Living Systems Dynamics : A New Approach for Knowledge Representation

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Abstract

In the perspective of formalizing abstraction as a fundamental facet of cognition, we study knowledge in its relationships to the biological substratum from which it outcomes. Our research is mainly founded on the works of F. J. Varela concerning the autonomy of living systems (autopoiesis) and of S. Lupasco on antagonism.

We show how autopoiesis brings a new enlightment upon knowledge, by turning representation problems to organization problems and how the autopoietic dynamics of living systems leads to a new formulation of machine learning. By developing new internal dynamics, a system does not learn to know its environment, but to adapt himself to it.

It follows that modelling an autopoietic system requires to focus, no more on sharing of semantic universes between a system and its environment, but on structural models producing behavioural regularities of the system in answer to environmental perturbations. Autopoiesis seems therefore more suited for developing adaptive and complex systems, especially when an exhaustive specification of the operating factors is prohibitive, as well as for providing a unified framework for modelling cognition. Moreover it provides a paradigmatic foundation to the design of massively parallel systems.

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1. INTRODUCTION

From the beginning of computer science, nature-mimetism was one of the two fundament approaches by which man tried to open up the age of automatic calculus and reasoning. However, f economical and technological reasons this direction was neglected for a long time in favour of a approach constituated around the so called architectural model of "Von Neumann". But, due to th constant progression of the scales (integration density of circuits, memory capacities, computin power), a new technological context is now in place. Unless from a harware point of view, massive parallel systems nowadays compete with biological brains and allow to restore to favour the natur mimetic approach [3].

In fact, it is perhaps much more than a simple restoring into favour, but even the only hope to take step forward in computer science. Actually, the applications more and more complex that we tackl come up nearly always against the same limitations, that is the incapability to learn and to ada themselves. Once it is configurated, even the most sophisticated software is unable to evolve. Most the time, it is simply not conceived to evolve, or if it is, it is only by inserting explicit and controll phases of learning into the operating process. Maybe, only the system software can be considered being adaptive. For example, by multiple and entangled algorithms of memory managemen ressource allocation, etc, present operating systems adapt themselves quite well to varying demand In the same way, the management software of computer networks disposes of quite resilient routin algorithms. Besides, we take as possible that this adaptability of system software is an "emergenc from the structural complexification of the machines, namely because of their layered structure. But the application level, even for advanced applications pertaining artificial intelligence, adaptability far from being obtained. Therefore natural systems, and in particular living systems may constitute remarkable source of inspiration for trying to break down these limitations.

As for us, our interest in living systems takes root in the difficulty to model abstraction. According cognitive psychology, we consider abstraction as a basic capability of human cognition, which cove as well the ability to generate concepts from facts (in case of learning) than the ability to focus certain features of an object or a situation (in case of problem solving). However in computer scienc one usually distinguishes, for example, reasoning from memorizing and one usually decompos reasoning into deductive, inductive and abductive modules. Hence, the need to tackle abstraction as whole led us naturally to join the "holistic" trend, in which genetic psychology and situation linguistics as well as the work done by Brooks in robotics [1] can be gathered together. Within th trend, abstraction is seen as an emergence of the activity of one living being fitted with a relative complex central nervous system and interacting with his environment. Therefore, one can hope th this approach can end in a reformulating of knowledge representation and knowledge acquisitio problems able to result in systems more adaptive and more humanoid than those of classical artifici intelligence.

The aim of this article is to communicate the investigations we made in the domain of living system with this underlying hope. Here are some of the questions we touched on:

- What are the links between the dynamics of living systems and the dynamics of th environment ?
- To survive, does a living system need to have an internal representation of its environment ?
- What can we call "knowledge" in the case of living systems ?

The paper is organized in two sections. The section 2 presents the conceptual frameworks proposed b F. J. Varela and S. Lupasco to tackle the dynamics of living systems. In the section 3, we discuss ho these frameworks lead to a new approach of knowledge.

2. LIVING SYSTEMS DYNAMICS

Starting with the work done by F. J. Varela [8][9] and S. Lupasco[6], we successively characterize the living systems dynamics in terms of autopoiesis, of antagonism, of homogenization and heterogenization, and finally of potentialization and actualization.

