Artificial Life Concepts in Cognitive Sciences

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Abstract

Cognitive Sciences and Artificial Life (often abbreviated as *ALife* in this paper) are two different multidisciplinary fields in Computer Science. Cognitive Science is interested in mind and its processes whereas Artificial Life is interested in complex systems such as life and its processes, evolution, etc. This paper introduces Artificial Life field briefly and examines chiefly how Artificial Life concepts are used in different sub fields of Cognitive Sciences.

Introduction

What is Life: Natural Life and Artificial Life

Life is a popular phenomenon used widely by the public in daily life, arts and literature. Intriguingly, the term is difficult to be formulated by a concrete description. It is a philosophical discussion how to define it and this goes back to the ancient times and still debatable today. For instance, some ancient societies with the anthropological construct called “animism” suggest each object, place or creature possesses different essence of spirit and life, or today, it is controversial in many countries’ legislative institutions that until which month an embryo can be considered as an alive creature referring the debate on abortion, or the futuristic question if a robot which looks human-like with highly developed AI (Artificial Intelligence) to act like a human instance having ability to simulate emotional actions could be considered as a living creature or not.

There are many descriptions for life or living creature like cybernetics definition, biological definition, etc and a practical one of them used in Artificial Life is that a thing meeting the criteria of motion, reproduction, consumption, growth and stimulus response is a living creature.

Natural Life is life as we know it in organic form. According to Christopher Langton, one of the founders of the field, artificial life is trying to perform the step from life as we know it to life as it could be.

Artificial Life tries to understand the characteristics of living systems by generating life concepts in software, hardware and bio-medicals. As many of the basic abstract properties of living systems (e.g. autonomous adaptive and intelligent behavior) are also studied by cognitive science, artificial life and cognitive science have an essential intersection.

Artificial Life Overview

Artificial Life has been named the first time by Christopher Langton in 1986. There are three parts of ALife studies: strong artificial life, weak artificial life and recently wet artificial life. Strong ALife is aimed at generation of life by experiments, weak ALife is aimed at simulating and understanding of life concepts, wet ALife is aimed at imitating biological features artificially on purpose.

Artificial Life has sub fields:

- Cellular Automata
- Conway`s Game of Life
- Langton`s Self-Replicating Loop
- Lindenmayer Systems
- Foundations of building structures, Nonlinear dynamics, Population dynamics
- Evolutionary Methods & Genetic Algorithms
- Self Organizing Criticality
- Swarm Behavior and Swarm Intelligence
- Braitenberg Vehicles
- Subsumption Architecture
- Bionics, (Biology inspired Robotics)
- Evolutionary Robotics

Cognitive Sciences Overview

Cognitive Science is the scientific study of the mind and its processes. It examines the nature, the tasks, and the functions of cognition in a broad sense. It is a multidisciplinary field among many different fields.

Cognitive Science is interdisciplinary with:

- Psychology
- Neuroscience
- Philosophy (Philosophy of Mind)
- Artificial Intelligence
- Linguistics
- Anthropology

Interdisciplinarity Between Artificial Life and Cognitive Sciences

Connection between Life and Mind

The American philosopher Mark A. Bedau, reviews the field of Artificial Life in detail to present this field to the readers of *TRENDS in Cognitive Sciences,* he touches on topics from robotics to molecular self-organization, and finalizes his review article *Artificial life: organization, adaptation and complexity from the bottom up* with the article *The connection between life and mind* explaining why Artificial Life and Cog. Sci. should overlap.

Many consider cognition was needed to be evolved against dynamic, unpredictable environment, as life had been. *Parisi* calls cognition as an adaptation that life need to develop against this kind of environment.

Artificial Life and Cognitive Psychology

In Psychology, Piaget's comprehensive theory and framework are proposed to understand development of human intelligence and identify processes during the development. The theory is also called Developmental Stage Theory since it divides the development into different theoretical stages based on progress. For instance, in sensor-motor stage, the time interval from birth to the acquisition of language, the expected cognitive development by months are explicitly indicated.

