Is chaos useful to model living beings?

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Abstract

Biological systems live and grow. Many aspects are inherent to the concept of "living", such as adaptation, interaction with the environment, and the ability to deal with limited resources. Following Wilhem Reich [19], an alternation of tension-charge-discharge-relaxation is specific to all living phenomena and encompasses every aspect of the autonomic life functions from amoeba to man. Living systems present multiple levels of organization, with elements at one level interacting and aggregating to create more complex behaviour at a higher level. In recent years, many new techniques used to investigate the spatio-temporal activity in living being have demonstrated the presence of features common to the behaviour of self organizing dynamical systems. Many experimental data support the dynamic chaotic modelling of living systems. Is this "chaos" useful to model living beings? The answer is very difficult, but there are some experiments showing that, at least order is not better then chaos. Complex behaviours such as perceiving, intending, acting, learning, and remembering arise as metastable spatio-temporal patterns of brain activity that are themselves produced by the cooperative interactions among neural clusters. May be supposed that life and knowledge are developed at "the edge of chaos".

In this paper we present and discuss the question, and try to give indication for a possible answer, with the aim at defining the basic features of a behavioural kernel for living artefacts.

1. Introduction

Many researchers in different fields from psychology to biology, from philosophy to AI tried to find out what characterizes the foundations of life.

People have found a lot of difficulties in trying to model the living being and its functions. Disciplines such as psychology have approached the topic at the macroscopic level of behaviour. Biologists have attempted the cellular level of analysis and studies on ion channels soon followed. Most neuroscientists were reductionists: they followed the thesis that macroscopic states can be explained through microscopic analysis. Some authors highlight the functional patterns that look particularly interesting.

Biological systems live and grow. The concept of 'living' has a lot of consequences such as adaptation, interaction with the environment, and the ability to deal with limited resources.

It is worth noting that time is the dimension in which all living being behaviours unfold. It is the context within which we understand the world. We recognize causality because causes precede effects. We learn that coherent motion over time of points on the retinal array is a good indicator of object presence. It is difficult to think about phenomena such as language, or goal-directed behaviour, or planning without some way of representing time. Time's arrow is such a central feature of our world that it is easy to think that having acknowledged its pervasive presence.

2. What characterizes a living being?

In recent years, many new techniques used to investigate the spatio-temporal brain activity (MEG, EEG, PET etc.) have demonstrated the presence of features common to the behaviour of self-organizing dynamical systems. Self-organization refers to the spontaneous organization of pattern and structure in an open non-equilibrium system exchanging energy or matter or information with the environment. After a series of experiments with humans, the psychologist Wilhem Reich claimed the existence of a "function" that he defined as base of the living nature. In [19] he said: "The creative force in nature. It is not a form of electromagnetism nor of matter but is fundamental to both". Moreover, he suggested that the subjective feelings of pleasure and anxiety were nothing other than one's perceptions of this "function", as it flowed from the core to periphery and from periphery to core, respectively. Reich named this "function", he considered the substratum of all nature, "orgone energy". Many scientists claimed for the existence of a fundamental characteristics of life similar to that: Franz Anton Mesmer called it "animal magnetism"; Charles von Reichenbach named it "odyle". While to Henri Bergson it was the "vital force". Sigmund Freud observed its functioning in human emotions and termed it "libido". All these people, trying to find a basic pattern for life, identified elements with characteristics that are typical of chaotic dynamical systems[1]. Our knowledge about "orgone energy" is partial and fragmentary in major respects. Nevertheless some interesting aspects arose from Reich's work that show how this concept is close to chaotic systems. "Orgone" is defined as being in constant motion with at least two distinct types of motion: a "pulsation" or alternating expansion and contraction, and a "flow".

To some extent it seems that orgone "contradicts" the law of entropy. It is "negatively entropic" in the sense that it acquires "energy" from its environment and/or generates information and it is attracted to concentrations of "orgone energy". "Non-entropic" orgonotic processes are the processes responsible for the growth of living things, for the process of learning, and for the evolution from simple to complex species. It forms units that are the foci of creative activity. As an examples of units characterized by the "orgone energy", Reich mentions cells, plants, animals, but also other phenomena like clouds and storms, that are usually modelled through chaotic dynamical systems. All of these units have common features. They have a "life cycle", passing through birth, growth, maturity, and decline.

