Attributes and Qualities: A Structural Approach for Complex Systems

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Abstract

Many natural or artificial systems are considered to be complex because we experience the greatest difficulties of expressing their external behaviors in a satisfactory mathematical form. The structural approach proposes a different methodology consisting in isolating and modeling the nodes of complexity of a system by a fine analysis of their internal organization.

1. Introduction

To have at their disposal a computer system which would setup itself, which would configure itself and repair itself is the dream of numerous system administrators. The Autonomic Computing project [2] aims at carrying out various building blocks making it possible to build such systems. One of the principal problems encountered in this type of project is the mastery of the complexity of the systems to be designed. In addition, these new systems must integrate a particularly delicate property to understand and to implement: autonomy.
Whatever system, artificial or natural, the method which prevails today in the study of complex systems carried out in specialized institutes consists in the mathematization of the interactions between the elements composing the system. However, all interrogations relating to the systems considered to be complex do not lend themselves to this mathematization. Let us take an example illustrating this difficulty: is the study of the intelligence of a natural system (individual or animal) a complex problem? It is unlikely that researchers answer by the negative. However, trying to represent with one or more mathematical equations this so particular property could only make the specialists in cognition smile. Lastly, even if certain aptitudes of some animal societies (ants, bees) qualified as collective intelligence or swarm intelligence were mathematized, this type of intelligence has only little to do with the property of intelligence understood in its most common sense, i.e. that which emerges from human cognition.
The object of this paper is to present through a particular self property, autonomy, a new theorized approach of complex systems: the structural approach. It provides the conceptual means making it possible to isolate and explore certain nodes of complexity which allow to consider that a system is complex.
For this purpose, we will reason on an abstract model of complex system, a sufficient model to specify the two elements which according to our work are sources of complexity of a system: the dynamic entities called agents or particles according to the considered field, and the interactions between the dynamic entities or between the entities and the environment in which they are immersed.
Reduced to these two major concepts, the agent and the interaction, the studying of the complexity within a system consists in determining its manifestations in the internal functioning of the agents and their relationships. The interactions between a multitude of

elements is a source of complexity known since the first work carried on the general systems (physical, biological, social systems, etc). The work which is described here concerns the study of the complexity reduced to only one element, called agent, immersed in a vaster unit called environment. In other words, only one dimension of complexity was explored: the complexity related to the internal functioning of an agent and carried by certain properties of this entity.

This paper is structured as follows. Section 2 presents the main conceptual tool of the structural approach: the attributes/qualities dichotomy. Then, two types of approaches are described which are at the disposal of a modelisator who wants to study a complex system. Section 4 briefly introduces the models of autonomy available to build an autonomous system considered as a complex system. Lastly, the two approaches are compared in relation to the criteria defined in section 3 and to the property of autonomy.

2. Properties of the agents

Several researchers synthesized in the form of lists the properties most often associated to software agents: it is mainly about perception, autonomy, flexibility, reactivity, adaptability, mobility and replication. When one wishes to integrate within the same agent two properties such as mobility and autonomy, he quickly reaches the conclusion that these two properties cannot be treated in the same way.

Our work led us to distinguish two categories of properties which have a deeply different nature: attributes and qualities.

2.1. Attributes

An attribute corresponds to the notion, the conceptual idea which one has of a property which is by nature simple (or complicated) such as for example the idea of *mobility* in MAS (Multi-Agent Systems). It materializes a property of an agent which can be reduced to a simple or complicated mechanism with perfectly known parameters. Thus, the *mobility* attribute can be provided with only one parameter: the next site to be reached. One or two data can parameterize the *replication* attribute: the replication rate and the site of replication when it is about a remote replication.

An attribute does not induce nor include a particular implementation of the property. The interest of the attribute concept is that it identifies without ambiguity a simple or complicated property.

2.2. Qualities

To the more or less simplicity of the attributes, we oppose the complexity of qualities. Whereas an attribute can be complicated to represent, modeling or implementing a *quality* is complex by nature, i.e. difficult (perhaps impossible) to have an intimate knowledge of it. Qualities are properties with not well determined borders, with their contents changing according to the points of view which one can have. They authorize multiple models and different interpretations, when these interpretations are not contradictory.

