Evolution of Simulation Paradigms in OR

Yang Li
British Telecom, UK

INTRODUCTION

Operational Research (OR), as studied by Kirby (2003), has its root back to World War II; it is a discipline that deals with the application of advanced analytical methods to help make better decisions. Such analytical methods, as generally termed as Business Analytics (BA), can be grouped into three categories: descriptive analytics to gain insight from historical data with reporting and scorecards, predictive analytics to forecast trend using statistical and machine learning techniques, prescriptive analytics to recommend decisions using optimization and simulation. Generally speaking, these methods are combined together to solve business optimization problems. For example, descriptive analytics is first used to obtain historical data, predictive analytics is then used to forecast future data, prescriptive analytics is finally used to recommend decisions.

Central to business analytical strength is its modeling and simulation capabilities. In OR, there are three groups of simulation paradigms, namely, System Dynamics (SD), Discrete Event Simulation (DES) and Agent-Based Simulation (ABS); these paradigms were invented and evolved in different socio-economic contexts. In academic research and industrial practice, there has been general confusion about the differences among these paradigms and when they should be used. In this chapter, the author presents them in the context of socio-economic evolution, in order to shed light on their origins, strength and limitation. In particular, the author explains the definitions of ABS from various subjects and current debates and opportunities around ABS in OR.

CO-EVOLUTION OF SOCIO-ECONOMY AND SIMULATION PARADIGMS

Figure 1 shows the co-evolution of socio-economy and simulation paradigms viewed by the author.

SD was created during 1950s by Professor Jay Forrester (1961). Typical constructs in SD are stock, flow and feedback. Mathematically, these could be represented as a set of differential equations. The key feature of SD is to look at things in aggregated volumes rather than from individual perspective. 1950s is a post-war era in which world economy was being recovered and re-built. In most countries, this is a decade when agriculture sector made the first and biggest stride to feed hungry stomachs. This is also a time when collectivism prevailed as there was very limited resource to consume. In the UK, National Health Service (NHS) was set up to centrally control health service resources to ensure people from all walks of life have access to the service. Typical SD applications in this era are chemical factory flows, weather forecast, agricultural throughput and epidemic disease propagation, all looking at dynamics of these systems in aggregated numbers.

DES emerged during 1960s and has remained the main industrial simulation technique for over 40 years. Banks et al. (2005) provided a reference book on this topic. Typical constructs in DES are entities, activities and queues. These constructs are linked together to form a complex process flow in which multiple entities flow across various queues and activities. Entities could also be stored in the resource pool attached to an activity and are used to match incoming entities. The

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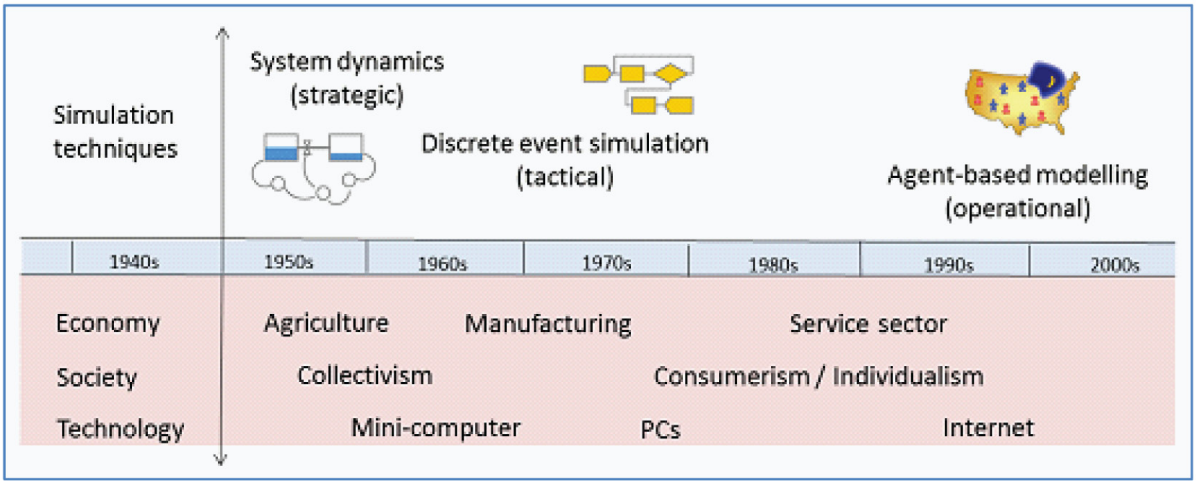
Figure 1. Co-evolution of socio-economy and simulation paradigms



matching in DES is generally a simple linear mapping, as most commercial DES toolkits do not have free coding capabilities to customize more sophisticated behavioral logic. DES models often employ probability distribution functions such as Normal, Uniform, Weibull and Fatigue Life to handle stochastic processes.

During 1960s and 1970s, manufacturing has gradually overtaken agriculture to become the dominating sector, as consumers once again aspired for mass-produced industrial goods for comfort. Large manufacturing factories employed DES tools to help simulate and optimize their production processes. In the DES models, product components are modeled as incoming entities, conveyors as queues, processing machines as activities and resources. In some factories, such as those manufacture automobiles or washing machines, human labor becomes part of the activities and resources; they are strictly trained and managed to perform in time and in quality comparable to machines such that the whole manufacturing processes are in harmony.

The abundance in consumer goods brought by manufacturing boom fueled a culture of consumerism in 1980s. Consumerism goes hand-in-hand with individualism; people were no longer satisfied with shared resources but looked for personalization and differentiations. In computer industry, there was evolution of computing machine from mainframe computers to mini computers and to personal computers, reflecting such change in culture. Individualism marks the crowning of service sector as the new dominating economy in 1990s. In the service industry, service customers are no longer passive receivers of uniform services but increasingly picky and unpredictable in purchasing and churning behaviors. Equally, the ever-growing diversity of service skills and rapid advancement in communication technology has generated a greater flexibility for service professionals both in work style and in productivity. ABS was invented to handle the complexity in human behaviors at individual level.

AGENT-BASED SIMULATION AND ITS APPLICATIONS

Agent-Based Simulation (ABS) is a relatively new paradigm that simulates the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena. There is no universal agreement in the literature on the precise definition of an agent; both operational research community and computer science community have different aspirations in agent-based modeling capabilities and applications.