2.1. AUTOPOIESIS

A living system is a dynamic system able to maintain itself in a diverse and changing environment. F. J. Varela defines a living system as being *autopoietic*, namely *auto-productive*. Autopoiesis is seen by Varela as a particular form of autonomy, where autonomy designates the capability of a system to define itself, and furthermore its non-controllable character. Varela defines the notion of autopoiesis as follows.

Definition : Autopoietic system
An autopoietic system is organized as a network of processes which produce components. These components continuously regenerate the network which has produced them through transformations and interactions. They constitute the system seen as a concrete unit in space by specifying the topological domain where the system realizes itself as a network.

In other words, the organization of an autopoietic system specifies the system structure and by the way its physical frontier, and this structure respecifies the organization in turn.

It follows that an autopoietic system continuously produces and specifies its own organization. An autopoietic organization is a network of processes which produces components. Of course, in a physical system, the components may change: the fact that the system is effectively constituted of an element A or of an element B does not matter. But the relations between the properties of the different types of components endows the system with a certain dynamical stability.

The dynamics of an autopoietic system may be defined in terms of three types of relations:

- *specification relations* governing the component production;
- *constitution relations* determining the logical structure of the system, i.e. its topology;
- *order relations* determining the execution order of the specification relations and of the constitution relations.

These relations describe processes which are interdependent for their realization and generation (cf. figure 1).

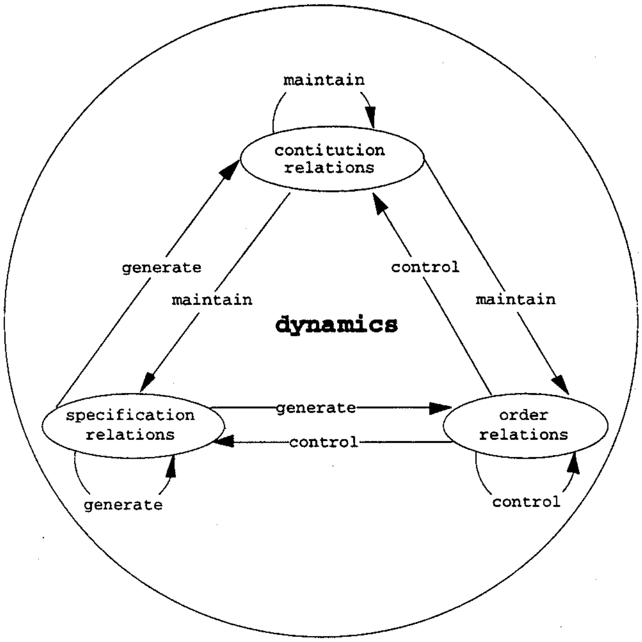

Figure 1. Autopoietic dynamics

The specification relations generate the constitution relations, the order relations and the specificatic relations, by producing the components which realize them. The order relations result from tl interdependence between the specification relations and the constitution relations. They control tl order of execution of the three types of relations and therefore they constitutes the dynami algorithm. The constitution relations define the logical structure of the system. This logical structu allows the renewal of the specification relations and therefore of the order and the constitutic relations. In other words, the logical structure enables the algorithm of the autopoietic dynamics to r again and again.

An autopoietic system defines its own dynamics. This dynamics emerges from the interactio between its components. The interdependence between the production of components and tl constitution of the internal structure induces the stability of an autopoietic system.

Now, we describe how an autopoietic dynamics gives a system the capability to maintain itself in diverse and changing environment.

Viability of a living system

An autopoietic system, such as a living system, maintains itself constantly far from tl thermodynamical equilibrium. This desequilibrium is preserved by the autopoietic dynamics, throu a constant exchange of energy and matter between the system and its environment. An autopoiet system is then necessarily open.

An autopoietic system is in a steady state when its interactions with the environment correspond to i needs and are therefore totally integrated in its dynamics.

However, the interactions coming from the environment are changing and varying. They do n necessarily match the needs of the system dynamics; they can even threaten it. Due to thi interactions coming from the environment are called *external perturbations* [4][7].

The environment is not the system designer. However, it participates in its morphogenesis. Indeed, tl autopoietic dynamics of a system can change in order to maintain the autopoietic organization and tl transformations inside the system can vary. The transformations due to new perturbations can diff from the transformations due to previous perturbations. The dynamics is replaced by a new one fo new context of perturbations.

The interdependence between the system state and the domain of possible perturbations forms the *structural coupling* [2].

