A Thought Structure for Complex Systems Modeling Based on Modern Cognitive Perspectives

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Abstract

One of the important challenges for complex systems modeling is finding an appropriate thought structure for designing and implementing a suitable simulation software. In this paper, we have proposed a suitable worldview for complex systems modeling according to Capra's conceptual framework, which is based on modern cognitive theories. With this worldview, the important and fundamental concepts for complex systems modeling are determined. Adding more details to the model that depends on the field of problem, we can simulate a complex system. Also using Popper's Three Worlds, the position of this simulation has been described. Following this thought structure, each simulation designer of complex systems can take advantage of modern cognitive theories in modeling.

Keywords: *Thought Structure, Complex Systems, Cognitive, Agent Based Modeling (ABM).*

1. Introduction

Appropriate modeling of complex systems is one of the fields of research today [1][2][3][4][5][6][7]. Researchers in this field are trying to extract appropriate concepts, provide frameworks and computational methods and mechanisms in order to create simulation models to describe the behavior of complex systems [1][2][3][4]. A complex system is made of interconnected components and as a result of the interactions between these components, the emergent behavior would appear [3][8][9]. Although we may describe the interactions among components with simple rules, but as the number of system components rises, the number of interactions between components will increase too.

Living systems such as cells, organizations, society and the earth in which there is the concept of life are all examples of complex systems [10]. These systems can be biological or social [10][11][12]. In living systems as complex systems, there are interactions between components for survival and evolution. One common approach in modeling living systems is Complex Adaptive Systems theory (CAS) [3][4]. In this theory, the living system is a complex system that adapts to its surrounding environment throughout its life for survival and evolution. Adaptation means how a system responds to the changing environment and adapts to it [1][2][3][4].

The modeling of complex systems usually leads to a simulation software, with which researchers can simulate and test their models and theories [8][12][14][15]. In addition, simulation software is a suitable alternative and in some cases the only possible way to test the models and theories [8][15]. Simulation approach both reduces costs and also enables researchers to study their models and theories with various parameters, aspects, and iterations [11][17]. A model is the foundation of simulation software which describes the main concepts, components, and processes as formal relationships [14][16][17]. The closer a model to reality, the better it will be. However, good modeling does not necessarily include more details, rather it means choosing and including features, components, and concepts that has a greater influence on reality [8][14].

A common terminology in complex systems modeling and simulation is agent [8][11][18]. Agent is an entity that can represent a cell, a human, or any living organisms in a complex systems modeling. Modeling based on the agent concept leads to Agent Based Modeling (ABM) [11]. With the advent of CAS theory and its wide applications, researchers found out that models use CAS and MAS (Multi-Agent System) to model nonlinear dynamic interactions that have been missing in the previous linear models [8]. However, it is suitable to utilize a thought structure that makes modeling and simulation of complex systems more accurate and produces a high quality software simulation.

In this paper, first the necessity of a suitable complex systems modeling worldview is explained and then it illustrated by Capra's conceptual framework. Then a thought structure for complex systems modeling with regard to Popper's Three Worlds is proposed. The first world is about complex systems worldview, the second world is about individual and social awareness and finally the third world is an artifact that is a methodology for simulator development.

2. Complex Systems Modeling Worldview

In complex systems, global behavior emerges form high number of interactions between components [3][4]. As the number of interactions is very high, the emergent behavior appears. Therefore, for understanding and modeling of complex systems, a special worldview is required. This worldview is the base of some methodologies such as CommonKADS and it precedes theory [19].

Overall, the methods that have been used for systems modeling during the past decades can be divided into two main approaches:

1) Model-oriented approach: It is based on methods of traditional system thinking. Worldview of this approach is based on reductionism. Reductionism is breaking a problem into smaller ones, solving each one separately and then combing the answers to get the solution of the main problem. In other words, for understanding the main system, we divide it to sub-systems and they can be further divided into smaller systems until we get to the systems that are knowable.
2) Data-oriented approach: The main idea of this approach is that complex systems cannot be understood with reductionism worldview. Therefore, as the behavior of the system is from bottom to top, for understanding it we need a new holistic worldview. In this worldview, emergent behavior becomes meaningful. It is according to this worldview that complex systems theories, cognitive theories, and other theories based on the new holistic thinking are used in complex systems modeling.