Also Kelley in [9] says that some orgone energy can be considered responsible for the special characteristics that differentiate living from non-living. He defined life as a kind of chain reaction in the creative process. Kelley identified the following qualities as typifying living as opposed to non-living orgonotic units:

- Reproduction of similar units from one or two parents
- Evolution of the units in the direction of higher development
- Presence of consciousness, the ability to experience feeling, at least to some extent, and to perceive the environment
- Presence of volition, the ability of an individual to control its own movement

Excluding reproduction, the remaining steps are summarized by the abilities to maintain its own internal equilibrium in a constant environment, and to adapt when there are changes in the environment in order to enhance its chances of further existence.

[1] In the most general terms, a dynamical system may be defined as a set of quantitative variables that change simultaneously and interdependently over quantitative time in accordance with some set of equations. From this perspective, Newton's equations of motion for physical bodies were the earliest dynamical model. A dynamical system is chaotic when it can be described by a system of non linear differential equations generating an attractor with a fractal dimension [20]

3. Evolution, adaptation and learning

One of the most remarkable aspects of the evolution in living system is their capability to increase their own internal complexity. This could mean that there are increasingly more parts, more complex relations between parts, more complex behaviours of the parts, etc. Moreover, elements or functions of the same system often come together to form a larger set that operates as a single system evolving to a complex adaptive system at a higher level.

Steels in [22], [23] described the class of evolving complex adaptive systems with four defining characteristics: self-maintenance, adaptivity, information preservation, and spontaneous increase of complexity. Living systems are an obvious subset of this class, but there are also autocatalytic chemical reactions with the same properties. Intelligent or cultural systems could be seen as other examples of this class. To avoid annihilation due to increased entropy, evolving complex adaptive systems need to constantly rebuild them by drawing materials from the environment and to establish a boundary between themselves and the rest of the environment. Maturana and Varela called this process autopoiesis [15].

The simplest living systems, such as unicellular organisms, have all the properties of evolving complex adaptive systems. They use metabolic pathways enclosed in cell membranes to maintain themselves while drawing materials from the environment. More complex living systems exhibit a much wider behavioural repertoire because groups of cells form organs with complex coordinated functions. Adaptivity is not only achieved using chemical means but by changes in behaviour, such as heavier breathing when oxygen content is lower or slower movement when it is very hot. One important evolving feature is the preservation of information by coding the system in terms of genes. The genetic mechanism also provides a much more powerful way to generate more complexity.

In [6] F. Di Primio et al. observed that prokaryotes and unicellular eukaryotes tackle complex and changing environments, both as individual creatures and as parts of populations. The "architecture" of the prokaryote sensorimotor apparatus is at the structural, and at the functional level comparable to that of higher organisms. They looked at these abilities as an indicator for cognitive phenomena. In their experiments they found that prokaryotes have a large number of external and internal sensors of different types. Di Primio et al. argued that these unicellular organisms are able to integrate different stimuli when given simultaneously and they can synthesize sensors and effectors when required and eliminate them when no longer needed. They established that cognition could be seen as the sum of abilities giving an organism the right flexibility and autonomy for coping with complex physical and social environments.

Does that mean that unicellular organisms like amoeba have a brain? If the brain is defined as a structure composed of numerous neurons with intricate connections, the answer is no. But if the functional capabilities of the brain are considered as the criterion for possessing one, the answer is yes. Amoebae also “breathe”, and use their pseudopodia for locomotion and to capture their “prey”. Going higher up the evolutionary ladder, the anatomy and physiology of this amazing structure become more complex.

Living systems have multiple levels of organization, with elements at one level interacting and aggregating to create more complex behaviour at a higher level. John Holland, in [10], gave as the example the ant nest with the simple, stereotypical behaviour of individual ants contributing to a colony that can adapt, evolve, and survive over long periods of time. He said "It is much like an intelligent organism constructed of relatively unintelligent parts". These agents or networks of agents are continually adapting and recombining in new ways as the system learns.

