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COMPLEX SYSTEM THEORY DEVELOPMENT

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***Abstract-* Complex system theory is a new and rapidly- developing field. A complex system is composed of many simple individual components that interact nonlinearly, giving rise to global behaviors and often unexpected, unprecedented and unpredictable that exhibit nontrivial emergent and self-organizing behaviors. In this context, a sub-domain has emerged under the name "complex adaptive systems: CAS". This current coming from the developments in evolutionary algorithms in 1980 years, focused on complex systems in relation with an environment in which they dynamically learn and adapt. The goal of this work is to explore the Complex system theory through a comprehensive survey, which clearly shows the properties, the mechanisms, the applications, and the different scientific currents that are related to the complex systems from 1940 until 2015.We present the effective approach for modeling and simulating complex systems. We undertake a fairly exhaustive and rigorous survey of applications of complex theory in various domains of science.**

Keywords - Complex systems theory, complex adaptive systems, complexity theory development, self organization, emergence , Agent based modeling.

I. INTRODUCTION

We can trace the notion of a complex system to Aristotle who cited the famous saying « The whole is greater than the sum of its parts ». Beyond this brief statement, the role of science called complex systems is to analyze this statement in a scientific approach. Complexity is increasingly recognized as an essential feature of the world in which we live and we perceive [2]. Although definitions of complexity vary greatly and are still a field of mines terminology, the scientific community agrees that the characteristics of complex systems are: a large number of autonomous entities, sensitivity and criticality to initial conditions, different organization levels, dynamic structures, emergent and self- organization properties [160].

In this context, a sub-domain has emerged under the name "complex adaptive systems". This current coming from the developments in evolutionary algorithms in 1980 years by Holland [3] who focuses on complex systems in relation with an environment in which they dynamically adapt.

Examples of systems called complex usually cited in the literature are: the omnipresent internet, groups of insects, the economy, the human brain, electricity distribution networks, transport networks, etc. A new kind of science has emerged to deal with such systems [161]. Understanding complex systems is done by their modeling. To do so, the approach of Agent based modeling (ABM) appears to be the best answer to the needs of the complexity theory [5].

The structure of the paper is as follows: We start with the History of complex systems theory, it definition and properties, we cited the different complex systems theories. This is followed with the definitions of Complex adaptive systems; we show its Characteristics, properties and applications. After we present complexity theory development until 2014. Then we show the effective approach for modeling and simulating complex systems, In the last we cited the several centers and research institutes working on complex systems in various countries, and we give an annotated bibliography of resources for those that deepen in complex systems.

II. COMPLEX SYSTEMS

1. History of complex systems theory

Following work in various disciplines, the theory of complex systems has no real base text. Rather, it is a point of convergence of various research data of biology, cybernetics, ecology, and economy [2].

Massachusetts Institute of Technology, in the United States has been the most fertile ground of the theory of complex systems (TCS) since 1940 [6], through the work of several researchers; namely, Heinz von Foerster and J. von Neumann who first worked on the self-organization problems before formulating their famous game theory.

Since its founding in 1984 , The Santa Fe Institute (SFI) has focused on creating a new kind of scientific research community based on the complexity science , and support for emerging science by providing multidisciplinary enormous attributions , physical biological, and social computing . There are many scientists who contribute to the field of complex systems; among them we can mention the two most famous scientists Murray Gell-Mann and John Henry Holland [7].

2. Definition and properties

There is no exact definition of complex systems, but generally there's a consensus on common properties of these systems. An analysis of the literature in relation with the sciences of complexity show that the features are limited to five concepts that we find in the definition given by Weaver [8], Simon [9], which are:

- The system is composed of interacting agents ;
- Their emergent behavior does not result from the existence of a central controller ;

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- The system's properties emerge from the interaction of its components ;
- The system may show unpredictable behavior or lead to uncontrolled explosion (e.g. earthquake or stock market crashes) ;
- Small change in the causes can imply dramatic effects.