2.1 Capra's Conceptual Framework as a Worldview

Capra's conceptual framework is based on new interpretations and definitions of cognition. Cognition is the process of knowing in life; knowing how and what capabilities are used for survival. With this definition, the smallest living organisms, such as cells are cognitive phenomena using cognition for survival in life. Defining cognition based on biological view enables us to use the cognitive concepts in a wide range to explain the behavior of living organisms. We can find network patterns everywhere, from the smallest cognitive living organisms such as cells to organizations and human societies. Thus, network is a common pattern for life [10].

One of the cognitive theories based on the biological view is Santiago theory [10]. According to this theory, cognition is synonymous with the process of life. The organizing activities of living systems at all levels of life are cognitive. These activities include interactions among living organisms such as plants, animals, or human beings and their environment. Thus life and cognition are inseparable, as though mental activity is immanent in matter. Santiago's cognitive theory expands the cognitive concept in a way that it involves the entire process of life including perception, emotion, and behavior. In this theory, cognition is not just for human beings with a brain and a nervous system, rather it can be for each living organism, from cells to social organizations [10].

Capra has presented a unique framework for understanding the biological and social phenomena in four perspectives. Three out of these four perspectives is about life and the fourth one is meaning. (Fig. 1)

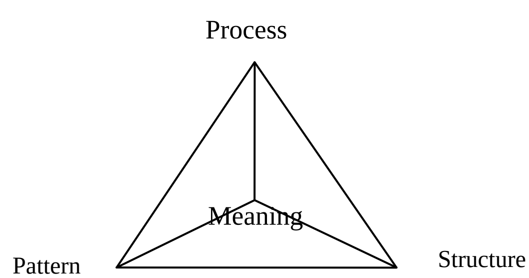

Fig. 1 Four perspectives of Capra's Conceptual Framework.

The first perspective of Capra's conceptual framework is pattern that includes various relations among system components. The organization pattern of a living system defines the relation types among the system components which determines the basic features of the system. Structure, the second perspective, is defined as the material embodiment of system pattern. The Structure of a living organism evolves in interaction with its environment. The third perspective is life process which integrates the pattern and the structure perspectives. For example, the study of living systems from these three perspectives includes the study of form (patterns of organizations), matter (or material structure), and process. From the perspective of form, the pattern of organization is a self-generating network. From the perspective of matter, the material structure of a living system is a dissipative one, that is, an open system that operates far from equilibrium. And from the process perspective, living systems are cognitive systems in which the process of cognition is closely linked to self- generating network [10].

When we try to extend new understanding of cognition to the social life, we immediately encounter many misleading phenomena - rules of behavior, values, goals, strategies, intentions, designs and power relations - that often do not have a role in non-human world, but they are essential for human social life. For expanding life to the social domain, meaning perspective is added to three other ones. Thus, we can understand social phenomena from four perspectives: pattern, structure, process, and meaning. Culture, for instance, has created and preserved a network (pattern) of communication (process) with embedded meaning. Material embodiment of culture includes art and literary masterpieces (structure) that transfer meaning from one generation to another.

As there is the concept of life and evolution in the living systems such as cells, organizations, and societies, there are all examples of a complex system. So, Capra's conceptual framework can be used as a worldview to understand complex systems.

2.2 Complex Systems Modeling in Capra's Conceptual Framework

According to Capra's conceptual framework, any complex phenomena can be discussed and studied in four perspectives. In order to close these four perspectives to the terminology of complex systems modeling, we replace "pattern" with "network" and "structure" with "agent".