2.2. ANTAGONISM

Through the work of Varela, we have seen that a living (autopoietic) system results from an equilibrium between its internal dynamics and the dynamics of its environment. The work of S. Lupasco adds that every autopoietic system results from an equilibrium between two antagonist forces, and that the notion of antagonism is present both inside an autopoietic system and in its relationship with its environment.

Lupasco's principle of antagonism

Every system results from an equilibrium between the antagonist properties of its components.

An autopoietic system involves two kinds of antagonism:

- *Internal antagonism.*

  The specification relations mutually generates themselves. They include the composition and the decomposition of certain components. To be autopoietic, a dynamics needs to include antagonist specification relations, namely to be both producer and destroyer of the components that generate it. The specification relations desintegrating components that produce the constitution relations, are called *internal perturbations*, because they momentarily endanger the viability of the system.

- *External antagonism.*

  The environment is both a source of material for the system and a source of (external) perturbations that the system must compensate in order to maintain its viability. The system is in a steady state when its dynamics permits him to compensate the external perturbations, namely when the antagonism between the autopoietic dynamics and the dynamics of the environment mutually equilibrate themselves.

Antagonism seems to naturally induce emergent behaviours and self-organization. Numerous examples from biology could be cited. One of them is provided by the pancreas: insuline and glucagon are two antagonist hormones produced by the pancreas. They control the level of glycaemia. The first one prevents hyperglycaemia and the second one prevents hypoglycaemia.

Antagonism reveals itself fundamental for the viability of an autopoietic system. In fact, antagonism allows the system to stay far from the thermodynamical equilibrium, i.e. to exist. Moreover, it plays a fundamental role in the system's morphogenesis.

2.3 HOMOGENIZATION/HETEROGENIZATION

Now, we show that antagonism enables to characterize autopoietic systems in terms of an opposition between homogenizing and heterogenizing dynamics.

Homogenization, i.e. the capability of positive entropy, obeys the second principle of thermodynamics. On the contrary, heterogenization, i.e. the capability of negative entropy, goes against this principle.

It may be outlined that an autopoietic system is at least composed of two different types of components. This is a necessary condition for the existence of an autopoietic dynamics. An autopoietic system is hence an heterogeneous system. An internal perturbation which desintegrates system components appears as a death process. The relations which are antagonist to these perturbations constitute therefore heterogenizing relations.

As a source of raw materials, the environment participates to the heterogenization process of the system. The external perturbations constitute an homogenizing pressure on the system: they tend to dissolve the system into the environment.

Inside a system, antagonism appears as a struggle between heterogenization and homogenization. Th autopoietic dynamics is an heterogenizing process resulting from an dissymmetric equilibriun between homogenizing and heterogenizing relations in favour of heterogenization. As long as i exists, an autopoietic system is an heterogenizing system.

2.4 POTENTIALIZATION/ACTUALIZATION

The organization of an autopoietic system is defined by a network of processes producin components. This network describes the interdependencies between specification relations and orde relations. The different possible traversals of this network correspond to the different possibl dynamics of the system. One dynamics is actualized depending on the internal or external curren perturbation.

In the context of changing perturbations, an autopoietic system switches from one steady state t another steady state by developing new dynamics or even new logical structures. The issue of ne external perturbations may be the development of new specification relations and by the way of ne internal perturbations.

We classify the possible transformations inside a system in two classes:

- *Complexifications*: they regroup the enrichments of the current network of componer production. The new current dynamics appears as a complexification of the previous one.
- *Reductions*: they regroup the internal transformations leading to a breakdown of the previou network.

A complexification constitutes a victory of the system against the homogenizing pressure c perturbations. It diplays the victory of heterogenization against homogenization. On the contrary, reduction constitutes a defeat. It displays a victory of homogenization against heterogenization. A the transformations inside an autopoietic system are determined by the system itself, i.e. they emerg from the interactions between its elements. So, complexifications as well as reductions are at *potential* state in the system and the perturbations possibly provoke their *actualization*. Consequentl the actualization of a complexification, respectively of a reduction, corresponds to a potentializatio of a reduction, respectively of a complexification (cf. figure 1).

In fact, a transformation occurring in the network of the system is generally a composition c complexifications and reductions. The new actualized dynamics integrates itself in a new networ containing a potential of logical structures and of dynamics. Moreover, the actualization of this ne network maintains at a potential state the compositions of reductions and complexifications of th previous network, able to be actualized by possible perturbations.