Based on these characteristics, the scientific community agrees to designate a system as complex systems composed of a set of homogeneous or heterogeneous elements interacting with each other with a nonlinear way and thereby implementing a dynamic allowing the overall system to exist as a whole, different from the sum of its components [10].

Therefore two levels are identified:

- A micro level, representing the component level, with local properties for each component;

- A macro level, representing the whole system with new properties that are not found in any of the individual components.

The main feature of a complex system is its circular or reciprocal causality, which translates in the existence of retroactive collective behavior and emergent properties (macroscopic) in behavior elements (microscopic). In a complex system, to know the properties and behavior of individual elements is not sufficient to predict the overall behavior of the system [65] unavoidable.

3. Complex systems theories

Complex systems theory is not a monolithic body of knowledge, but a series of short stories. Whether it will one day become integrated to form a single coherent theory is a matter of current debate [11]; a study conducted by Newman[11] tried to assemble the complex systems theory and its literature, which we have summarized in the following table:

Complex systems theory	Literatures
Lattices and networks	Strogatz [12]; Watts [13] ; Boccaletti [14] ; Cohen [15] ; Newman [16].
Dynamical systems	Strogatz [17]; Peitgen [18] ; Arenas [19]; Barrat [20].
Discrete dynamics and cellular automata	Gardner [21]; May [22]; Feigenbaum [23]; Langton [24]; Dennett [25]; Ilachinski [26]; Wolfram [27].
Scaling and criticality	Simon [28] ; Bak [29]; Drossel and Schwabl[30] ; Bak [31]; West [32]; Carlson[33]; Mitzenmacher [34]; West and Brown [35]; Newman [36].
Adaptation and game theory	Koza [37]; Smith [38]; Mitchell [39]; Davis[40]; Myerson [41]; Challet and Zhang[42]; Gould [43]; Dawkins [44]; Axelrod [45]; Watson [46]; Gintis [47].
Information theory	Shannon [48]; Pierce [49]; Bennett [50]; Cover [51]; Badii [52].
Computational complexity	Garey [53]; Aaronson [54] ; Moore [55]
Agent-based modeling	Schelling [56]; Ray [57]; Palmer [58]; Epstein [59]; Berry [60]; Macy [61] Grimm [62]; Gilbert [63]; Page [64].

Table 1: literatures of complex systems theory

The complexity of a system lays in the emergence induced retroactive interactions. In the dynamics of the system, these interactions allow to implement the mechanisms of its (system) adaptation and evolution relative to changes in his environment. So we speak about "Complex Adaptive Systems".

III.COMPLEX ADAPTIVE SYSTEMS

Under the study of complex systems, a sub domain is detached under the name of "CAS" .This current introduced by the interdisciplinary Santa Fe Institute by John Holland and Murray Gell-Mann [66].

1. Definitions

In the context of complexity science, there are several definitions of a complex adaptive system. We will choose the definitions from the collective work rather than isolated dictionary definition.

Among researchers who study these systems, the team Tefatsion [67], who gave three definitions for a complex adaptive system:

- Definition 1: A complex adaptive system is a complex system that includes reactive units, i.e., units capable of exhibiting systematically different attributes in reaction to changed environmental conditions.
- Definition 2: A complex adaptive system is a complex system that includes goal-directed units, i.e., units that are reactive and that direct at least some of their reactions towards the achievement of built-in (or evolved) goals.
- Definition 3: A complex adaptive system is a complex system that includes planner units, i.e., units that are goal-directed and that attempt to exert some degree of control over their environment to facilitate achievement of these goals.

