MODELING AND SIMULATION TECHNIQUES

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Summary

This chapter presents modeling and simulation techniques for complex systems such as life support systems. One uses a model instead of real situation or system to understand something about it. Simulation with model helps us in making decisions and raise hypothetical scenarios. If the model is valid experimenting with it by computer can save money, time and efforts. Computer simulation designs a model of a studied object, executes the model on a digital computer, and analyzes the execution output. The knowledge base of data contains coordinated determination of the model external

variables and parameters and information regarding model expected behavior. The first and the hardest problem in simulation is determining the exact method to use for creating a model. The chapter presents a review on techniques used in model design (conceptual, declarative, functional, constraint, and multi), techniques used in simulation model execution (serial and parallel discrete-event simulation), and techniques used in simulation model analysis (calibration, validation, verification, goal-seeking).

1. Introduction

A model is something that one uses instead of the real thing in order to understand something about that thing. Any model is much simpler then the reality it describes. In spite of this, mathematical modeling and simulation are basic methods for analysis of complex life support systems states and for forecast of system evolution. Besides, one uses models because it is very costly, dangerous and often impossible to make experiments with real systems. Provided that models are adequate descriptions of causal relationship in reality (they are valid), experimenting with them by computer (simulating of reality) can save money, woes and quite often time.

The system model is written either as a computer program or as some kind of input into simulator software. Computer simulation is the discipline of designing a model of a studied object, executing the model on a digital computer, and analyzing the execution output. Within the overall task of simulation, there are several possible foci: model design, model specification, model execution, and model analysis. A model is a high level specification. Models are what scientists use to communicate about system design. The semantics of a model are assumed to be known and common when scientists employ common model types. Specifications can be written in many ways; but all of them define algorithms. The algorithms formally specify how the models behave and are simulated over time. Model execution is different from model design because one model design may be executed in many different ways.

They often use the term simulation synonymously with computer simulation. Simulation is an applied methodology in that one describes the behavior of complex systems using mathematical models. Our model serves as a hypothesis for how a system really behaves over time. One learns about an environment in an extremely effective way and modifies rules while seeing the effects of our interaction.

To come to a decision on practical needs by model and simulation it is necessary to interpret them in model terms. A problem of interpretation for matters reach in content of reality in model terms cannot be resolved one day forever or automatically. As a rule they divide the problem into two parts:

- description of a knowledge base which is used also for model validation and verification,
- choice of the model parameters by techniques of calibration and identification.

The knowledge base contains coordinated determination of the model external variables and parameters and information regarding model expected behavior. It is necessary to use the coordinated determination to execute analytical or forecast calculations by model and simulation. The information about expected behavior of model is acquired either from an expert or from data obtained from an existing system and previously validated models.

2. Techniques in Simulation Model Design

Process of model design may be divided into the next stages:

- conceptual model design or pre-model formulation accompanied by pre-formation of a knowledge base,
- declarative model design or description in form of mathematical equations that cast aside the nonessential factors,
- functional model design or formulation of mathematical laws that the object obeys,
- calibration of the model, formation of knowledge base and purpose of study,
- investigation of the problem in particular by computer experiment,
- comparison of results of model investigations with practice results and results obtained from another model.

Perhaps the hardest general problem in simulation is determining the exact method to use for creating a model. After all, where could one finds the starting point? Just as the discipline of software engineering has emerged to answer this question for software, in general, modelers also face a similar problem: how does one engineer models? While there are many modeling techniques for simulation, one is often in doubt as to which model technique to use, and under what conditions it should be used.

2.1. Conceptual Models Design

In the statement of a problem existing concepts are always assumed. However, it is expected that new concepts will also be created during the solution process. Concepts are, however, of little value until they are expressed, usually through the medium of language or block-schemes. It is only then that individuals can communicate their ideas to others, and can co-operate in problem solving.

As a rule they use such techniques to design a conceptual model as:

- choice of main agents and main subsystems they act,
- choice of main values described states of studied system,
- design of a block-scheme of interacting agents and subsystems that contains flows for fixed values.

Nowadays these techniques are formalized only for very simple models. In formal model every entity being modeled in the real world has an obvious and one-to-one correspondence to an object in the model (agent, subsystem, value). Because conceptual model maps directly from entities in the real world to objects in the computer-based model, they make it easier to design and implement systems. The resulting systems are easier to use since they are semantically obvious to users who already know the problem area.