Artificial Life provides important theoretical and methodological tools for the investigation of Piaget's developmental theory. A recent study by Parisi and Schlesinger suggests that artificial life might reinvigorate the Piagetian framework. Currently Piaget's framework for understanding development is not very popular among contemporary developmental psychologists. This new method uses artificial life neural networks (ALNNs) to simulate living phenomena in a computer.

In psychology, the connectionism is the approach that uses neural networks to study the behavior and cognition of organisms. However, when neural networks are used as part of the broader enterprise of Artificial Life they are somewhat different from the neural networks of classical connectionism. The main differences are that

ALNNs

i. have a physical body
ii. live in a physical environment
iii. have an inherited genotype
iv. are members of evolving populations.

ALNNs are used in many examples to simulate Piaget's theories as explained in detail in the study of Parisi and Schlesinger.

The Artificial Life method is studied and criticized in the paper of Ulrich Mueller and K.H. Grobman by its comparison with traditional cognitivist approaches. For instance, The assumption that intelligent behavior consists in the adaptation of an organism to the environment lies at the core of cognitivist Siegler's rule-based overlapping wave model of problem-solving strategy selection. Siegler's model draws on evolutionary forces (e.g. competition) to explain development. When it comes to compare Piagetian framework and AL method, the paper is discussing the role of innateness in development, and examining the relation between physiological and psychological explanations of intelligent behavior.

Artificial Life and Higher Level Cognition

In his paper, *Domenico Parisi* describes ALife as study of biological phenomena through their reproduction in artificial systems and cognition as a form of adaptation. Therefore he argues cognition falls in area of ALife. Intriguingly, he attempts to use Artificial Life in higher level cognition, stating that even though basic level cognition used to be studied by ALife and NNs, higher level cognition used to be seen accountable only by symbol manipulation models that ignore biology and evolution. There occurs a need to show how higher level cognition might rise up evolutionarily, developmentally, and culturally/historically from lower level cognition.

He indicates that three kinds of researches on generation of more complex forms of cognition are described using ‘‘ecological’’ neural networks that live in a simulated environment:

i. Networks that learn to predict the consequences of their actions in the environment;
ii. Networks that are not passive receivers of input but control in various ways the input to which they respond;
iii. Populations of networks that evolve language to help classifying environmental inputs in useful categories

Artificial Life and Neuroscience

Artificial Life has proved the computational power of collective behaviors presented by natural swarms using the swarm algorithms inspired by them. Swarm Cognition studies how cognitive processes are created by collective swarm algorithms. *Vito Trianni and Elio Tuci* examines this field with the article of the same name, reviewing the recent work which meets swarm intelligence and cognitive processes of brain.

The foundations of Swarm Cognition can be found in of self-organizing systems as dynamical systems, particularly biological systems that have cognitive behavior, and in computational models of brain functions as computational neuroscience.

In sake of Swarm Cognition, the paper builds the argument by how collective intelligence can evolve to cognition with some case studies. The case studies include swarm cognition in honey bees, decision-making in brain and insect colonies. It draws attention to the similarity that brain and insect colonies work with multiple states and some threshold values to decide things.

At the last step, after giving interesting similarities between cognition and swarm intelligence, the paper concludes its argument by giving three direction of studies with ALife approach in Swarm Cognition, believing that Artificial Life is complementary to Cognitive Sciences as they explicitly stated.

These three directions are:

- Beyond Connectionism:

  Neurons should be also seen as generic artificial agents. The goal should be the identification of the mechanisms underlying cognitive processes, as a result of the dynamical interactions among cognitive units.