Most researchers in this field adopt the definition of Kevin Dooley [68] who considers holistic: « A CAS behaves/evolves according to three key principles: order is emergent as opposed to predetermined, the system's history is irreversible, and the system's future is often unpredictable. The basic building blocks of the CAS are agents. Agents are semi-autonomous units that seek to maximize some measure of goodness, or fitness, by evolving over time. Agents scan their environment and develop schema representing interpretive and action rules. These schemas are often evolved from smaller, more basic schema. These schemas are rational bounded: they are potentially indeterminate because of incomplete and/or biased information; they are observer dependent because it is often difficult to separate a phenomenon from its context, thereby identifying contingencies; and they can be contradictory. Schemas exist in multitudes and compete for survival. »

Cloutier has synthesized the work and research of Holland [69] on complex adaptive systems: their properties and characteristics [3], he conclude that the complex adaptive system is a set of agents with a certain freedom of action to adapt or learn, intricate in such a way that each of them (by its interactions with other agents), contributes to emergence of an overall non-deterministic behavior.

2. Characteristics and properties

Based on the previous definition of Cloutier [3], it's clear that the agents in the CAS had some freedom to adapt or learn. However, this process is not conducted randomly. Every problem can be decomposed into sub-problems whose solutions already exist. Thus, the solution of the problem will be composed of sub- elements, called building blocks [69] [3]; When a new problem is encountered, the agent can then evaluate the sub-problems and implement existing blocks, which often take the form of a set of rules (These rules can be provided of the type (s) condition(s)/ action (s) or condition (s) / message (s)) [3]. The combination of these building blocks constitutes the solution. When the latter is applied, the agent evaluates the performance of each of the blocks and will remember this performance and this combination; It's called the appropriation [69] [3]. This allows the agent to develop new solutions from the blocks. for this type of sub-problem, these blocks have superior performance compared to objectives of the agent. This process, which occurs by the recombination of the most powerful elements, is called "discovery rules" and is a form of genetic algorithm [69] [3].

Through the process of "discovery rule", agents and the system become adaptive. Indeed, since there is little or no central control in a CAS [3] and the behavior of the system is defined by the interactions that occur [3], the adaptability of components is then transposed to the entire system, which is evolutionary [69]. The agents also base their actions on performance expectations for each of the building blocks according to objective which may be more or less defined [3]. This performance (since it also depends on systemic behavior) can vary greatly over time, as other agents evolve. Thus the set of building blocks and solutions constitutes a model of how the agent believes can act on the system to achieve its objectives. He will base his actions on this model. It is therefore possible to speak about "an ability to anticipate" [69] and [3].

They are the different features that create an appearance of erratic behavior during the observation of these systems. Because, since the behavior is in interactions, and these interactions are multiple and sometimes circular or reciprocal; the retroactive loops occurs [3]. These feedback loops have a polarity: In other words, an input (Whether positive or negative) may give a result that can be positive or negative [3], depending up on the polarity obtained. In addition, because of these loops, outputs are not necessarily proportional to inputs. So a small change can be of much consequence, like a big change may have little or no effect on the system. CAS is non linear systems [3].

Serena Chan [7] counted and collected the various characteristics and properties of CAS from the literature at the Santa Fe Institute, presented bellows:

- Distributed Control: There is no single centralized control mechanism that governs system behavior. Although the interrelationships between elements of the system produce coherence, the overall behavior usually cannot be explained merely as the sum of individual parts.
- Connectivity: As noted earlier, complexity results from the inter-relationship, inter-action and inter-connectivity of the elements within a system and between a system and its environment. This implies that a decision or action by one part within a system will influence all other related parts but not in any uniform manner.
- Co-evolution: With co-evolution, elements in a system can change based on their interactions with one another and with the environment. Additionally, patterns of behavior can change over time.
- Sensitive Dependence on Initial Conditions: CAS are sensitive due to their dependence on initial conditions. Changes in the input characteristics or rules are not correlated in a linear fashion with outcomes. Small changes can have a surprisingly profound impact on overall behavior, or vice-versa, a huge upset to the system may not affect it.
- Emergent Order: Complexity in CAS refers to the potential for emergent behavior in complex and unpredictable phenomena. Kauffman uses computer simulations of CAS demonstrate that it is possible for the order of new survival strategies to emerge from disorder through a process of spontaneous self organization.
  - Order can result from non-linear feedback interactions between agents where each agent goes about his own business. Emergent behavior can be easily seen in the flocking behavior of birds. Research using computer simulations has shown that one can model the flocking behavior of birds by using a few simple rules such as the distance each bird maintains between itself and other birds and other objects. These rules are entirely local to each bird. There is no explicit rule to form a flock. If a flock does form, it would have done so from the bottom up, as an emergent phenomenon. Indeed, flocks did form every time the simulation was run. Thus, it appears that self-organization is an inherent property of CAS.
- Far From Equilibrium: In 1989, Nicolis and Prigogine [70] showed that when a physical or chemical system is pushed away from equilibrium, it could survive and thrive. If the system remains at equilibrium, it will die. The "far from equilibrium" phenomenon illustrates how systems that are forced to explore their space of possibilities will create different structures and new patterns of relationships.
- State of Paradox: Other research in CAS has indicated dynamics combining both order and chaos. This reinforces the idea of bounded instability or the edge of chaos that is characterized by a state of paradox: stability and instability, competition and cooperation, order and disorder.

Niazi & Hussain have grouped and classified characteristics of CAS introduced by Holland on seven basics; four of these are properties and three are mechanisms [162]. The following discussion is based on Holland's description of properties and mechanisms of CAS [163]:

1. *Aggregation (property):* Aggregation is useful in two ways, firstly as a generalization where different items can be categorized in a single big and oft-reused umbrella, e.g. animals, plants, bags, etc. Secondly, this is a way of abstraction as well since it allows focus on the important details to be modeled and ignores those which are less important. Holland pointed out the formation of complex agents called meta-agents in living and social systems (whether natural or artificial) based on complex behavior of smaller, simpler agents .
2. *Tagging (Mechanism):* Tagging is a mechanism which is frequently observed in CAS. Tagging allows for the

formation of aggregates. Tagging is exhibited in CAS in the same manner as flags are used to identify troops or messages are given IP addresses to reach the correct destination in a network.

3. *Nonlinearity (Property):* Nonlinear interactions are the norm in CAS and are one of the reasons in the emergent global behaviors which indicate that the system is a CAS.
4. *Flows (Property):* Another property of CAS is the formation of dynamic networks and flows. As such there are numerous attributes such as seen in Economics e.g. The multiplier effect when an extra amount of a resource is added to a flow causing it to transform as well as transmit between different nodes. Another important behavioral property that can be observed in flows is the recycling effect where resources are recycled over the flows via the network nodes thus enriching the emergent behavior.
5. *Diversity (Property):* The species of a rainforest, people living in large towns, vendors in malls, structure of the mammalian brain all exhibit extreme diversity. It is rare to see the same type of components if any of these CAS are explored in depth. Being a dynamic property, diversity also has self-repairing and self-healing characteristics.
6. *Internal Models (Mechanism):* Internal models are a mechanism by which agents inside a CAS keep models of other individuals.
7. *Building Blocks (Mechanism):* Internal models as described in the previous section need to be enhanced by realistic mechanisms. These realistic mechanisms are termed as the ‘‘Building blocks’’. As an example, a diverse numbers of human beings form the 6 Billion human population and they can each be basically differentiated from each other based on only a few set of building blocks such as eyes, nose, lips, hair, face etc. Variations in these blocks include changes in constituent attributes such as their color, shape etc. and eventually form the basis of the internal models.

IV. EVOLUTION OF COMPLEX SYSTEMS

1. Complexity theory development, State of the art from 1940 and 2010

Fig 1 shows a global map of the different scientific currents that are related to the complexity of the systems and in particular the issue of self-organization which is the starting point of complexity science between 1940 and 2010 [164].