The behaviour of complex adaptive systems is non linear: the interactions within the system yield behaviour more complicated than the sum of the behaviours of the agents. Connections between cause and effect tend to be much less direct and obvious than thinking regarding simpler systems has suggested.

4. Oscillation as a life mechanism

Information process in the brain can be described in terms of different level of synchronization of the activity of various neuron sets [4]. This idea has been confirmed by some recent electrophysiological experiments that show the fundamental role of oscillations and chaos in the functioning of the nervous system. Many models of olfactory, visual and motor systems as well as models of memory and attention have been proposed.

As reported before, following Reich in [19], an alternation of tension-charge-discharge-relaxation is specific to all living phenomena and encompasses every aspect of the autonomic life functions from amoeba to man. This to-and-from movement represents the basic life function of pulsation, i.e. contraction-expansion, experienced by man as pleasure or anxiety whenever a certain threshold is reached. He defined the pulsation as a continuous alternate movement of expansion and contraction characteristic of all living beings. This concept is characterized by an alternation phase between instroke and outstroke. It allows the building of a bridge between observations ? knowledge of behaviour ? growing up. Charles Kelley [9] defined life processes as “continual cycles of instroke and outstroke”. Some of these cycles are slow, others are fast, and many different cycles and rhythms are superimposed on each other in a living system. In the human body, there are fast beating cycles like brainwaves, the heart-beat is a slower one, and the cycle of sexual arousal and release is slower still. Some of these cycles are quite fixed in their frequency, others are more flexible and changeable.

The variability of these cycles can be considered cyclic itself with a more evident association to instroke and outstroke. For example, EEG signals, change from the state of wakefulness (outstroke) to the sleeping state (instroke). Again the sleeping state shows variations in cycle. During the night the sleep of a normal subject can be divided into different cycles of 60 to 90 minutes. These cycles can be decomposed in slow sleep followed by paradox sleep (REM). The subject dreams during the paradox sleep and his muscle tonus decreases. His EEG shows similarities with the EEG in state of wakefulness (outstroke). The slow instroke sleep can once again be divided in four phases, and so on.

The outstroke creates, directs and allows the experience. The instroke acts as a feedback organizing the experience. This flux alternation allows the shaping of boundaries between the inside and the outside world. We live and move in an unknown environment and we need to model it. We search to detect cause-effect connections in what we perceive. The construction of model of shape and information allows and drives our growing up. The existence of boundaries between the inside and the outside enables the organization of the experience and supports the learning process. Boundaries protect the living being from the environment. An example of possible “enemy” is the excess of information. Stimuli can reach such a high level of complexity that the living systems become unable to process them causing it to jam.

Within the outstroke stage, the living system is open to receive input information from the environment. The being can protect himself from a possible information overload by shutting down the input channels and thus switching to an instroke phase. To get lost in information means to lose the ability to decide on the basis of the environment state.

The organism has priorities and needs. It will use them to build the goals of its life. Within the interaction between needs, priorities, goals and environment inputs the living being will make decisions. The pulsing mechanism guarantees that in any situation the system will choose a solution.

Almost all events in the brain should be characterized as a continuous coupling between brain, body, and environment that unfolds in real time. There is a constant “change” that the system undergoes while receiving continuous inputs from various neurons, and processing them. This change helps the system to stabilize itself and to carry out the proper adaptive operations.

5. Experimental emergence of chaotic behaviour

Many experimental data confirm the dynamic chaotic modelling of living systems. Is this chaos useful to model living beings? The answer is very difficult, but there are some experiments showing that, at least order is not better then chaos. In Nature ‘full’ periodicity is very rare. Rapp in [16] measured EEG while the subjects counted backwards by sevens showing that the level of brain function seems to be intimately related to the degree of chaos in the brain waves. He observed variations in the alpha waves, which became more erratic, unpredictable and complex as the person counted backwards. Rapp also monitored the brain waves of epileptics and has found that they become dramatically less chaotic during a seizure, i.e. they become more regular and periodic. The same was found to be true of heart beat intervals, the fluctuations were more chaotic in healthy hearts than in diseased ones.

