

Regenerative Simulation of Stochastic Petri Nets with Discrete and Continuous Timing

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Abstract

We present a regenerative simulation method applicable to a special class of non-Markovian stochastic Petri net (SPN) that may be useful in practice for constructing and solving performance models. Introduced in [1], this special SPN is called a phased delay Petri net (PDPN) and was conceived to allow efficient numerical analysis while increasing the modeling fidelity. The PDPN permits phase-type firing delays in both discrete and continuous time simultaneously in the same model. However, exact numerical analysis requires that the discrete-time transitions be synchronized when active. We propose here, instead, a new regenerative simulation technique that offers efficient analysis of PDPNs where numerical solution by exact means or other (known) types of regenerative simulation is too difficult.

1. Introduction

As far as we know, simulation of phase-type models has not been specifically addressed before in the literature—not surprisingly, since phase-type distributions are typically introduced to allow an exact numerical solution. One might ask: Why simulate models with phase-type probability distributions when completely general distributions could be sampled instead? Well, regenerative simulation of PDPNs is an interesting idea for at least two reasons. First, simulating a PDPN is easy and efficient, as only exponential random variables and uniform random variables between zero and one are needed; the former are used to determine the time until the next phase-change event in continuous time (this time is a constant τ for discrete-time delays), the latter are used to select the next phase from the stochastic transition matrix associated with each phase-type distribution. The second reason is that, unlike general SPNs, PDPNs possess properties that aid the identification of hidden regenerative structures and easier determination of regeneration times.

2. Background

We adopt the standard SPN definitions: a bipartite graph with two finite sets of nodes, places, P , and transitions, T , which are connected by directed arcs. Places can contain tokens and the marking $M \in \mathbb{N}^{|P|}$ denotes the number of tokens in each place. Marking changes occur when an enabled transition fires, possibly after delaying a (finite, random) amount of time, thereby removing tokens from input places and depositing tokens in output places according to the arc multiplicities. We assume that the transition selected to fire is the one with the minimum remaining firing time (RFT) over all enabled transitions.

The marking process, $\{M(\theta) : \theta \geq 0\}$, observes the marking evolution over time. This gives rise to an underlying stochastic process amenable to mathematical analysis. Among the most convenient stochastic processes are the discrete-time Markov chain (DTMC), which results when firing delays are geometrically distributed, and the continuous-time Markov chain (CTMC), which results when firing delays are exponentially distributed. When the applicability of these Markovian models to more complex and realistic systems is questionable, other extensions attempt to incorporate non-Markovian behavior. However, the complexity of exact solutions to non-Markovian processes oftentimes limits the practical usefulness to problems with small dimensions unless simulation is employed.

A phase-type random variable is defined as the time to absorption of a given Markov chain with at least one absorbing state. We let `ph_int` and `ph_real` refer to phase-type random variables (or distributions) in discrete and continuous time, respectively. An absorbing CTMC (DTMC) is used to define a `ph_real` (`ph_int`) distribution, which includes initial state probabilities to be used when sampling the distribution. We let T_{real} denote the set of `ph_real` transitions and T_{int} , the set of `ph_int` transitions. The set T_{zero} contains the immediate transitions with zero firing delays, and $\mathcal{T} = T_{\text{real}} \cup T_{\text{int}} \cup T_{\text{zero}}$.

In general, the state of an SPN model is the current

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simulation output The most obvious methodological advantage of simulation is that in principle it is applicable to stochastic systems of arbitrary complexity In practice however it is often a decidedly nontrivial matter to obtain from a simulation information that is both useful and accurate and to obtain it in an efficient manner These difficulties arise primarily from the inherent variability in a stochastic system and it is necessary to seek theoretically sound and computationally efficient methods for carrying out the simulation Apart from implementation considerations important concerns for simulation relate to efficient methods for generating sample paths of the underlying stochastic process the design of simulation experiments and the analysis of simulation output

Regenerative Stochastic Simulation G.S. Shedler, Ordinal Optimization Yu-Chi Ho, Qian-Chuan Zhao, Qing-Shan Jia, 2007-09-12 Performance evaluation of increasingly complex human made systems requires the use of simulation models However these systems are difficult to describe and capture by succinct mathematical models The purpose of this book is to address the difficulties of the optimization of complex systems via simulation models or other computation intensive models involving possible stochastic effects and discrete choices This book establishes distinct advantages of the softer ordinal approach for search based type problems analyzes its general properties and shows the many orders of magnitude improvement in computational efficiency that is possible *ACM Transactions on Modeling and Computer Simulation*, 2001

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Handbooks in Operations Research and Management Science: Simulation Shane G. Henderson, Barry L. Nelson, 2006-09-02 This Handbook is a collection of chapters on key issues in the design and analysis of computer simulation experiments on models of stochastic systems The chapters are tightly focused and written by experts in each area For the purpose of this volume simulation refers to the analysis of stochastic processes through the generation of sample paths realization of the processes Attention focuses on design and analysis issues and the goal of this volume is to survey the concepts principles tools and techniques that underlie the theory and practice of stochastic simulation design and analysis Emphasis is placed on the ideas and methods that are

likely to remain an intrinsic part of the foundation of the field for the foreseeable future The chapters provide up to date references for both the simulation researcher and the advanced simulation user but they do not constitute an introductory level how to guide Computer scientists financial analysts industrial engineers management scientists operations researchers and many other professionals use stochastic simulation to design understand and improve communications financial manufacturing logistics and service systems A theme that runs throughout these diverse applications is the need to evaluate system performance in the face of uncertainty including uncertainty in user load interest rates demand for product availability of goods cost of transportation and equipment failures Tightly focused chapters written by experts Surveys concepts principles tools and techniques that underlie the theory and practice of stochastic simulation design and analysis Provides an up to date reference for both simulation researchers and advanced simulation users **Regenerative Stochastic Simulation: Simultaneous Trigger Events** G. S. Shedler,1992 **Proceedings of the ... Winter Simulation Conference** ,2002 **International Workshop on Timed Petri Nets, Torino, Italy, July 1-3, 1985** ,1985 **Proceedings of the ... European Simulation Multiconference** ,1999 **Timed Petri nets** International Workshop on Timed Petri Nets,1985 **The Process View of Simulation** W. R. Franta,1977 Using the scenario approach to model program development this book discusses how to develop a simulation system **System Modelling and Simulation** S. G. Tzafestas,Alfredo Eisinberg,Luciano Carotenuto,1989 Very Good No Highlights or Markup all pages are intact

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