2.2. Declarative Models Design

A model is declarative if the current state of the system determines the actions of agents and the ways in which that state will be changed. In other words, declarative models specify reactions to states. As a contrast, imperative models specify a subsequent state based on a given state. Dynamic imperative models yield sequences of states without specifying how they are achieved whereas declarative models specify the actions taken and changes made.

The declarative modeling techniques enable the modeler to include qualitative considerations without loss of accuracy. In practice, they develop models in such a way that simulation outputs include numerical series, which can meaningfully be compared with some statistical data series.

2.3. Functional Models Design

The purpose of functional model of a studied system is to describe what the operations on the system should do. Functional model may contain functional entities of different types. Each type of entity is defined by the functions it contains.

2.4. Constraint Models Design

Each constraint (e.g., $x + y = z$, "the triangle is inside the circle") restricts the possible values that variables can take, it represents some partial information about the variables of interest.

All entities in a declarative model are described initially with the constraints that define their nature and the relationships between them. The search program code is kept separate from the model description. To design a model in terms of constraints it is necessary to transform its description from the natural language to the language of constraints. Both choosing the right model and choosing the right constraint satisfaction algorithm is crucial for efficient solving of the problem.

2.5. Multi-models Design

Multi-modeling is an extension of object-oriented design. The key contribution of the object-oriented methodology for simulation is the mapping between physical objects and digital world. Classes are connected to form hierarchical structures using two possible connectors: generalization or aggregation. An object is an instance of a class. Each object will have attributes and methods. Attributes refer to properties of an object while methods refer to the functions and procedures that operate upon the attributes. Attributes can be one of two types: static and dynamic. A static attribute is one that does not change over time while a dynamic attribute represents a component of the state vector associated with the object. Simulation is mainly concerned with dynamic attributes. A model is created by constructing objects and connecting them through message passing.

Technology of multi-model design consists of the next stages:

- conceptual model design for an investigated life support system,
- breaking the system into a hierarchy of multi-model (abstractions),
- identification of models to represent those abstraction levels.

Some levels may be declarative or functional in nature, and some might combine these elements. A multi-model is a collection of individual models connected altogether to promote intersection of levels. Identification is a process of selection of appropriate model for each level. When the selection fulfils on the basis of statistical data this process contains processes of data collection, and model calibration – adjustment of model parameters.

After the model has been designed, it needs to be executed. The way that one executes a model depends on the type of model.

3. Techniques in Execution of Simulation Models

A simulation is the technique of imitating the behavior of some system or situation by means of an analogous model, situation, or apparatus, either to gain information more conveniently or to train personnel. Discrete event simulation concerns the modeling of a system as it evolves over time by representing the changes as separate events. This is the opposite of continuous simulation where the system evolves as a continuous function. Although, discrete event simulation could conceivably be carried out by hand it can be computationally intensive, therefore will invariably involve computers and software.

A simulation is the execution of a model, represented by a computer program that gives information about the studied system. The simulation approach of analyzing a model is opposed to the analytical approach, where the method of analyzing the system is purely theoretical. As this approach is more reliable, the simulation approach gives more flexibility and convenience.

Computer simulation has a tremendous influence on all facets of life because it is often too costly or prohibitive to build real physical systems. Simulation helps you to make decisions and raise hypothetical scenarios. A key activity of applied scientists is to model some aspect of reality, and the computer plays a central role in modeling. If it is necessary to speed the execution process for a large-scale model, they parallelize the model.

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Biographical Sketch

Nicholas Olenev is Senior Scientist at the Department of Mathematical Modeling of Economic Systems, Dorodnicyn Computing Center of the Russian Academy of Sciences (CC RAS), Senior Scientist at Joint Supercomputer Center, Moscow, Russia, Docent at Moscow Institute of Physics and Technology, where he teaches parallel programming by message passing interface, Docent of mathematics at Peoples' Friendship University of Russia, where he teaches mathematical modeling for economic and ecological systems. He holds a Ph.D. from the CC RAS, 1993. He previously occupied permanent positions at Department of Economic and Mathematical Methods for Poultry Industry of Scientific and Research Organization "Complex," Moscow Region, where he was a leader of team that constructed a logistical system for drafting of poultry deliveries. He was a visitor at the Central and East European Economic Research Center, Warsaw University, where he studied dynamics of employment structure in transition economy and constructed a production function of skilled and unskilled labor for Russian non-growing economy. He has constructed and studied numerous models of transition economy and models of economy and environment interaction. His main interests are in the field of mathematical modeling of economic structures for various branches of national economy, constructing of network ecological demographical economic simulation games for several countries, developing models for study ecological consequences of economic growth.