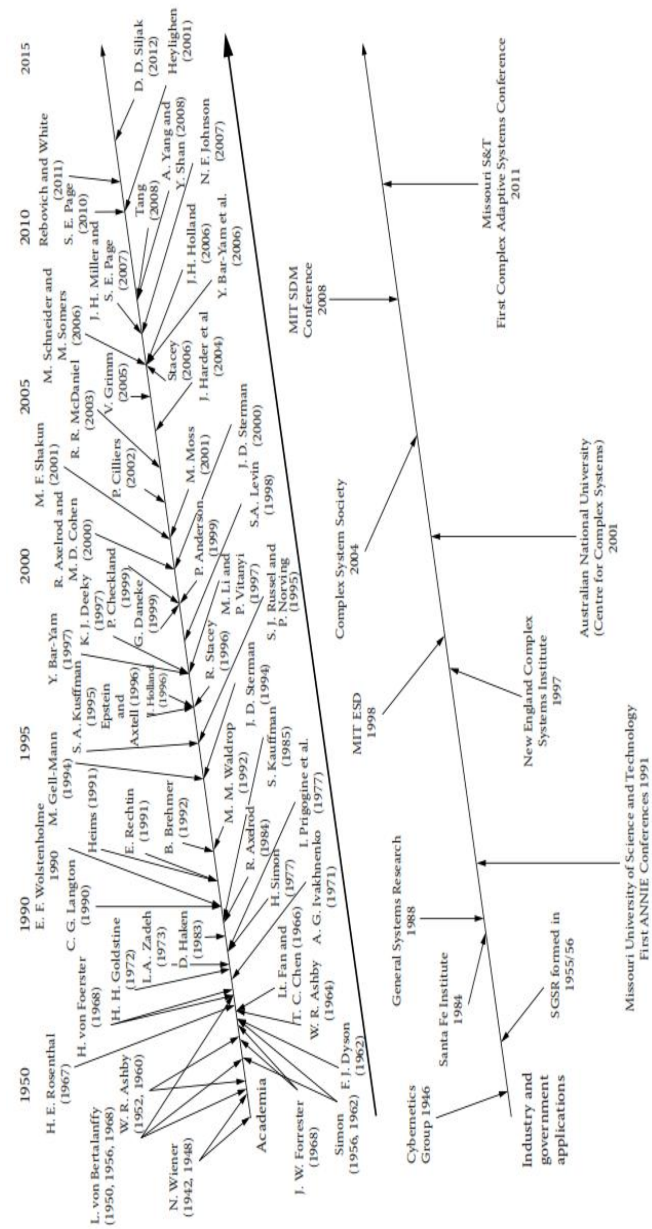

Fig1. Complexity theory development, from 1940 and 2010

We cited the work of Newman [11] that divided the applications of complex systems into 5 types with principal references. It’s synthesized in the following table:

Applications	Principal references
Physical systems	Anderson [71]; Sethna [72]; Sander [73]
Ecosystems and biological evolution	May [74] ; Kauffman [75]; Kauffman [76]; Levin [77]; Holling [78]; Solé [79]; Nowak[80]
Human societies	Jacobs [81]; Wasserman [82]; Scott [83]; Watts [84]; Batty [85]; Bettencourt [86]; Batty [87]; Bettencourt [88].
Economics & markets	Mandelbrot [89]; Jackson [90]; Easley [91].
Pattern formation and collective motion	Turing [92]; Nagel [93]; Vicsek [94]; D. Helbing [95]; Winfree [96]; Ballerini [97]