The cortex activity becomes more coherent as the subject is far from the wakefulness state. The neurons coherence is maximum in Creutzfeldt-Jacob syndrome [2]. In [1] Babloyantz, starting from EEG signals, built a model of the brain showing that the cortex activity follows spatio-temporal chaos laws. The variability in measures of spatio-temporal patterns of brain activity grows up prior to switching from one activity pattern to another. This results in generating critical fluctuation in signals with the consequent decrease in variability after the switching has happened.

Thelen et al. in [24] showed that the development of kicking and reaching in infants is described in terms of dynamic notions such as the stability of attractors in a phase space defined by body and environmental parameters. Movements to new stages in development are explained using bifurcations to new attractors as a result of changes in order parameters, infant weight, body length, etc., as the infant grows. Thelen and Smith believe that “higher cognition” is ultimately rooted in these types of spatial skills learned in infancy, and thus that higher cognition will itself be best understood dynamically.

Treue et al. in [25] studied those neurons about halfway up the visual hierarchy that deals with motion in monkeys trained to watch moving dots on a screen. When the monkeys did not have to follow any dot in particular, the motion cells simply burst into activity every time they spotted a dot heading in their preferred direction. But as soon as the monkeys were asked to concentrate on a single dot (they had been trained to do this without moving their heads or their eyes in order to stimulate always the same retina cells), when the target dot came into view, the cells went wild, doubling their firing rate, while the response from the same neurons to non-target dots moving in the correct direction became weaker. The cells turned the volume up in response to the movement that is the focus of attention, and muted it in response to other movement. This also raises the question of how the brain's mental state is managing to transmogrify the cell's spike pattern.

Neuroscientists dread any hint that something spooky might be going on. They try to slide past the problem of the brain's mental state interfering with the clarity of the long-sought after neural code with euphemisms such as "selective attention effects" or "state-dependent modulations". Desimone et al. in [5] has even found that cells right at the bottom of the visual hierarchy, those that take the "freshest" input from the eyes and might be expected to be least influenced by the brain's mental state, are also at its mercy.

Leopold et al., reported in [14] the results of an experiment in which monkeys looked through stereoscopic displays so that each eye saw a different image of gratings angled in different directions. The brain makes sense of such a conflict by allowing the view of one eye to dominate. The monkey is consciously aware of seeing only a single image.

According to the old view of the brain, the cortex cells that get their input direct from the eyes should not be involved in the mental trick that suppresses the image from one eye. It should happen higher up the hierarchy. Instead, Leopold and Logothetis found that the firing of about a fifth of cells in the primary visual cortex depended on which image the monkeys signalled they were seeing. Even at the lowest level, there was an attention effect working as a strong filter on the input processing.

Bressler et al. in [3], suggested that the spike patterns of a cell are like a whirl erupting in moving water, a local expression of a much wider balance of forces. After all, it is no secret that most of the 5000 input lines to the average brain cell are actually parts of feedback loops returning via neighbouring neurons, or those higher up in the hierarchy. A tenth of the connections come from sense organs or mapping levels lower in the hierarchy. Every neuron is plumbed into a sea of feedback. The signals coming up the chain may provide the seed of a response, but in the end, the cell's spike patterns evolve in concert with how the rest of the brain is reacting to the stimulus. The spike pattern is less a crisp code and more the chattering of a system forever moving towards equilibrium.

When a cell is firing in relative isolation, for example, when an animal is unconscious, its response will be at its most hard-wired, a simple sum of its sensory or lower inputs. Like a ringing phone, the neuron will announce that it has a message, but no one lifts the receiver to get the conversation going. The experiments with wide-awake monkeys show, as soon as a cell becomes drawn into some greater wave of processing, its firing appears far less hard-wired. Of course, it takes time for the wave to build up, which is why attention effects usually show up about a tenth of a second behind the first exposure to the focus of the attention.