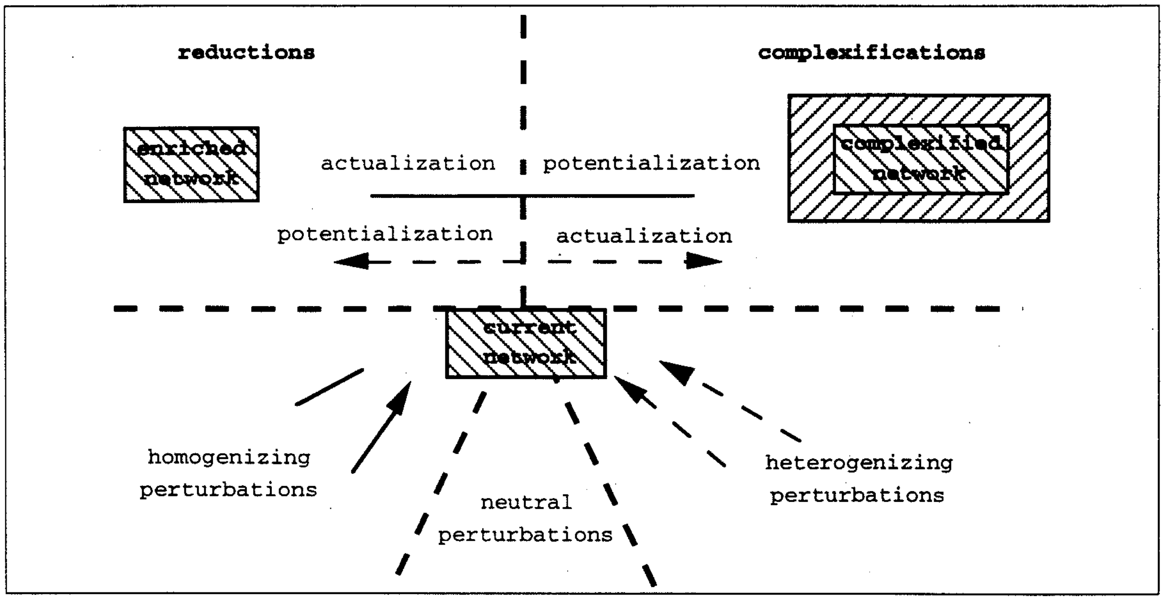

Figure 1 : Morphogenesis of an autopoietic system

The current network of component production is subject to three types of perturbations (internal and external). It compensates them in three different ways:

1. Neutral perturbations can be compensated through one of its dynamics. The network is left unchanged.
2. Homogenizing perturbations lead to the actualization of a reduction of the current network, and consequently to the potentialization of a complexification.
3. Heterogenizing perturbations lead to the actualization of complexification and consequently to the potentialization of a reduction of the current network.

3. LIVING SYSTEMS AND KNOWLEDGE

In this section we present the innovative aspects of autopoiesis for representation and knowledge acquisition. We show that autopoiesis joins the current research in distributed artificial intelligence.

3.1 AUTOPOIESIS AND KNOWLEDGE REPRESENTATION

The viability of an autopoietic system appears as the capability to adapt itself to the perturbations coming from the environment. This adaptability remains quite different from the ability to "know" an environment, especially in the "representational" sense traditionally used in artificial intelligence.

An autopoietic system does not have knowledge about its environment: it just compensates the perturbations it generates in order to maintain its viability.

An autopoietic system defines itself and manages itself by developing adequate dynamics for different contexts of internal or external perturbations. Even if the perturbations induce changings of dynamics or changings of logical structures inside the system, they do not necessarily explain the internal functioning of the system. This because there is no necessary semantic correspondence between the events of the system and the events of the environment.

The autopoietic dynamics emerge from the interactions between the components of the system. To conceive an autopoietic system, one has then to describe the interactions between its components.

These interactions have to include:

- antagonist specification relations;
- constitution relations.

From these relations emerge the order relations. The more the network, composed of order relation is complex, the more it is able to resist to changing perturbations.

Modelling autopoietic systems requires to be interested no more in the sharing of semantic universe between the system and the environment, but to be interested in structural models producin *regularities of behaviour* in front of perturbations of the environment.

In the framework of autopoietic systems, *knowledge representation problems* turn over t *organization problems*. The notion of knowledge merges with the notion of organization.