Table 2: Applications of complex systems theory

There are other references that are interesting for those who want to deepen in and application of complexity, it's presented below: Al-Suwailem [98]; Wang [99]; Burt [100]; Alaoui[101]; Mitchell [102]; Robert [103]; Minai [104]; Bellomo [105]; Khairy [106]; Miller [107]; Garnsey [108]; Eisner [109]; Rosser [110]; Byrne [111]; Sunny[112]; Boccara [165]; White [166]; Haken [167]; Page [168]; Aslaksen [169]; Dyer [170] ; DeRosa [171]; Yang and Shan [172]; Cotsaftis [173]; Aumann [174]; Heylighen [175]; Johnson [176]; Mitchell [177]; Bar-Yam [178]; Braha [179]; Holland [180]; Norman [181]; Schneider [182]; Gharajedaghi [183]; Grimm [184]; Bar-Yam [185]; Bar-Yam [186]; Baldwin [187]; Crawley [188]; Mitleton [189]; Urry [190]; Chiva-Gomez [191]; McDaniel [192] ; Abraham [193]; Cilliers [194] ; Marion [195]; Moss [196]; Olson [197] ; Sterman [198] ; Anderson [199] ; Koch [200]; Cilliers [201]; Bar-Yam [202]; Li and Vitanyi [203]; Jervis [204]; Holland [205]; Stacey [206]; Waldrop [207] ; Lewis [208] ; Brehmer [209] ; Rechtin [210] ; Puccia [211] ; Steward [212]; Zadeh [213]; Ivakhneko [214] ; Fan and Chen [215]; Dyson [216].

2. Survey from 2010 until 2014

After the year 2010 until 2014, other sciences dealing with complex systems have emerged in new areas presenting in the following:

2.1. Complex industrial systems engineering

The notion of complex system discussed until now had its origin in the observation of the natural system [113]. But there are complex systems designed and built by human for a specific function. Among these systems, there are complex industrial systems engineering [113]. In this context, was held in 2010 the first Complex Systems Design & Management conference in an international academic-industrial conference dedicated to all academic researchers and industrial actors working on complex industrial systems engineering [114].

The aim of the Complex Systems Design & Management conference is to cover as completely as possible the field of complex systems sciences & practices. Thus, the two following types of contributions were welcome [115]:

- Scientific contributions: scientific and technical methods & tools for analyzing, modeling, simulating, optimizing, verifying, validating and qualifying complex industrial systems;
- Industrial contributions: case studies, returns of experience & exchanges of good practices with respect to general or specific types of complex industrial systems.

Designing complex industrial systems is today a fundamental strategic challenge for all large enterprises, most notably in developed countries. A relatively new discipline centered on systems architecture & engineering, emerged in the academic environment. This discipline intends to develop theory, methods and tools that shall allow engineers to manage the increasing complexity of the technical systems they must design and implement [114].

The scope of the complex industrial systems engineering covers the following Industrial domains [114]: Constructors & operators of transportation systems; Defense & security, Electronics & robotics; Energy & environment; Health & welfare services; Media & communications; Software & e-services, and Maintenance & Production.

2.2. Risks and catastrophes as complex systems

The analysis of risks and catastrophes as complex systems provides a remarkably pertinent framework for addressing major risks and to identify what subsystems/components are critical to safety in general [116]. Methods of risk assessment and management adapted to complex systems were developed initially for airplanes, soon after for nuclear reactors [117], and then for Catastrophes in nature & society [118].

2.3. Educational systems as complex systems

Another movement of researchers who began in 2010 to address the educational system from the perspective of complexity [119], which opens new perspectives to explore. It's to see the education system as complex system consisting of a large number of players interacting with each other. Resulting from these interactions, properties, often unexpected emerge a new system. The socio-economic segregation observed between schools can be seen as one of the emerging phenomena. This way of looking at things can take into account individual freedom and open the way for action in the mechanisms leading to segregation.

2.4. Complex systems in applied linguistics

In 2008, Larsen and Freeman [120] use the grid produce with the Center for the study of complex systems at the University of Michigan, that summarizes the nature of complex systems from a range of fields using these key features, together with examples of emergent behavior' to describe, in a preliminary and very generalized manner, aspects of complex systems in linguistics.

