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A conceptual modeling framework for discrete event simulation using hierarchical control structures

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ABSTRACT

Conceptual Modeling (CM) is a fundamental step in a simulation project. Nevertheless, it is only recently that structured approaches towards the definition and formulation of conceptual models have gained importance in the Discrete Event Simulation (DES) community. As a consequence, frameworks and guidelines for applying CM to DES have emerged and discussion of CM for DES is increasing. However, both the organization of model-components and the identification of behavior and system control from standard CM approaches have shortcomings that limit CM's applicability to DES. Therefore, we discuss the different aspects of previous CM frameworks and identify their limitations. Further, we present the Hierarchical Control Conceptual Modeling framework that pays more attention to the identification of a models' system behavior, control policies and dispatching routines and their structured representation within a conceptual model. The framework guides the user step-by-step through the modeling process and is illustrated by a worked example.

1. Introduction

Conceptual Modeling (CM) is one of the most important aspects of a simulation project (see [24]). It involves the abstraction of a model from the real world system, identifying what has to be modeled and how. Despite its importance, CM has only recently gained popularity in Discrete Event Simulation (DES) literature. As a consequence, the definition of CM is still evolving and is interpreted slightly differently by varying authors. However, there is a common agreement that it should be independent of any implementation paradigm, or software solution, and that it is initiated early in the simulation project life-cycle and iteratively revisited. According to Pace [20], a conceptual model is a tool of communication between all parties in a simulation project. In addition, among other features, it provides the basis of the model documentation; guides the development of a computer model; provides guidance for experiments; and is an aid for model verification and validation (see [25]). On the other hand, Balci and Ormsby [4] and Balci et al. [5] discuss CM for large scale models and therefore address re-usability of simulation models as the largest gain from structured and standardized CM in addition to the previous features.

A recent summary on definitions, frameworks, representations and other aspects of CM was published by Robinson et al. [27]. Robinson [29] gives a brief tutorial on CM. Issues and further research requirements for CM were summarized by Robinson [24]. Among others, Robinson [24] identifies the following key research requirements: developing consensus over

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the definition of CM; the identification of requirements of CM; developing methods for designing conceptual models; the definition of modeling frameworks; and moving towards standard methods for representing and communicating conceptual models.

This paper proposes a new framework for CM and hence addresses mainly the design and definition aspects of the research requirements discussed in Robinson [24]. The concepts of the framework are based on previous definitions and frameworks for CM, but replace queuing networks by both more sophisticated mechanisms for entity behavior that enable explicit, centralized control policies (such as dispatching). Control mechanisms (such as optimized dispatch) with complexity beyond common queuing methods have been identified as the key factor for accurately representing a real system, especially for health care models (see [8]). Hence the prevailing practice of representing DES models with queuing networks may not always be appropriate. The paper is structured as follows: Section 2 revisits the most common definitions and views on CM and discusses their relevance for this paper; Section 3 includes a summary and discussion of frameworks for CM and representation methodologies; Section 4 introduces the proposed framework and the new concepts are illustrated by a example from Birta and Arbez [6]; the paper concludes in Section 5 with final remarks and further research topics.

2. Definition of a conceptual model

As mentioned in the introduction, to date no generally accepted definition of a conceptual model and the associated modeling tasks exists. This section gives a brief overview of existing literature and concludes with the authors' view on CM.

Zeigler [35] is the first work that pays attention to different abstraction levels of simulation models by identifying five elements: the real system; the experimental frame; the base model; the lumped model; and the computer model. The experimental frame denotes the circumstances under which the real system is observed (input & output patterns). The base model is a hypothetical, complete representation of the real world, which is obviously not known. The lumped model is a simplified version of the base model that is able to reflect all input & output patterns and the computer model denotes the implementation of the lumped model. In the terminology from Zeigler [35], the lumped model is mainly independent to the computer model and represents what is now understood as a conceptual model.

Balci [3] analyses the early stages of a simulation study and identifies iteratively repeated steps that include model formulation, model representation and programming. Nance [14] distinguishes between the model that exists in the mind of the modeler, the conceptual model, and its representation for use in for communication, the communicative model. In the defense sector, Pace [17,19] interpret the conceptual model as a definition of what has to be modeled and how, providing information on assumptions, algorithms, characteristics, relationships and data. Further, Lacy et al. [12] distinguishs between a domain-oriented problem that describes the requirements of the model and a design-oriented model that is used as a basis for model implementation.

More recently, Balci and Ormsby [4] discuss CM for large scale simulations. Thereby, they identified three major abstraction layers that a simulation model passes through in it's life cycle: simulation conceptual model; simulation design model; and simulation model implementation. They argue that the implementation is accomplished by using programming languages as Java, C++ or C#. The transition between the design layer and the implementation layer is undertaken by the use of discrete-event world views, e.g. event scheduling, three-phase approach or process interaction (see for example [2]). Hence, the design model is a description of the components of the implementation model using object-oriented or procedural paradigms. The conceptual model represents the highest layer of abstraction and is the model that is formulated in the mind of the modeler. Note that their work is motivated by large scale models in the defense sector. The number of modelers and domain experts involved in these studies is usually large. Hence, requirements for CM differ to business oriented models by focusing on documentation, communication and re-usability (see [25]).

In Birta and Arbez [6] state that CM is concerned with developing a meaningful representation of the real system. Further, they define two major requirements for a conceptual model: it must be sufficiently transparent to be used as a means for discussions by all stakeholders in the project; and it must be sufficiently transparent so that it can serve as a specification for the computer program.

In Karagöz and Demirörs [10] state that CM is a tool that provides a clear understanding of the target domain or problem. Hence, it is a simplified representation of the real system including structural and behavioral features.

The most recognized definition of a conceptual model is given in Robinson [25]. Robinson argues that a conceptual model is derived from an understanding of the problem situation, which is external to the conceptual model. Hence, it is a partial description of the real world that is sufficient to address the problem situation. Further, it consists of four main components: objectives; inputs (experimental factors); outputs (responses); and the model content. Content is further divided into the scope of the model and the level of detail. During the identification of the model's content assumptions and simplifications have to be made. This leads to the following definition of a conceptual model (see [25]):

> "The conceptual model is a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model".

The task of conceptual modeling is therefore concerned with an understanding of the problem situation and the identification and determination of the components of a conceptual model. Furthermore, in Robinson [28] the model design is added as an artifact to the project life-cycle. The model design is defined as the design of constructs for the computer model, see also Fishwick [7].