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Simulation Approaches for System of Systems: Events-Based versus Agent Based Modeling

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Abstract

In order to understand how we may engineer system of systems (SoS), we will have to rely significantly on our abilities in modeling and simulation. While there are some models of non-specific SoS, few attempts have been made to demonstrate these models with simulation. Simulations of SoS are usually specific cases. Likewise, in the description of a SoS, most of the approaches have focused on their characterization, yet this characterization has not been greatly utilized as an underlying feature in the modeling and simulation of SoS. We review different modeling techniques and use two converse techniques, i.e. agent-based and event-based modeling, to run a simulation of hypothetical systems collaborating into a SoS. The results of the empirical comparison indicate an agent-based modeling approach would achieve a characterization model better with validation achieved through an event-based approach.

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1. Introduction

There would be no argument that modeling and simulation plays a vital role in our ability to engineer the integration of systems into a system of systems (SoS) [1]. Consequently, there have and continue to be many efforts on modeling SoS, yet few attempts at demonstrating these models with simulation. Likewise, a review of the

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literature reveals many endeavors to define a SoS by their features or characteristics [2], while only a few of these models have greatly utilized these underlying features or characteristics. We contend that simulating a SoS via the characteristics is one way to validate the attributes that produce the objective SoS.

Consequently, we are seeking to simulate the behavioral characteristics that a systems engineer may be able to modify in order to influence certain aspects of a SoS. Specifically, we want to determine how altering the degree of specified characteristics could impact the formation of SoS [3]. Equipped with this knowledge, a systems engineer may modify the chances of forming a SoS or at least have some predictor for the likelihood of the formation.

SoS has become a readily accepted term to classify an arrangement of independent and interdependent systems that delivers unique capabilities. There have been many attempts at defining and depicting these complex systems based on experience, and while many of the definitions designate SoS as a new entity, the definitions vary [4,5]. Gorod, et al. [2] revealed many endeavors to define and characterize SoS and concluded that a characterization is a more optimal approach to understanding them. Given the diverse descriptions of SoS, the characterizations are usually a list of various features that appear mostly anecdotal.

We are seeking to understand SoS and their properties through modeling and simulation. In this paper we will present a review of the literature regarding modeling and simulating. To determine the optimal simulation platform for a non-specific SoS, we contrast the major modeling paradigms from the literature and perform a comparison of agent-based modeling (ABM) versus event-based modeling (EBM) (also known as discrete modeling). Agent-based modeling, or individual based modeling as it is known also, has been extensively used in ecology where the researcher can program particular behaviors for entities and then watch the simulation produce interactions among many entities [6]. Event-based modeling is a common approach for systems engineering since the researcher can program different states a system undergoes in order to learn something about its underlying behavior. In section 4, we present an experiment to evaluate ABM and EBM to determine the utility of each modeling and simulation approach to SoS given the accepted characterization. We conclude with a discussion of the implications of this study.

2. Modeling and Simulation of SoS

Many studies in the literature examine SoS to understand them better [4], but we would like to learn more than passive observation allows. First we adopt a description of a SoS as a composite system composed of autonomous, diverse constituent systems that are dynamically connected and belong through contributions to the goals of the SoS [7]. Therefore, we argue that a SoS must have at least four basic attributes: autonomy, belonging, connectivity, and diversity. Furthermore a SoS exhibits emergence [8], although we defer exploring this characteristic to future work. To briefly summarize the definitions of these attributes, autonomy is the ability of a constituent system to complete its own goals within limits and without the control of another entity. The system's goal is the reason the constituent system exists [4]. Belonging is the ability of a constituent system to choose to contribute value to the goals of another system in exchange for value to its own goals [9], and diversity ensures the different systems have different goals [7,8]. Finally, connectivity is more than just having a connection but refers to a dynamical nature of information flow between constituent systems.

Given the behavioral characteristics that have been associated with SoS, modeling and simulation is one approach to validate the characteristics and simultaneously search for additional properties. By definition, a model is a simpler representation of some system of interest, and a simulation is the operation of the model for usefully inferring behavior [10]. More specifically, a model reproduces the characteristics of interest in order to observe specific behaviors [11]. This model should contribute to the understanding of the SoS. Although there have been various attempts at modeling SoS, few examples for simulating SoS from the literature are presented below.

One EBM approach to simulating a SoS involves the Discrete Event System Specification (DEVS) formalism. DEVS models interoperability events using architectural modeling techniques, such as the Unified Modeling Language (UML) or the Department of Defense Architectural Framework, which is commonly referenced as DoDAF. Once the interactions of the systems are understood, the messages that pass between systems are captured using the eXtensible Markup Language (XML). Basic models known as atomic models simulate each system in the SoS. The DEVS simulator imitates the SoS by taking the XML data as input to atomic models and outputting processed XML data [12]. A similar technique has been used to model the Global Earth Observation System of