Field	Spoken interaction	Classroom language learning
Agent	Speakers, Their language resources	Students, teachers, language
Heterogeneity	Speaker backgrounds, Styles, discourse topics	Ability, personality, Learning demands
Organization	Dyads, speech communities	Class, groups, curricula, grammars
Adaptation	Shared semantics, pragmatics	Imitation, memorizing, Classroom behaviors
Dynamics	Conversation dynamics, Negotiation of understanding	Classroom discourse, talks, Participation patterns
Emergent behavior	Discourse events, idiom, Specific language e.g; english	Language learning Class/group behavior

Table 3: complex systems in applied linguistics [120]

From this temptation of Larsen and Freeman, a group of scientists have begun in 2011 to study the origin of language by asking the following question [121], The 6000 languages in today's world are they all originated from a single parent language? To answer this question, they appealed to the complexity theory by focusing on the characteristics of emergence.

There are other important recent works that continue to search into applications of complex systems, we cited: Naciri and Tkiouat [160] [241] [242][244], Gilstrap[122]; Farmer [123]; Al-Suwailem [124]; Teglio [125]; Philip [126]; Matta [127]; Arthur [5]; Gorod [164]; Niazi and Hussain [162]; D'Agostino and Scala [217]; Lewis [218]; Ireland [219]; Edmonds and Meyer [220]; Sheard [221]; Kovacic [222]; Lorrenza [223]; Sokolova [224]; Siljak [225]; TonJörg [226]; Luzeaux [227] ; Pardo [228], Érdi [235]; Fromm [236]; Gregersen [237]; Edgar morin [238] [239].

V. MODELING AND SIMULATION OF COMPLEX SYSTEMS

Epstein defined modeling as the development of a *simplified* representation of *something*. Epstein also clarified misconceptions about modeling and simulation giving a list of different reasons for modeling [229].

A model of a system is a simplified mathematical representation of this system, which should be as simple as possible but, however, being able to capture the key elements of the system allowing to eliciting highly relevant questions [165]. Simulation model is a set of instructions, rules, equations or constraints for generating input and output behavior [230].

While it is easy to make models of some aspects of a Complex system, it is quite difficult to model it entire and its emergence [162]. Previously, a number of aspects of the Complex System have traditionally been modeled using simplification of complex components of aggregates [165], for example, by using differential equations, system dynamics or Monte Carlo simulations. Mathematical models rely on the identification of the key system components, often representing them in a discrete manner. This limits mathematical models because emergence present in complex systems arises as a consequence of local interactions, and cannot be previously identified as a key system component [161]. Mathematical models are analogues, but cannot provide significant insight into the continuous internal process of a complex system [231]. Moreover, they only take into consideration the global point of view, usually not explaining the reasons locally leading to the global behavior of the modeled system [232].

However, more recently, we can see by examining the literature that complex system researchers often prefer to use agent-based (or individual) modeling approaches, to modeling and simulating complex systems [162].

1. Agent Based Modeling

The multi-agent modeling and multi-agent simulation allows to study and understand complex systems. It represents complexity of a phenomenon through the interaction of all its agents [233] [243].

According to Drogoul [234], the principle of multi-agent simulation can be shown in Fig 2. The real phenomenon is decomposed into a set of elements that act or interact. Each of these elements is modeled by an agent, and the general model is the result of interactions between agents.

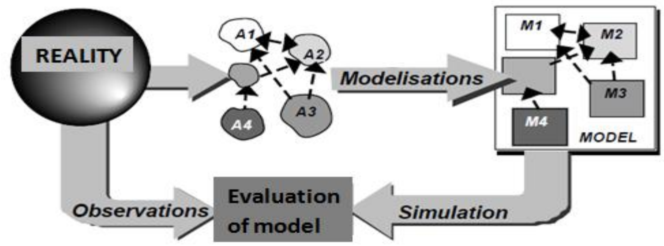

Fig 2 : Multi-agent simulation principle according to Drogoul [234]

The multi-agent simulation provides solutions to the limitations of the mathematical approach [234]. It allows to model the entire of complex systems and its emergence.