Following [8], the phenomenon of attention is one of the most important in the cognitive processes. The event driving us from the state of inattention to the state of attention may contain a very small amount of information. It can be a friend’s voice, or a colour and it can be very close to us or very far away. Only after we have paid attention, our brain becomes able to analyse and to evaluate the information flux coming from the environment.

The brain is always in a state of tension. There is a steady tick-over of at least three or four spikes a second even in an area of the brain that seems to be doing nothing. The temptation is to dismiss this activity as meaningless, just as a leakage of current. The spikes bouncing around the brain's connections must be maintaining it at a certain level of tone, giving each new input something to disturb in the first place.

This background firing presumably supports knowledge to some extent. The brain stores memories as patterns of connections between cells. New experiences prompt the strengthening of old connections, or the growth of new ones. The echoing of the tick-over firing around the brain could be a defocused representation of everything you have ever learnt or known. When the brain processes new information, it is not a matter of lighting up dark circuits but of driving a generalized, weakly defined state of representation towards a specific one. The brain is always on. It just needs tuning in.

6. The edge of chaos

When a continuous change in a control parameter crosses a critical value, the system's behaviour may change qualitatively or discontinuously. Such changes always arise due to instabilities. Instability is a dynamic mechanism underlying spontaneous, self-organized formation of patterns and pattern change in nature's open systems [12]. In such systems that are open to material and communication exchanges with their environment, these are called "non-equilibrium phase transitions" or "bifurcations".

At each level of complexity, novel properties appear whose behaviour cannot be predicted from knowledge of component processes alone. Self-organization occurs on several levels from the single cell up and shares many of the same dynamic characteristics across levels. Kelso in [11] maintains that "The brain is fundamentally a pattern forming self-organized system governed by potentially discoverable, non-linear dynamic laws. Behaviours such as perceiving, intending, acting, learning, and remembering arise as metastable spatio-temporal patterns of brain activity that are themselves produced by the cooperative interactions among neural clusters. Self-organization is the key principle".

One of the most significant ideas of complexity science is that "life is developed at the edge of chaos." While specific facets of this concept remain under debate, complexity researchers argued that systems that are most adaptable and alive operate in a zone between order and disorder. In [13], Christopher Langton recognized that this zone was much more than a boundary. There was another state besides order and chaos, and this intermediate region was where a system was most alive. Stuart Kauffman in [7] stated, "To engage in the Darwinian saga, a living system must first strike an internal compromise between malleability and stability. To survive in a variable environment, it must be stable to be sure, but not so stable that it remains forever static." Ralph Stacey [21] called this the "zone of creativity at the edge of disintegration." He cited the similarity of this complexity concept to findings of psychodynamic theory. Similar to the idea of the "edge of chaos" is a characterization of such systems as non-equilibrium or far-from-equilibrium. These terms refer to the way systems become fertile breeding grounds for an emerging order when they are no longer bound to conditions maintaining the status quo or "equilibrium" a state in which things are done in the same old way.

7. Living artefacts

Living beings adapt at multiple levels and time-scales to changes in their environment and grow up in dimension and/or in knowledge. On the other hand, living artefacts are autonomous, self-sufficient and self-motivated systems characterized by finite resources. Like living beings, living artefacts should capitalize upon interactions among different levels of adaptation and growth.

Slowly, within the growing up process, the number of processable information increases. A living artefact grows up when its capabilities, abilities/knowledge, shift to a further level of complexity, i.e. the complexity rank of its internal capabilities performs a step forward. The new level can "slave" the level or the levels below, or it is possible to see a kind of co-evolution towards greater complexity.

A living artefact should be able to increase its own internal complexity during its operation. It spontaneously performs an increase in complexity. Moreover instances of the same system often come together to form a larger whole that operates as a single evolving complex adaptive system at a higher level. It is possible to identify different instances of these evolving complex adaptive systems. Each instance builds further upon the previous instantiations and adds more powerful machinery so that self-maintenance and adaptivity are more successful. Information is better preserved and the growth of complexity becomes faster.

A living system can grow up starting from a pre-structured set of functions. It develops new abilities to adapt better to the environment with a movement from childhood to the maturity. During these phases, the being will learn to make its experience through interaction with the environment. It will acquire the behaviour of new stages from a qualitative point of view.

