



A hierarchical composite framework of parallel discrete event simulation for modelling complex adaptive systems



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ABSTRACT

As complex adaptive systems(CAS) continue to grow in scale and complexity, and the need for system adaptability increases, systems modelling has become an essential concern. Parallel discrete event simulation became a preferred choice as logical process world view, which bridges complex system modelling and high-performance computing. To resolve the shortcoming of this world view identified with respect to modularity and scalability. A hierarchical composite modelling framework was proposed, which is a three-level architecture intended to support the composition and integration of sub-models. The bottom layer is simulation model component(SMC), which is not a model but implement some simulation-specific support functionality. The middle layer is logical process model(LP), which describes an agent which can react to the current situation by executing a sequence of SMCs. The top layer is CAS system model, which defines a CAS model consist of several LPs and also the interactions between these LPs. The hierarchical composite modelling process and parallel simulation execution strategy are discussed to support the modelling and simulation of a CAS. In order to verify its effectiveness, a complex social opinion system model is proposed based on this hierarchical composite modelling framework. The experimental results confirms the viability of utilizing multi-level architecture for simulating large scale complex adaptive systems.

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1. Introduction

Whether designed to predict the spread of an epidemic, understand the potential impacts of climate change, or model the acoustical signature of a newly designed battle plane, computer simulation is an essential tool. By using simulation models that capture the complex behaviour of the real world, scientists can explore system dynamics that are too costly to test experimentally and too complicated to analyse theoretically.

Complex adaptive systems (CAS) [1] are such systems that have a large number of agents that adapt and interact. CAS problems are pervasiveness, such as encouraging innovation in dynamic economies, providing for sustainable human growth, predicting changes in global trade, understanding markets and so on. Mostly CAS share the features of modularity, adaptation, and evolution [2]. To understand their intricate dynamics it is often beneficial or necessary to use different kinds of

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models to represent each sub-system [3], then the structures and behaviours could be easy to adjust to change as the systems may continuously reconfigure themselves to adapt to different situations [4]. For example, a social ecological system typically evolves over time to adjust to the new environment. Therefore, to model this type of complex systems, a composite modelling framework is needed, as it greatly enhances the modelling capability.

A composite framework is an architecture or infrastructure intended to support and enable the integration and interoperation of individual sub-models [5]. It may consist of concepts, standards, control mechanisms, interfaces, and processes aimed to facilitate the efficient, and flexible assembly of systems from sub-models in a possible setting [6]. Component-based, standardized, multi-formalism modelling, system theory, and logical process world view are popular approaches for describing composite dynamic systems. Different modelling paradigms are suitable for various kinds of needs. Component-based simulation systems are immensely helpful to users who wish to build complex systems by composing existing software components, thereby shielding them from the underlying complexity of component resources. Discrete-event System Specification(DEVS) supports component-based modelling and simulation by emphasizing the theory of hierarchical modelling. The structure of input and output data is complicated as data for DEVS models are specified in terms of messages each defined in terms of port and value pairs. A standardized modelling approach is the High Level Architecture(HLA), which is aimed at handling interoperability needs with some limited capability for model composability as supported by the Object Model Template. Multi-formalism modelling approach composes different models using a model which handles the differences between modelling formalisms, but common forms of data transformation are inherently supported.

On the other hand, CAS can be modelled by a vast numbers of agents that interact by sending and receiving messages. The agents produce scores of interactive messages, and the actions of agents in a CAS usually depend on the messages they receive. Moreover, the complexity of CAS rises above the handling capacity of monolithic sub-models[7,8]. Therefore, the composite modelling framework is also needed to cope with the requirement for scalable modelling capability and high-performance simulation power.

Parallel discrete event simulation(PDES) became a preferred choice for studying complex systems as logical process worldview, which bridges complex system modelling and high-performance simulation [9]. A PDES program can be viewed as a collection of logical processes(LP). For example, a physical process such as a battle plane or a water station is modelled by a LP, and interactions between physical processes are modelled by scheduling events [10]. Each event contains a timestamp that represents a point in simulation time at which the state of a LP changes. The state variables that capture the state of the system being modelled changes when a corresponding event computation occurs. Recently studies into the parallel simulation of LP-based models has usually attempted to overcome the performance bottleneck. There has been useful work on algorithm optimization, but few effective methods for composite modelling methodology of CAS. Research on modelling CAS using LP paradigm currently suffers from: (1) event scheduling and event processing within a LP couples tightly, so that a LP is hard to achieve flexible composition of sub-models; (2) LP couples tightly, so that it is difficult to enable the efficient, and flexible assembly of a CAS-oriented simulation system from LPs.

To resolve the above problems, this paper proposed a hierarchical composite modelling framework, which is a three-level architecture intended to support the composition and integration of sub-models. The hierarchical composite modelling process and the parallel simulation execution strategy is discussed to support the modelling and simulation of a CAS. To verify its effectiveness, a complex social opinion system model(SOSM) is proposed based on this hierarchical composite modelling framework. The experimental results confirms the viability of utilizing multi-level architecture for simulating large scale complex adaptive systems. The main contributions of this paper are as follows:

- (1) Encapsulate a group of action rules of an agent into a SMC. It enables flexible assembly of an agent from SMCs; thus, an agent reacts to the current situation by executing a sequence of SMCs.
- (2) Decouple the interaction between agents. An agent only contains the behaviour processing logic. The interaction between agents implements by configuring the interactive relationship in a possible setting.
- (3) Mapping an agent to a LP and mapping the interactions between agents to scheduling interactive events between LPs, which enables the high-performance collaborative execution of a CAS model on existing PDES platforms.

The remaining of this paper is organized as follows. Section 2 gives the background and related works. Section 3 introduces the three-level architecture and the formal definition of sub-models in each level. Section 4 depicts the hierarchical composite modelling process for CAS and the execution of a CAS model. Section 5 analyses a case study of social opinion system and illustrates the merits of our framework. Finally, our conclusion will be made with an indication of the future work in Section 6.

2. Background and related work

There has been useful work on simulation platforms of multi-agent modelling for complex systems and complex networks. GAMA [11] aims at providing field experts, modellers, and computer scientists with a complete modelling and simulation development environment for building spatially explicit multi-agent simulations. RepastHPC [12] is a useful and useable agent-based modelling and simulation system explicitly focusing on larger-scale distributed computing platforms. It allows the use of different structures (Networks, Grids) which can be coupled in a same simulation to represent different types of interactions. However, one of the limitations in RepastHPC is no communication is allowed between remote agents.

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