An Overview of Artificial Life

[1]Awodele O.
Department of Computer Science
Babcock University, Ilishan-Remo, Ogun State, Nigeria

[2]Taiwo O.O
Department of Computer Science
Babcock University, Ilishan-Remo, Ogun State, Nigeria

[3]Kuyoro S.O.
Department of Computer Science
Babcock University, Ilishan-Remo, Ogun State, Nigeria

Abstract-For some time now, people have speculated on what makes the living different from the non-living; and what the possibility of creating synthetic system from natural system is. From the mid-1980s, artificial life (ALife) has studied living systems using a synthetic approach. This approach builds life in order to understand it better in any of the three branches of ALife i.e. software, hardware, or wetware. Being an area that is related with other disciplines, ALife seems to be losing its boundaries and merging with other fields. This paper gives an overview of the historical background of ALife, its application areas, the common properties, and the classification of research in ALife.

Keywords-Artificial Life, Artificial Intelligence, Adaptation, Self-organization, Synthetic biology.

I. INTRODUCTION

Life appears to be one of the most basic categories of actual natural phenomena The fact is that today there is no set of individually necessary conditions for life, yet, it is difficult to say what exactly life is. Artificial life (ALife) is the study of man-made (synthetic) systems that exhibit behavior characteristics of natural living systems. The primary goal of this field is to create and study artificial organisms that mimic natural organisms. ALife complements the traditional biological sciences concerned with the analysis of living organisms by attempting to create life-like behaviors within computers and other artificial media. Artificial Life can contribute to theoretical biology by modelling forms of life other than those which exist in nature [1]. [2] defined contemporary ALife as an inter-disciplinary study of life and life-like processes, whose two most important qualities are that it focuses on the essential rather than the contingent features of living systems, and that it attempts to understand living systems by artificially synthesizing simple forms of them. In this way, ALife attempts to synthesize properties of living systems in computers, machines, and molecules. Thus, ALife aims to understand biological life better by creating systems with life-like properties and developing new forms of life. Generally speaking, evolution is a phenomenon specific to life on earth. By extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on earth, ALife can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be [3].

The only example of life at hand is carbon-based life on earth. All forms of life on earth involve the same basic mechanisms. They all reproduce and develop under the control of the protein and DNA templating machinery. However, it is all clear and obvious that this is not the only possible basis for life. It is easy to conceive of other forms of life, in different media, with a variety of different reproductive and developmental mechanisms. A general property of ALife is that the whole system's behavior is represented only indirectly, and arises out of interactions of individuals with each other. In this context, known as the philosophy of decentralized architecture, we can say that ALife shares important similarities with some new trends in Artificial Intelligence (AI), including connectionism, multi-agent AI, and evolutionary computation [4]. This paper surveys the brief history, application areas and some of the research areas of Artificial Life.

II. HISTORICAL BACKGROUND OF ALIFE

The concept of artificial life had taken diverse meanings. In its current usage, the term artificial life (ALife) was coined in the late 1980s by Christopher Langton (1989), who originally defined it as "life made by man rather than by nature," i.e., the study of man-made systems that exhibit behaviors characteristic of natural living systems. However, with time, Langton found fundamental problems with this definition, and redefined it as "the study of natural life, where nature is understood to include rather than to exclude, human beings and their artifacts" [5]. In the 19th century, people debated on the nature of life in view of the impressive technological and scientific advances of the age. Then they raised questions like: What are the causes and conditions of life? Can living creatures be created by human? Such questions were asked from the dawn of history. Let's consider, for instance, the artificial creatures found in the Greek, Mayan, Chinese, and Jewish mythologies, where human beings acquire the divine ability to make living creatures through magic. Other examples can be found during the middle ages, such as the automata created by al-Jazari (including the first programmable humanoid robot) and the legendary Albertus Magnus' brazen head (an automaton reputed to be able to answer any question) and its mechanical servant (which advanced to the door when anyone knocked and then opened it and saluted the visitor).

Later on, during the Italian Renaissance, several automata were designed [6]. Leonardo da Vinci's mechanical knight (a humanoid that could stand, sit, raise its visor and independently maneuver its arms) and its mechanical lion (which could walk forward and open its chest to reveal a cluster of lilies) are just two examples of this kind of automata.

There is also a legend that says that Juanelo Turriano created an automaton called "The Stick Man." It begged in the streets, and when someone gave it a coin, it bowed. Through the modern age, automata became more and more sophisticated, based on and leading to advances in clockwork and engineering [7]. Questions related to the nature and purpose of life has been central to philosophy, and the quest of creating life has been present for centuries [8]. Being able to imitate life with automata, can we understand better what makes the living alive?

The intellectual roots of contemporary artificial life grow back to the first half of the twentieth century, and the two deepest roots reach to John Von Neumann and Norbert Wiener. [9] designed the first artificial life model (without referring to it as such) when he created his famous self-reproducing, computation-universal cellular automata. Below is a figure that shows the historical root of Artificial Life.

