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Synergies of simulation, agents, and systems engineering

Tuncer Ören [a,*], Levent Yilmaz [b]

[a] McLeod Modeling and Simulation Network (M&SNet) of SCS, School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, ON, Canada
[b] (M&SNet): Auburn Modeling and Simulation Laboratory, Computer Science and Software Engineering Department, Auburn University, Auburn, AL, USA

A R T I C L E I N F O

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A B S T R A C T

Simulation, software agents, and systems engineering are three important disciplines; each of which support many application areas. In this article it is pointed out that their usefulness and efficacy can be significantly improved by first and higher order synergies.

1. Introduction

Simulation, software agents, and systems engineering are independent and important disciplines. The synergy of simulation and software agents is the essence of agent-directed simulation (ADS) which has important practical implications (Yilmaz & Ören, 2009a, 2009b). ADS as clarified in the sequel, consists of contributions of simulation to agents (i.e., agent simulation) and contributions of agents to simulation (i.e., agent-supported simulation and agent-based simulation). Synergy of simulation and systems engineering has two important aspects: contributions of simulation to enhance systems engineering and contributions of systems engineering to simulation. In the article these synergies and the synergy of agent-directed simulation and systems engineering as well as synergy of agents and systems engineering are outlined in a systematic way. Furthermore, the synergies have cumulative effects; while synergy of simulation and systems engineering is very important, synergy of agent-directed simulation and systems engineering opens new vistas.

Recent trends in technology as well as the use of simulation in exploring complex artificial and natural information processes (Denning, 2007; Luck, McBurney, & Preist, 2003) have made it clear that simulation model fidelity and complexity will continue to increase dramatically in the coming decades. The dynamic and distributed nature of simulation applications, the significance of exploratory analysis of complex phenomena (Miller & Page, 2007), and the need for modeling the micro-level interactions, collaboration, and cooperation among real-world entities is bringing a shift in the way systems are being conceptualized. The emergent need to model complex situations whose overall structures emerge from interactions between individual entities and cause structures on the macro level to emerge from the models at the micro-level is making agent paradigm a critical enabler in modeling and simulation of complex systems.

This paper aims to provide a basic overview of potential synergies of systems engineering with uses of agents for simulation, as well as the use of simulation technologies to study simulation for agents. Agent systems are defined as systems that are composed of a collection of goal-directed and autonomous physical, human, and logical software agents situated in an organizational context to cooperate via flexible and adaptive interaction and cognitive mechanisms to achieve objectives that can not be achieved by an individual agent. Agent-Directed Simulation (ADS) is promoted as a unified and comprehensive framework that extends the narrow view of using agents simply as system or model specification metaphors (Yilmaz & Ören, 2009a).

Fig. 1 represents synergies of simulation, software agents, and systems engineering. The rest of the paper is structures as follows: First, the salient features of simulation, agents, and systems engineering are given; then the four synergies are elaborated on.

2. Background: the three disciplines

2.1. Simulation

Two recent articles and a recent keynote presentation provide comprehensive and integrative views of modeling and simulation (M&S) (Ören, 2009a, 2009b, 2010). Two aspects of simulation are experiments and experience. From the perspective of *experiments*, simulation is performing goal-directed experiments using models of dynamic systems. Experiments are performed for decision support, understanding, and education. Different types of use of simulation for decision support are outlined in Table 1. From the point of view of *experience*, simulation is gaining experience by the use of a representation (or a model) of a system.

Gaining experience through simulation is done for two categories of activities, i.e., for training and for entertainment.

* Corresponding author.
E-mail addresses: oren@site.uottawa.ca (T. Ören), yilmaz@auburn.edu (L. Yilmaz).