VI. INSTITUTES AND RESEARCH CENTERS OF COMPLEXITY

There are several centers and research institutes working on complex systems in various countries, namely: Institute for Complex Systems and Mathematical Biology (ICSMB) [128]; Center for Nonlinear Phenomena and Complex Systems (Cenoli)[129]; Complex Systems and Networks Lab (COSNET) [130];Northwestern Institute on Complex Systems NICO[131]; Center for the Study of Complex Systems and Cognition (CENECC) [132]; Complex Adaptive Systems, Master's, University of Gothenburg [133]; Max Planck Institute for the Physics of Complex Systems [134]; The University of Vermont [135]; Complexity science center [136]; Centre for Complexity Science [137]; Center for interdisciplinary research on complex systems [138]; Center for complex network research at northeastern university [139]; Center for Social Dynamics and Complexity CSDC [140]; Research Center for Social Complexity CICS [141]; Center for Complex Systems and Networks Research CNetS [142]; Institute of Complex Systems Simulation (ICSS) [143]; Center for Complexity in Business/ Robert H. Smith School of Business, University of Maryland [144]; Center for the Study of Complex Systems (CSCS) [145]; Complexity in Health Group CHG [146]; Center for Complex Systems and Brain Sciences CCSBS [147]; Center for Social Complexity at George Mason University CSC [148]; York Centre for Complex Systems Analysis YCCSA [149]; Complexity Science Group center [150]; Complex Systems Research Center [151]; Collective Dynamics of Complex Systems (CoCo) Research Group [152]; Complex and Adaptive Systems Laboratory (CASL) [153]; Institute for Cross-Disciplinary Physics and Complex Systems IFISC [153]; Waterloo Institute for Complexity and Innovation [154];

A number of journals focus specifically on complex systems, of which the best known are: Advances in Complex Systems [155]; Complexity [156]; Complex Systems [157]; Interdisciplinary Description of Complex Systems [158]; International Journal of Complex Systems in Science [159].

VII. CONCLUSION

This paper presented the state of the art of complex systems, we have presented clearly its definitions, its properties, its mechanisms, its applications, and the different scientific currents that are related to the complex systems from 1940 until 2014. We give an annotated bibliography of resources for those that deepen in complex systems.

We have also recalled that mathematical approaches are limited to understanding complex systems and the agent based modeling approach is the most optimal concept that can model and simulate the interaction between different agents and explain phenomena and mechanisms associated with complex systems include emergence and self-organization.

We conclude that the theory of complex systems is not a monolithic body of knowledge, but several theories that has many origins in many disciplines including anthropology, artificial intelligence, artificial life, chemistry, computer science, economics, evolutionary computation, earthquake prediction, meteorology, molecular biology, neuroscience, physics, psychology and sociology. Hence the need to assemble and integrate them into a single coherent theory.

BIOGRAPHY

Nawfal Naciri earned his Polyvalent state Engineering degree (2006) from ENSAM (L'École Nationale Supérieure d'Arts et Métiers) Morocco-France. He is a PhD student in Studies and Research Laboratory in Applied Mathematics (LERMA) and Islamic Financial Engineering Laboratory (IFELab), in Mohammadia School of Engineering. He is in Charge of studies at the Head of Government of the Kingdom of Morocco. His main areas of research include complex systems, artificial intelligence, agent based modelling and simulation, complexity economics, Islamic financial engineering.

Mohamed Tkiouat earned his Doctorate of Mathematic Sciences (1991) from the Univertsité Libre de Bruxelles (ULB) on Markovian and semi-Markovian models and applications, Belgium. Previously, he completed his third cycle thesis (1980) in Operations Research at Faculté des Sciences de Rabat on perturbed Markovian chains models and application to hydropower management, prepared at INRIA France. He is a Professor at Ecole Mohammadia d'Ingénieurs, Université Mohamed V Agdal à Rabat. His main areas of research include Markovian models and applications to reliability and finance, risk management and multi-agent games theory models.

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