- Embodiment and Swarm Robotics:

  Each robot can be cognitive unit. To study emergence of cognitive abilities such as categorization, decision making, attention and learning by the embodiment of the robots without “reasoning”

- Bridging the Gap between Behaviour and Cognition

  By integrating neurocomputational controllers in swarm of robots, an highly complex system could be synthesized, composed of three different organizational levels hierarchically stacked, from the neurocontroller internal dynamics, through the embodied cognition displayed by the individual robot, up

to the cognitive processes displayed by the group dynamics. In this way, we could have a physical realization of multiple-level dynamical hierarchies that truly generate cognition from the bottom-up.

Artificial Life and Linguistics

Language is one of the most complicated behavior of living creatures. Even, it has been termed the most complex natural system, since it results from the interaction of three complex adaptive systems that operate on different timescales:

- language learning on an onto-genetic timescale,
- language evolution on a historical timescale,
- the evolution of the brains of language users on a phylogenetic timescale.

Them bottom-up, artificial life methods are ,as expected, being used to understand aspects of language. For instance, phonetics and phonology, language acquisition, language change, the evolution of signaling systems, the reasoning of symbols and the evolution of meanings, the emergence of complex structured languages, and the co-evolution of languages and language learning mechanisms.

Artificial Life and Cognitive Robotics

Evolutionary robotics, adding evolutionary property to robotics can be considered as another form of cognitive robotics, given that changing behavior based on environment is a sign of "cognition". It is the reverse of how some philosophers see evolution metaphysically: an external force such as "Mother Nature" might consciously change creatures due to changing environment by evolution.

Evolutionary robotics is a field of research that employs evolutionary computation to generate robots that adapt to their environment through a process analogous to natural evolution. The generation and optimization of robots are based on evolutionary principles of blind variations and survival of the fittest, as embodied in the neo-Darwinian synthesis (Gould, 2012).

Evolutionary robotics is typically applied to create control system for robots. Although less frequent, evolutionary robotics can also be applied to generate robot body plans, and to co-evolve control systems and body plans simultaneously (Lipson and Pollack, 2000).

Evolutionary robotics is used in digital art and visual effects software development for evolving visual creatures and evolving 3D morphology and behavior. (Karl Sims, 1994)

Artificial Life for Virtual Lab in Cognitive Science Experiments

There are many applications of Artificial Life in simulation. Many projects based on ALife principles are indeed used in molecular biology, evolutionary biology, medicine and also cognitive sciences. *Netto's* paper gives examples on the projects used in Cognitive Sciences. Some of them are *WOXBOT, Behavior on Artificial Life Societies*, *ALGA, Adaptive Cognitive Virtual Characters*, etc.

The first one, *WOXBOT*, is a virtual lab to evaluate the evolution of virtual beings through generations, with the only criterion which is their survival abilities. To sense the environment it uses neural networks and deliver input to a cognitive machine that takes decisions. That machine is state machine, that may evolve through generations. The evolution is provided by genetic algorithms.
The second, *Behavior on Artificial Life Societies*, is used to study social evolution. It uses Bayesian rules to predict actions that should be taken by people in small communities. Characters are aware of the role performed by the other society members, and take the most suitable actions in different situations. Cultural heritage can be therefore evaluated considering characters flow among independent groups.
The third, *ALGA,* an environment with artificial members that get their basic knowledge through

communication with other members. The purpose here is to evaluate the learning abilities, using language as a support for reasoning. Markov chains are used for reflexive analysis of their decisions and consequences of their actions.
The last one, *Adaptive Cognitive Virtual Character,* simulates how artificial students can follow real ones and produce their way of thinking, giving an opportunity to us for a better understanding of some cognitive actions, as reasoning on problem solving.

Conclusion

Artificial Life is an intriguing field in Computer Science which tries to conceptualize life and its processes and implement useful applications based on these. Since life is a complex system , and full of achievements acquired by adaptation in evolutionary perspective, the artificial life field could contribute many to different sub fields of Cognitive Sciences because mind is another complex system and closely related to the living creatures as a product of evolution of life.

Many argues that cognitive processes should be evolved by collective neurons and neuron is a cognitive unit, as life evolved by collective cells and a cell is living unit. Based on these similarities these two fields should be overlapping.

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