Chapter 19
A Simulation Model for Large Scale Distributed Systems

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ABSTRACT
The use of discrete-event simulators in the design and development of Large Scale Distributed Systems (LSDSs) is appealing due to their efficiency and scalability. Their core abstractions of process and event map neatly to the components and interactions of modern-day distributed systems and allow designing realistic simulation scenarios. MONARC 2, a multithreaded, process oriented simulation framework designed for modeling LSDSs, allows the realistic simulation of a wide-range of distributed system technologies, with respect to their specific components and characteristics. This chapter presents the design characteristics of the simulation model proposed in MONARC 2. It starts by first analyzing existing work, outlining the key decision points taken in the design of the MONARC’s simulation model. The model includes the necessary components to describe various actual distributed system technologies and provides the mechanisms to describe concurrent network traffic, evaluate different strategies in data replication, and analyze job scheduling procedures.

INTRODUCTION
Large-scale grids and other federations of distributed resources that aggregate and share resources over wide-area networks present major new challenges for scientists. In this chapter we focus on the challenge to enable scalable, high-level, online simulation of applications, middleware, resources and networks to support scientific and systematic study of Large Scale Distributed Systems (LS-DSs). The field of modelling and simulation was long-time seen as a viable alternative to develop new algorithms and technologies. It enables the development of LSDS when analytical validations are prohibited by the nature of the encountered problems.

In this chapter we describe the approach used to design and implement a generic simulator for distributed systems. We present the design characteristics of a model for the simulation of such systems that integrates components and mechanisms that enable realistic simulation
A Simulation Model for Large Scale Distributed Systems

experiments for LSDS. The model incorporates the necessary components and characteristics that allow the complete and accurate design of realistic simulation experiments of complex Grid architectures, consisting of many resources and various technologies, ranging from data transferring to scheduling and data replication, with resources working together to provide a common set of characteristics. The proposed simulation model includes the components to describe various actual distributed system technologies, and provides the mechanisms to describe concurrent network traffic, evaluate different strategies in data replication, and analyze job scheduling procedures.

The model is part of a multithreaded, process oriented simulator for LSDS called MONARC 2. The first version of such a generic simulator for LSDS was developed in the late '90s (Dobre & Stratan, 2003). It started with the LHC physics experiments that needed data processing and storage capacities beyond what was available at that time. The size of the LHC experiments and the unprecedented scale of data resulted in the need to look at resources outside of European Organization for Nuclear Research (CERN). This context led to the proposal of the hierarchical distribution model (the Tier architecture), according to which facilities from all around the world are putting together resources in order to provide the necessary computing power and data storage space needed for the experiments (Legrand, et al., 2003). In many ways this architecture was the predecessor of modern LSDS. Still, because the architecture represented a novel approach, and to eliminate further suspicions that the model might not in fact deliver the envisioned processing and storing capacities, a mix team of researchers from CERN and California Institute of Technology designed and developed the first version of a generic simulator, called MOdels of Networked Analysis at Regional Centers (MONARC). It was actually used for the first validation experiments of the model that was later used in the processing of the data actual generated in the LHC experiments (Dobre & Cristea, 2007).

Still, the original simulator included only limited functionality. It was able to evaluate limited simple models, including several components needed in the physics experiments. Later on the author of this chapter redesigned the simulation model, adding new components and capabilities to allow the simulation of a wider range of distributed systems architectures. The model was evaluated in the implementation of the second generation of a more generic and flexible simulator, capable of delivering higher performance results. It was named MONARC 2. The simulator allowed the development of experiments with thousands of nodes and the evaluation of models ranging from Computational Grids to Data Grids, scheduling and replication algorithms, networking protocols, data warehouses, almost anything Grid related. MONARC 2 also took advantages of the current progress that was made by newer Java Virtual Machine implementations since the original MONARC project. The original simulation engine was redesigned to allow much larger systems to be simulated, comprising more components and running jobs. In the same time it improved the running performances by integrating state-of-the-art algorithms and structures. The simulation components were redesigned to consider many more parameters and others new were added into the simulation models. For example, the possibility to simulate data replication, distributed scheduling, fault tolerance, security, represent capabilities were introduced in the new simulation framework. The output representations of the simulations were redesigned. Higher aggregate functionalities were introduced to allow for a higher level analysis of the produced simulation results.

By incorporating state-of-the-art algorithms and technology solutions, the simulator allows the realistic simulation of a wide-range of distributed system technologies, with respect to their specific components and characteristics. The modelling instrument provides the means to faster simulate distributed system of larger scale, involving a large number of resources and applications. Its characteristics, such as its robust architecture,