systems. However, the ‘living thing’ approach can be seen as a step towards such a definition. Indeed, the potential of the heuristic approach lies principally in the understanding gleaned from efforts to refute the proposal and, hence, to clarify the boundaries of the “complex system” concept.

A potential practical advantage of this approach is that it allows any complex systems to be analysed in the light of the same ‘living things’ concepts. For example, it could be interesting to use the notions of ‘birth’ or specific ‘lifespan’ (e.g., given an observer scale) to characterise any complex system from any field of study, medicine, economics, psychology [64] or physics; this could help to develop generic formalisation in integrated models, e.g., mechanistically rich models [65], where diverse sets of systems interact.

Beyond these practical aspects, these concepts could be considered common features of natural things in general. The proposal would then generate a scenario in which billions of ‘living things’ would be continually coming to ‘life’ and ‘dying’ or ‘tipping’ (without necessarily ‘reproducing’). This would occur at each and every scale in Nature, from $10^{-35}$ m to $10^{27}$ m [66] and from the life span of the Universe to that of the tiniest spark, given the perpetual renewal and modification of relationships in both the material and immaterial worlds.

## ACKNOWLEDGMENTS

The author thanks D. Bourguet, P.Huissoud and J.F. Cosson for valuable comments on the proposal, J. Sappa for useful clarifications on the manuscript.

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# PROŠIRENJE KONCEPTA ŽIVOTA NA KOMPLEKSNE SUSTAVE

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## SAŽETAK

Još uvijek ne postoji konsenzus oko definicije kompleksnih sustava. Ovaj članak heuristički istražuje mogućnost uporabe pojmova vezanih uz život kao transverzalnih koncepta za definiranje kompleksnih sustava. Navedeni pristup razvijen je u okviru opće klasifikacije sustava. Pritom se kompleksne sustave razmatra u općoj kategoriji ‘živih stvari’ unutar koje posebnu klasu čine živa bića. Koncepti pridruženi životu kao prvo su itraženi u kontekstu kompleksnih sustava: rođenje, smrt i trajanje života, adaptacija, ontogeneza i rast, razmnožavanje. Nakon toga, pristup opovrgavanja je primijenjen za testiranje predložene klasifikacije na različitim sustavima. Pritom su uključeni referentni sustavi, krajnji slučajevi sustava te nematerijalni kompleksni sustavi. Sažetak analize zatim se koristi za generiranje definicije kompleksnih sustava pomoću pojma kompleksnih adaptivnih sustava i biologije, uz podlogu kibernetike. Uporaba pojmova kao što su ‘rođenje’ ili ‘životni vijek’ u vidu transverzalnih koncepta može biti od heurističke vrijednosti za generičku karakterizaciju kompleksnih sustava, čime se otvaraju novi pravci istraživanja za unaprijeđenje njihove definicije.

## KLJUČNE RIJEČI

kompleksni sustavi, koncept života, pristup opovrgavanja, heuristika