The properties which we identified as qualities play an essential role in agent oriented systems for at least two reasons. First of all, qualities make it possible to distinguish various classes of agents (autonomous agents, intelligent agents, etc). Indeed, in the MAS field, agent designers lean on a principal quality to characterize their agents: *autonomy* (Franklin and Graesser), *autonomy* and *intelligence* (Jennings and Wooldridge), *sociability* (Huhns and Sing). Then, a quality present in an agent identifies a node of complexity of this agent. In order to untangle the various nodes present in a complex system, we developed a *structural approach* of the complex systems.

3. Approaches for complex systems

It is frequent to confuse *complicated system* and *complex system*. Often, this confusion is caused by the same great number of elements which compose the two types of systems and by the difficulty of understanding the interactions occurring between their elements. Moreover, in both cases, the *system* term means a *representation* or a *pre-representation* of the studied phenomenon. However, there is a difference in nature between these two categories of systems: a *complicated system* can *be simplified* skillfully in order to be able to carry out a particular calculation, whereas a *complex system* cannot be reduced to a *complicated system* by any handling under the penalty of losing the intelligibility of the studied unit.
Various causes seem to be at the origin of the complexity of a phenomenon: the number of elements, the diversity and the nature of the interactions between its elements, the mixture of determinism and indeterminism, order and disorder, the cascade or circular internal transformations, the presence of emergent processes. However, certain systems made up of few elements or provided with few simple rules express a complex behavior. Consequently, all complex systems are not of comparable nature and a single approach is not appropriate to study all complex systems.
We defined a new theorized approach of complex systems called *structural approach* which is more based on the architecture of the complex systems rather than on the number of elements which compose it. Two types of approaches usable by a modelisator to study a complex system can thus be distinguished: the traditional approach called *equational* approach and the *structural* approach. The main characteristics of these two methodologies can be stated in the following way:

Equational approach
- The elements are many and indistinguishable: they are considered as *particles*
- It does not take into account the internal composition of the system's elements because this composition is not regarded as relevant in the study of the complexity of the global system: the constitution of an element (internal architecture, components) is transparent for the observer
- It uses powerful mathematical formalisms
- It favours obtaining quantitative results (prediction, optimization).

Structural approach
- Elements are not numerous
- It takes into account the internal composition of the system's elements because it is regarded as one of the sources of the system's complexity. It adapts to the presence of heterogeneous elements
- It proceeds by analysis and synthesis
- It favors obtaining qualitative results (interpretation, explanation).

In order to illustrate the specificity of the structural approach, we will use as examples systems composed of autonomous agents and the models of autonomy which they convey. Then, the characteristics of the two approaches mentioned above will be compared point-to-point, by taking typical examples treated by the equational approach.

4. Autonomy models

Autonomy is a paradigmatic example of what we called a quality. Indeed, autonomy seems difficult to synthesize with only one theory or model. In fact, reducing autonomy to a single model eliminates the essence of this property. This is why many models of autonomy were proposed by researchers in the Artificial Intelligence field. Various aspects can be released from these various models: *organic autonomy* of biological inspiration (Varela, Bourgine), *social autonomy* based on the social relationships between agents (Castelfranchi, Scerri) and *decisional autonomy* founded on the choice of the agent (Barber, Vendryès).

Rather than describing in detail these various models of autonomy, we will present the three criteria which enabled us to synthesize them: (1) autonomy as a *global* or *partial* property of the agent, (2) *social* or *nonsocial* autonomy, (3) autonomy as an *absolute* or *relative* property.

Autonomy is called *global* when its definition applies to the entire agent. Autonomy is *partial* when the property applies to a part of the agent. In this case, the agent is autonomous with regard to something.

Autonomy is described as *social* when its definition or characterization explicitly refers to one or more other agents. It is *nonsocial* in the contrary case.

Autonomy is *absolute* when only one level of autonomy is defined: the agent (or part of the agent) is autonomous or is not autonomous. Autonomy is *relative* when several *levels* of autonomy are defined.

The criteria presented above make it possible to sketch a taxonomy of autonomy models: the agent autonomy presented in [1] is *partial*, *relative* and *social*. The model developed in [3] is a *global*, *absolute* and *nonsocial* autonomy.