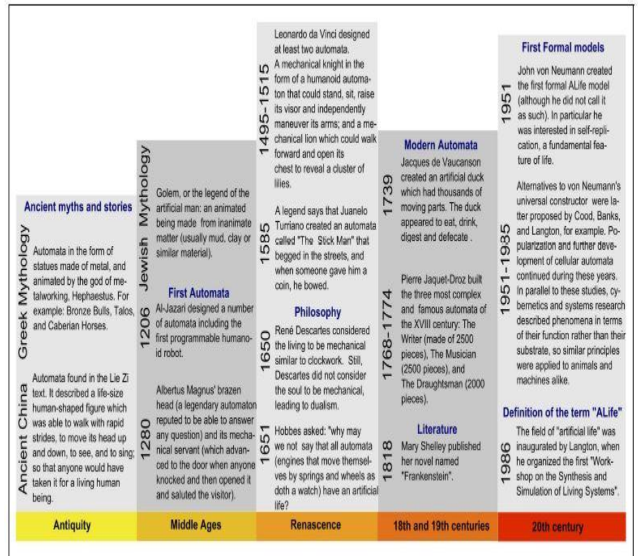

Figure 1: The historical root of Artificial Life [10]

III. RELATED WORKS

ALife has been an interdisciplinary research field bringing together biologists, philosophers, physicists, computer scientists, chemists, mathematicians, artists, engineers, and many more [11]. It has also been related to several fields, having a strong overlap with some of them, such as complexity [12], natural computing, evolutionary computation, language evolution [13], theoretical biology and evolutionary biology, philosophy, cognitive science robotics, artificial intelligence (AI), behavior-based systems [14], game theory, network theory [15], and synthetic biology [16], among others. ALife uses a synthetic methodology. It complements traditional biological sciences concerned with the analysis of living organisms and finds the mechanisms of evolutionary processes for automatic design and creation of artifacts. A general property of ALife is that the whole system's behavior is represented only indirectly, and arises out of interactions of individuals with each other.

In this context, known as the philosophy of decentralized architecture, we can say that ALife shares important similarities with some new trends in AI, including connectionism, multi-agent AI, and evolutionary computation [17]. [18] described the three broad and intertwining branches of artificial life which correspond to three different synthetic methods. They are: (i) Soft ALife, which creates simulations or other purely digital constructions that exhibit life-like behavior; (ii) Hard ALife, produces hardware implementations of life-like systems; and (iii) Wet ALife, which synthesizes living systems out of biochemical substances.

IV. Applications of ALife

ALife has been applied in various areas. Some of these areas:

1. *Robot Control:* Recently, the robotics area has relied heavily on evolutionary computation (EC) for designing controllers. EC with neural networks (NNs) is especially dominant. This subsection includes evolving controllers, which involves the combination of EC and NNs,
2. *Computer Graphics:* This deals with designing virtual characters, 2D image generation, and animation. As a result of the difficulty experienced in evaluating the product objectively, interactive evolutionary computation is used to design them.
3. *Natural Phenomenon Modeling:* This deal with Cellular Automata based modeling, ecological modeling such as that of fish behavior, flock behavior modeling and its applications, and applications of Lindenmayer system (L-system). The usage of L-systems is relatively large in this area. It has been extended to agricultural modeling such as that of cotton and plant-eating insects, and to explaining the evolution of fossils [19]. These authors created artificial fish for real-time interactive virtual worlds aimed at desktop environments with hardware 3D support. The artificial fish can move, sense and think.
4. *Entertainment and Game:* Designing AI of computer game players is tedious and knowledge-oriented work. ALife can reduce the worker's load by allowing an evolutionary strategy search and realistic modeling of human behavior.

Other areas of application of ALife include Economics, Internet and Information Processing, Industrial Design, Simulation Software, Electronics, Security, Data Mining and Telecommunication. Successful applications of ALife have common properties, which can be summarized as follows:

1. *Achieving similar behavior to biological creatures*. This property is a major reason why some applications receive great interest from the public. This is because they show similar behavior to biological creatures [20].
2. *The details of the final results have not been described before experimentation*. In traditional engineering approaches, the final results of applications are mostly described in advance [21].
3. *Designing without expert knowledge*.
4. *Interdisciplinary cooperation*. ALife is an interdisciplinary study of life and life-like processes that use a synthetic methodology [17].
5. *Huge computational requirements*. The evolutionary approach requires huge computational power.
6. *Evolution based on simple primitive shapes such as box and pipe.* In successful applications of ALife, the primitive shapes of a physical body are the simple box and the pipe [20].
7. *Computer simulation.* Most of the successful results use computer simulations but there are a few projects based on real hardware platforms. The hardware platforms suffer from very long evolution time, high cost, and uncertainty. In contrast, computer simulation can minimize the required time and cost by ignoring the details of the real world. With the growth of virtual worlds such as the Internet, the influence of computer simulation on users' lifestyles has increased [4].