Pattern perspective is the relationship between components, thus network is a good terminology. Structure is a set of features that evolves during life. These features together make the agent concept. Therefore, Capra's conceptual framework is redefined in four perspectives: network, agent, process, and meaning (Fig. 2).

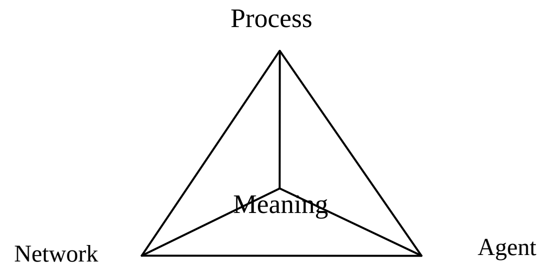

Fig. 2 Redefinition of Capra 's Conceptual Framework for Complex System Modeling

3. Extending the Thought Structure Using Popper's Three Worlds

According to Popper's Three Worlds, the first world is the physical world which is related to the worldview. The second world is the subjective realm in which theories and concepts are formed. And the third world is the objective one which is the realm of artifacts and objective knowledge [20].

In the previous section, the worldview of complex systems modeling in Capra's conceptual framework has been described. Now, we define individual and social awareness as the second world in Popper's Three Worlds. According to Fig. 3, individual and social awareness are both affected and affect agent, network, and process in the first world. Individual awareness refers to what knowledge each agent has and what it has learned from its environment and also from other agents. In other words, individual awareness is a memory that every agent has from its surrounding environment and this memory evolves during the life of the complex system. Hence, individual awareness is a mental model and every agent makes decision based on situation awareness. In a complex systems modeling, a set of agents are related to each other in order to achieve certain goals; therefore, in addition to individual awareness, social awareness is formed. Social awareness is the knowledge that a set of agents create together. It is a collective memory that is created by agents interacting with each other. The collective memory is a shared mental model that appears as shared situation awareness and can be used for coordination in social environments [21].

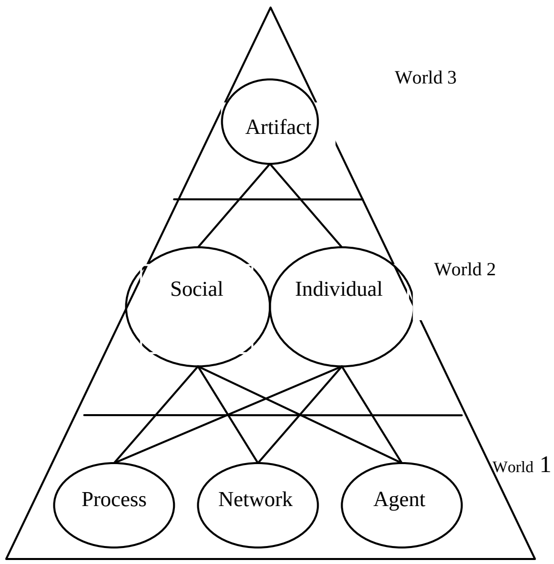

Fig. 3 General Thought Structure for Complex System Modeling Using Popper's Three Worlds

But, how individual and social awareness are created in a complex system? Although it is difficult to answer this question clearly, agent, network, and process influence the creation of individual and social awareness (Fig. 3). To observe this influence in the formation of awareness, modeling and simulation are suitable approaches. In other words, the first world that views the complex system from the perspectives of agent, network, and process can be developed and examined as a simulation software.