Growing up implies an enlargement of the knowledge internal map. The object of knowledge, once defined and processed as a gestalt, can be compared with older knowledge and with known gestalts belonging to different contests. From the knowledge level, i.e. processing and analysis, growing up introduces a new level of comprehension of the objects in relationship to other known objects. It produces meaning. The new object representation can be more abstract and it strikes roots in the experience connected to a preceding familiar object. It can have a more complex structure. When a human being successfully reorganize its knowledge map, pleasure is felt because confusion is decreased. The internal cognitive map grows up having learned a new gestalt and after comparison with the preceding gestalt. The two gestalts have been combined to form a gestalt of higher order.

Different steps can be identified in the whole process of information processing. Firstly there will be a “steady” state characterized by a certain level of order/chaoticity. Secondly there will be a level of growing of chaos when a new set of information comes inside without being included in the known gestalt. The system can find conflicting information. When the actual internal map organization does not allow any satisfying configuration, a new order will be necessary to allow the coexistence of conflicting information. The system at this stage challenges the whole internal map organization. Here there is a break-up. A chaotic phase follows as a tentative reorganization. The living system needs a certain level of order in the environment knowledge, so it reorganizes old and new information to let them to coexist.

Lastly a new order will appear as a result of the creation of a new internal map path compatible with the pre-existing knowledge organization.

8. Learning as growing up

According to Piaget in [18], humans "build” their own knowledge through their experience. Experiences enable them to create schemas (mental models) in their heads. These schemas are changed, enlarged, and made more sophisticated through two complementary processes that are crucial for processing from stage to stage: assimilation and accommodation. Assimilation refers to the way in which a child transforms new information so that it makes sense within their existing knowledge base. That is, a child tries to understand new input in terms of his/her existing knowledge. For example, a baby who is given a new object may grasp or suck on that object in the same way that he or she grasped or sucked other known objects. Accommodation happens when a child changes his or her cognitive structure in an attempt to understand new information. For example, the child learns to grasp a new object in a different way, or learns that the new object should not be sucked. In that way, the child has adapted his or her way of thinking to a new experience.

These two schemas become filters even for the acquisition of information in a process that is auto referring and that grows up. Taken together, assimilation and accommodation make up adaptation, which refers to the child's ability to adapt to his or her environment. According to Piaget, development is driven by the process of equilibration. Equilibration encompasses assimilation (i.e., people transform incoming information so that it fits within their existing thinking) and accommodation (i.e., people adapt their thinking to incoming information). Piaget suggested that equilibration takes place in three phases. Firstly children are satisfied with their mode of thought and therefore are in a state of equilibrium. Secondly they become aware of the shortcomings in their existing thinking and are dissatisfied, i.e., are in a state of disequilibration and experience cognitive conflict. This step is a more chaotic state. Finally they adopt a more sophisticated mode of thought that eliminates the shortcomings of the old one, (i.e., reach a more stable equilibrium). This step is characterized by a new level of order state.

9. Conclusions

In this paper some analysis on the possible usage of chaos modelling for living being has been done in order to extract characteristics for building a living artefact.

Growing up implies an enlargement of the knowledge internal map. Different steps can be identified in the whole process of information processing. Firstly there will be a “steady” state characterized by a certain level of order/chaos. Secondly there will be a level of growing of chaos when a new set of information comes inside without being included in the known gestalt. The system can find conflicting information when the actual internal map organization does not allow any satisfying configuration. A new order will be necessary to allow the coexistence of conflicting information. The system at this stage challenges the whole internal map organization. Here there is a break-up. A chaotic phase follows as a tentative reorganization. The living system needs a certain level of order in the environment knowledge, so it reorganizes old and new information to let them to coexist. Lastly a new order will appear as a result of the creation of a new internal map path compatible with the pre-existing knowledge organization.

A living artefact grows up when its capabilities, abilities/knowledge, shift to a further level of complexity, i.e. the complexity rank of its internal capabilities performs a step forward. The new level can “slave” the level or the levels below, or it is possible to see a kind of co-evolution towards greater complexity.

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