V. Applications of ALife

The current ALife research can be classified into the 14 areas but 7 are discussed briefly in this section: origins of life, autonomy, self-organization, adaptation, ecology, artificial societies, behavior, computational biology, artificial chemistries, information, living technology, art, and philosophy.

1. Origin of Life

ALife has had a close relationship with the community of scientists working on the origins of life. Similar to the subdivision of ALife into two rather distinct areas focused on either individual autonomy or population evolution, there have been two major theories about the origin of life, known as the metabolism-first and replicator-first approaches [22]. The metabolism-first approach typically views the origin of life as related to the emergence of self- producing and self-maintaining far-from-equilibrium structures, autocatalytic networks and reaction- diffusion systems [23]. Replicator-first approaches, on the other hand, had to make recourse to membrane boundaries and metabolic activity, for example, to give rise to individuated protocells capable of competition

2. Autonomy

[24] proposed that the "basic autonomy" is the capacity of a system to manage the flow of matter and energy through it so that it can regulate internal self-constructive and interactive exchange processes under far-from-equilibrium thermodynamic conditions. This conception of autonomy, as referring to processes of self-production is distinguished from the terms commonly used in robotics, where it is employed more loosely as the capacity of a system to move and interact without depending on remote control by an operator. Nevertheless, it is the strong sense of autonomy that allows us to talk about a system as being an individual that acts in relation to its intrinsic goals, i.e., of being a genuine agent

[25], rather than being a system whose functions are heteronomously defined from the outside.

3. Self-Organization

The term “self-organizing system” was defined by [26] to describe phenomena where local interactions lead to global patterns or behaviors, such as in swarms, flocks, or traffic [27]. A special case of self-organization is self-replication. As a replicator, it has to conserve and duplicate its organization by itself. Another special case of self-organization is self-maintenance, which is related to homeostasis and has been studied in relation to artificial chemistries. Self-assembly is another form of self-organization. There have been several examples in hard ALife of self-assembling or self-reconfigurating robots. Some of these robots have taken inspiration from insect swarms. Their self-organization has served as an inspiration in computational intelligence. Recent attempts to guide self-organization are using information theory to develop systems, which are able to *adapt* to unforeseen circumstances [28].

4. Adaptation

Adaptation is defined as “a change in an agent or system as a response to a state of its environment that will help the agent or system to fulfill its goals” [27]. Adaptation is a central feature of living systems and is essential for autonomy and survival. One of the major criticisms of AI has been its lack of adaptability, as it traditionally attempted to predict and control rather than to adapt [29], while part of ALife has focused on bringing adaptability to AI. Still, both adaptability and predictability are desirable properties in natural and artificial systems.

5. Ecology

Ecological study in ALife is described as interactions between individuals from different species and with their environment. ALife models can study how regulation can occur as a consequence of multiple ecological interactions [30]. ALife ecological models, including cellular automata and agent-based have been used already in ecology for applications such as resource management and land-use models which have to include the social dimension [31].

6. Computational Biology

Theoretical biology preceded ALife in the abstract study of living systems. In return, ALife has contributed to theoretical biology with the development of computational models and tools. Computers have enabled the study of complex systems in a similar way as microscopes enabled microbiology. Studying ensembles of such networks, the functional effects of topologies, modularity, degeneracy, and other structural properties can be measured [32], providing insights into the nature of adaptability and robustness. The study of biological neural networks led to the proposal of several models of distributed computation. Some of these have been used in ALife for the evolution, development/learning of “artificial brains” with different applications. In a similar way, the computational study of immune systems has led to developments in computer security and optimization [33].

7. Living Technology

There have been hundreds of papers published on applications of ALife as stated by [4]. More recently, the term “living technology” has been used to describe technology that is based on the core features of living systems. Living technology is adaptive, robust, autonomous, and self-organizing. Living technology can be classified as primary and secondary living technology. *Primary* living technology is constructed from non-living components, while *secondary* living technology depends on living properties that are already present in its elements [34][35].

VI. Conclusion

An ALife technique is possible for many areas because they can provide methods for generating complex situations with simple rules. They show fascinating and remarkable results in movies, computer graphics, robotics, games and many more. Of course, many applications are developed in engineering areas, but the most successful ones are those that are evaluated only by humans. This means that surprise, emotional aspects, naturalism, creativity, and emergence are the key points for the success of the applications in the domain of ALife. Showing human-like natural characteristics is a main criterion for the evaluation of applications. With this, they are very different from traditional applications. Although the emphasis of ALife is on the scientific discovery of the meaning of life, the outcomes of the research can be fruitful in the real world. Therefore, ALife provides much potential for generating real-world applications by reducing tedious human effort.

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