On our side, we developed a model of autonomy called *autonomy with regard to an attribute* [4] where autonomy is *partial*, *absolute* and *nonsocial*. This autonomy is: (1) *partial* because it applies only to a part of the agent (a particular attribute), (2) *absolute*, the agent is autonomous (or is not autonomous) with regard to this attribute, (3) *nonsocial*, the model does not require the presence of a second agent.

After this short presentation, it is easy to notice that autonomy models are at the same time numerous, heteroclite and with disjoined contents. Being able to take into account strongly heterogeneous components is one of the advantages of the structural approach.

5. Comparison of the two approaches

In order to clearly distinguish the methods and application domains related to the equational and structural approaches, we compared them using the four criteria mentioned in section 3: the number of considered elements, the architecture of an element, the representation of the selected aspects and the type of results which are produced.

<u>Number of the system’s elements</u>:

Complex systems generally considered by the equational approach are composed of a very great number of elements. Let us mention as examples meteorology (each element of the system is a small cube of the total space) or economic systems (each element of the system is called an economic agent). The elements of these systems are undifferentiated and the addition or the removal of an element of the system does not have any significant influence on the global behavior of the system.

In autonomous agents systems and whatever the model of autonomy considered, agents are very few. The most meaningful example is our system only composed of one autonomous agent. Consequently, the addition or the removal of an agent causes significant effects on the system. Even in the autonomy models which integrate several agents, like adjustable autonomy, the modification of the number of elements has considerable effects on the distribution of the control inside the system.

Internal architecture of an element:
In the equational approach, the modelisator is unaware of the internal architecture of the system elements: the contents of the elementary space cube or the internal architecture of the economic agent are not considered. Only the external behavior of the elements is taken into account in modeling.
In the structural approach, the internal composition of an element is of the utmost importance, in particular with respect to the attributes and qualities incorporated into the element. The modeling of the system is built by applying the attribute/quality filter to the properties of the elements and by specifying the relations existing between these attributes and these qualities. For example in our model, autonomy is related to an attribute (ex: autonomy with regard to the agent mobility, autonomy with regard to the replication). In other models of autonomy, an agent contains a representation of the behavior of the other agents composing the system.

Representation:
In the equational approach, the tools used to model the behavior of complex systems are essentially mathematical ones (nonlinear differential equations, statistical physics, cellular automata). It studies complex systems using a *"1 to 1" modeling*: this modeling means that for a given complex system corresponds only one set of mathematical formulas which will make it possible to lead to the result.
In the structural approach, modeling is based on the individual properties of the system’s elements, properties expressed in terms of attributes and qualities, but also in terms of relations existing between the properties kept for modeling. Moreover, it studies complex systems using a *"1 to N" modeling*: a given complex system can be represented by several parallel models, each one modeling a different aspect of the same property. Let us consider the system made up of only one agent autonomous with regard to the replication attribute. This agent exhibits a nonsociable autonomy model but it is possible to provide a complementary sociable autonomy model which would be triggered by the presence of one or more other agents introduced into the system. The two models of autonomy represent different aspects of the same property and are simultaneously present in the complex system which is the agent.

Expected results:
The equational approach is primarily used to calculate or predict a result: what will be the weather like in Boston tomorrow? What is the dynamics of the simulated economic system? It is also used to optimize a system functioning: in a computer network, what is the best path for a set of packets?
Results offered to the modelisator by the structural approach are more qualitative than quantitative. It proposes several explanations related to the same complex system or phenomenon. This multiplicity of models especially aims at improving the global comprehension of the system without denaturing it, comprehension articulated in terms of attributes, qualities and inter-properties relations.

6. Conclusion

The structural approach was illustrated using a precise example: autonomous agent systems. It is obvious that a theoretical methodology cannot be justified on a single example. This is why it can be useful to give some indications on the manner of treating another quality. Studying an *intelligent system* using the structural approach would require determining what the relations are between this quality and other properties, attributes or qualities, in order to lead to various models of intelligence. The designer of such systems could then choose and combine the appropriate models for his own project.

Lastly, the structural approach clarifies in a different way the question of the c*omplexity measurement* of a system. Whereas the equational approach proposes a certain number of measuring instruments, from the point of view of the structural approach the complexity of a system is revealed by the presence or the non presence of qualities. The result is that a system is not considered as more complex than another but is seen as complex or not complex by nature.

7. References

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