3.2 AUTOPOIESIS AND KNOWLEDGE ACQUISITION

We show now that an autopoietic system is able to learn and that the autopoietic dynamics is a ne approach of machine learning.

The perturbations entail transformations of the internal knowledge of the system by provokin changings of its organization. The basic changings inside the system in front of perturbatio (complexifications and reductions) constitute two opposed behaviours for knowledge acquisition:

- In case of a complexification, the system enriches its knowledge: it *learns* to adapt itself to i environment.

  At any time, an external or internal perturbation can reactualize very close relations, eve similar to an older state of the system dynamics: the system is able to *remember* its past.
- In case of a reduction, the system looses a part of its knowledge by undergoing a parti collapse of its organization: it *forgets* its past.

  A return to an older state of the dynamics can constitute a *re-learning* of a past event.

In the general case, a changing is a composition of a complexification and a reduction. Then, the ne network of relations results both from an enrichment and a partial collapse of the previous networ The system learns and forgets at the same time.

Via actualizations and potentializations, triggered by perturbations, the autopoietic dynamics explai the emergence of knowledge inside the system. Recurrent perturbations may for example actuali same states of dynamics and by the way induce behavioural regularities enabling to speak knowledge. However in this context, knowledge does not presuppose any symbolic status and has representation value: knowledge is a purely dynamic notion.

3.3 PRACTICABILITY OF AUTOPOIESIS IN COMPUTER SCIENCE

Here, we discuss the practical interest of the concepts of autopoiesis for the design of systems computer science.

Programming languages conceptually evolved from the procedural style to the object-oriented sty and then to the paradigm of *multi-agent systems*. In this paradigm, objects, which are more or le complex entities, become active. This conceptual evolution also coincides with the evolution hardware to massively parallel architectures. This one naturally requires a distributed formulation the problems, which involves either *cooperating* units, as for example complex units representi experts, or *interacting* units whose behaviours are reduced to simple *reactions* to events.

Inside the trend of reactive multi-agent systems, we conceived a programming language based on naive physics, in which the interactions between agents are based on attraction-repulsion phenome induced by *charges*. The language allows to gather different types of charges inside an agent syste All the dynamics of a system is governed by the concurrent action the charges (for further details, s [5]).

Such a programming language seems a good basis for building autopoietic systems. Actually the dynamics generated by the concurrent actions of charges is autopoietic in the sense that the system continuously reorganizes itself in order to reach some equilibrium. This self-organization is achieved both by movings of mobile agents in the environment and by changings of charges inside agents.

Despite antagonism is not forced by this language, one kind of antagonism can however trivially be introduced in an agent system by the use of typical interaction schemes involving couples of charge types shared between agents. Such an antagonism is still able to induce very interesting self-organization phenomena.

Moreover, charges are entities naturally coupled with actualization and potentialization mechanisms. But in order to have knowledge (as we defined it previously) emergence, the dynamics of an artificial autopoietic multi-agent system must be enrootened in an antagonism of homogenizing and heterogenizing dynamics. This means that the second principle of thermodynamics must apply to artificial autopoietic systems for becoming their foundation.

The autopoietic dynamics constitutes a very promising reformulating of knowledge representation and knowledge acquisition problems able to overcome the major limitations of present software methodology. First, it can lead to really adaptive systems. Second, it is adapted for developing complex systems, where an exhaustive specification of the operating factors is often prohibitive. Finally, it may provide a unified framework for modelling cognition.

4. CONCLUSION

The antagonism principle expressed by S. Lupasco seems to be fundamental for self-organization in living systems. It is a necessary condition of the existence and the viability of an autopoietic system. It grounds autopoiesis and through actualization and potentialization mechanisms results in the emergence of knowledge.

Therfore, autopoiesis enlightened by antagonism leads to a new formulating of knowledge representation and knowledge acquisition problems. Antagonism shows that in order to exist, an autopoietic system does not need to "know" its environment, at least in the representational sense traditionally used in artificial intelligence, but only to adapt itself to it.

Namely, due to the ability of the environment to produce recurrent perturbations, the coupling between the system and the environment produces behavioural regularities in the system. In this way, we can say that an autopoietic system "learns".

In the context of autopoiesis, the notion of knowledge acquires therefore a dynamic sense. In this way, knowledge finds again its prime etymological sense. Our bet is that this dynamic view of knowledge induced by autopoiesis enables to improve the modelling of cognition and in particular the abstraction capability.

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