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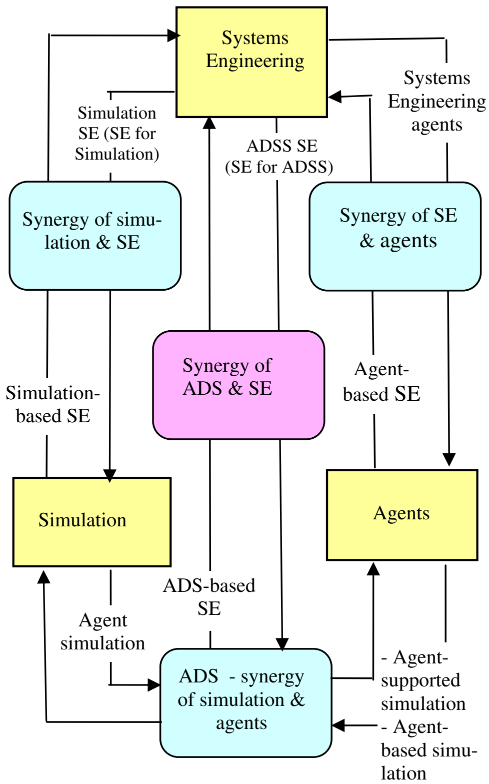

Fig. 1. Synergies of simulation, agents, and systems engineering.

Table 1
Types of use of simulation for decision support.

Prediction of behavior and/or performance of the system of interest within the constraints inherent in the simulation model (e.g., its granularity) and the experimental conditions
Evaluation of alternative models, parameters, experimental and/or operating conditions on model behavior or performance
Sensitivity analysis of behavior or performance of the system of interest based on granularities of different models, parameters, experimental and/or operating conditions
Evaluation of behavior and/or performance of engineering designs
Virtual prototyping
Testing
Planning
Acquisition (or simulation-based acquisition)
Proof of concept

Simulation-based training is gaining/enhancing competence on any one of the three types of skills:

(1) Motor skills (by virtual simulation, or simulators),
(2) decision making and communication skills (by constructive simulation or, gaming simulation –or serious games– including business games, war games, peace games), and
(3) operational skills (by live simulation).

Simulation-based entertainment is the essence of simulation games.

2.2. Agents

Agents are autonomous software modules with perception and social ability to perform goal-directed knowledge processing over time, on behalf of humans or other agents in software and physical environments. When agents operate in physical environments, they can be used in the implementation of intelligent (smart) machines and intelligent (smart) systems and they can interact with their environment by sensors and effectors. The core knowledge processing abilities of agents include: goal-processing, goal-directed knowledge processing, reasoning, motivation, planning, and decision-making.

The factors that may affect decision-making abilities of agents (in simulating human behavior) are: personality, emotions, cultural backgrounds, irrationality, and dysrationalia. Abilities to make agents intelligent include: anticipation (pro-activeness), understanding, (avoiding misunderstanding), learning, and communication in natural and body language. Abilities to make agents trustworthy as well as assuring the sustainability of agent societies include: being rational, responsible, and accountable. These characteristics lead to rationality, skillfulness and morality (e.g., ethical agent, moral agent).

To appreciate the characteristics of agent-based computation, it may be useful to see it from the spectrum of computational paradigms.

Table 2 outlines computational paradigms based on type of knowledge processing.

Each computational paradigm represents advancement so far as the role that the computational systems undertake to free the user to perform some tasks. In the sequel, Tables 3–5, adopted from (Yilmaz & Ören, 2009b) outline the roles of users and the computational system for procedural, intentional, and goal-directed knowledge processing.

Table 2
Spectrum of computational paradigms.

Type of knowledge processing	Computational paradigms
Procedural	Algorithmic
Intentional	Declarative
Goal directed	Interactive (event-based)
	AI-based (heuristic, rule-based, frame-based)
	Agent-based

2.3. Systems engineering

The International Council on Systems Engineering (INCOSE) defines systems engineering as follows (INCOSE, 2011):

"Systems engineering is an interdisciplinary approach and means to enable the *realization of successful systems*. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the *complete problem*: Operations, Performance, Test, Manufacturing, Cost & Schedule, Training & Support, and Disposal.

Systems engineering integrates all the disciplines and specialty groups into a team effort forming a *structured development process* that proceeds *from concept to production to operation*.

Systems engineering considers both the *business* and the *technical needs* of all customers with the goal of providing a quality product that meets the user needs."

INCOSE Systems Engineering 2020 (INCOSE-SE, 2011) lists also attributes of systems used to observe changes over time. They are given in Table 6.

Systems engineering has gained momentum and many application areas have already adopted/tailored systems engineering for their needs. Table 7 lists 37 types of systems engineering according to specific application areas.

Table 8 lists domain-independent types of systems engineering.