3.1 Layers of Simulation Software

Before we develop a simulator software, an architectural design is required which is based on some theories. In other words, the simulator development is based on the theories that explain a given phenomenon. Overall, design and implementation of the simulation software can be described in three layers (Fig. 4):

1 - Theoretical basics
2 - Software architecture
3 - Computational models

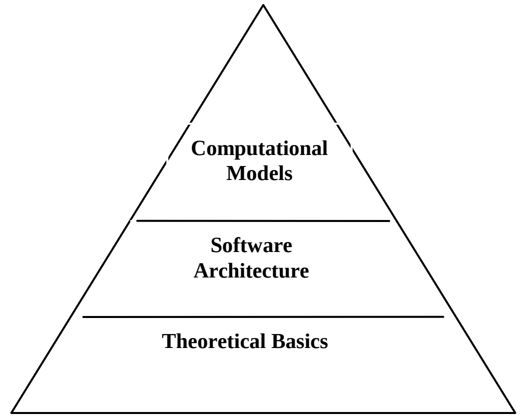

Fig. 4 Three Layers of Simulation for Complex Systems.

Theoretical Basics Layer: Theories refer to the philosophy of problem-solving method of simulation software. Therefore, theoretical basics are the base of simulation pyramid (Fig. 4). In simulation software design and implementation, for example, complex systems theory, graph theory, queue theory, and network theory can be used. That which theories should be used in the design and implementation is determined by answering this question: What theories justify modeling and simulation for a simulation developer? In other words, which theories are consistent with a given simulation problem?

Given to the adopted worldview, and after examining the given problem, we select appropriate theories for modeling and simulation in order to have theoretical basics.

Software Architecture Layer: Having determined the theoretical basics, software architecture is defined. It is based on theories and consists of software components, and relationships between them. Software architecture is an overall design that defines building blocks, relationships between blocks, and entities within each block [22]. There are two main approaches for modeling entities: object-oriented and agent-oriented. As the agent concept has more capabilities than the object concept, it models the entity better and is often used in the simulation software development. This approach is called Agent Based Modeling (ABM).

Computational Models Layer: Computational models express software components and relationships between them in the architecture layer in the form of mathematical and computational relations. In other words, computational models provide computational mechanisms that a software developer uses to generate executable codes. Therefore, this layer is the provider of a formal language for simulator software. Computational models are chosen based on theoretical basics and software architecture (Fig 4). For example, we can use soft computing such as genetic algorithms, neural networks, and fuzzy computations in this layer.

3.2 Development Methodology as an Artifact

Two worlds out of Popper's Three Worlds for complex systems modeling have been described so far. The first world is the complex systems modeling worldview that we redefined in three perspectives of agent, network, and process, based on Capra's conceptual framework. The second world is individual and social awareness of agents that is essential for their coordination.

We call the third world of Popper's Three Worlds artifact (Fig. 3). This world is objective knowledge and is falsifiable, that is, it is true as long as we cannot prove its falseness. Artifact is a methodology in our proposed thought structure. This methodology determines what concepts, components, and methods should be used for complex systems modeling. In other words, it illustrates and confirms the effect of meaning perspective (the fourth perspective of Capra's Conceptual Framework) in the form of some general principles. In a way, meaning is the interpretation of simulation results. We can interpret the results of simulation according to a given meaning. Overall, this methodology determines general principles for software architecture. For example, what principles and structures should be used for network design? What features are more important for agent design and definition? What kinds of processes are suitable for modeling a given complex system?

The principles obtained from the results of modeling and simulation can be used in the design of products and real applications. That is, these principles are used in the design of agent, network, and process in order to create a given meaning. They can be reviewed and revised after being used in real applications.

4. Conclusions

Complex systems modeling is one of the challenges and necessities of today's researchers which demands a suitable thought structure. Many researchers consider a living system as a complex system that adapts to its surrounding environment for survival and evolution. Consequently, cognitive theories and thought frameworks suggested for describing living systems can be utilized for understanding complex systems. Capra's Conceptual Framework is based on modern cognitive theories; therefore, we have used its modified version as the proposed thought structure worldview. This thought structure is based on Popper's Three Worlds. The first world is the complex systems modeling worldview that we have redefined in three perspectives of agent, network, and process. The second world is individual and social awareness that concerns with individual and shared situation awareness. The third world is an artifact that explains methodology for complex systems modeling. In other words, the artifact determines general principles and approaches for the software architecture.

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