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# PERFORMANCE and DEPENDABILITY VALIDATION of HIGHLY PARALLEL FAULT-TOLERANT SYSTEMS

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## 1 Introduction

Key problems in dependability and performance analysis of highly parallel fault tolerant computer systems include the combined evaluation of performance and dependability and the largeness of the underlying (semi-)Markov models. During the course of this grant, we have obtained major results in three distinct areas: novel solution methods for large performance and dependability models, on the methods of combined evaluation of performance and dependability and application of our methods to practical problems.

## 2 Large Markov Models

We have made considerable progress in developing methods that avoid the generation and the solution of a large Markov model. The generation is facilitated by a compact model specification method. Stochastic Petri Nets (SPNs) have been advocated as a means of automatically generating large Markov models. Nevertheless, storage and processing of a large underlying Markov model is necessary.

We have developed a new solution method for the steady state analysis of Markovian stochastic Petri nets that can often provide a more efficient solution over the standard solution method [1].

Besides largeness practical models are also plagued by stiffness of their generator matrices. Stiffness causes the solution time to be inordinately long. We have developed a method

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for the transient analysis of stiff Markov chains [8]. This method reduces the solution time by several orders of magnitude.

Sensitivity analysis of continuous time Markov chains has been considered recently by several researchers. This is very useful in performing bottleneck analysis and optimization on systems especially during the design stage. In [6], we extend parametric sensitivity analysis to SPN models. The rates and probabilities of the transitions of SPN models are defined as functions of an independent variable. Equations for the sensitivity analysis of steady-state and transient measures of SPN models are developed and implemented.

In order to avoid construction and solution of a large CTMC, in [2], we have proposed decomposing the SPN into a set of subnets and separately solving individual subnets. Dependence among the subnets requires that, after solving each subnet, certain quantities be *exported* to other subnets. A fixed-point iteration is then used over the exported quantities. We discuss ways of decomposing a net into subnets, the type of quantities that need to be exchanged between subnets, and the convergence of the fixed-point iterative schemes.

### 3 Composite Performance and Reliability Analysis

The common approach to formulating and solving performability problems is to use (semi-)Markov reward models. We have proposed Stochastic Reward Nets (SRNs) to facilitate convenient specification of performance, dependability and composite performance and dependability models [1, 9].

We have been very active in the area of composite performance and reliability modeling. A new algorithm for the distribution of accumulated reward in a Markov reward process has been developed [11], a unified framework of performance and reliability analysis of a system with cumulative downtime constraint has been developed [10]. An invited state of the art survey on the topic was written for the book edited by H. Takagi [11].

In the domain of real-time systems, Shin and his colleagues have developed methods of incorporating the effects of failures in a performance model. On the other hand, Meyer and his colleagues have developed the framework of performability. We have recently managed to combine these two views in a single framework [9].

Performability models normally incorporate throughput-like performance measures. In many systems, however, response-time distribution may be a more critical index of performance. Computing response time distribution for all but simple queues has been hitherto considered to be a very difficult problem (short of expensive simulation). We have developed a new method based on a "tagged job approach" for this difficult problem. We have further incorporated this performance measure in a performability model [7, 9].

Performability models use decomposition, taking advantage of different time scales of performance-related and failure-related events. If we want a more accurate analysis that

takes into account the loss of work following a failure and checkpointing, advanced stochastic process methods have to be used [5]. Although, we have obtained some success along these lines and solved 'small' problems, more research is necessary on this topic.

## 4 Applications

We have applied the techniques we have developed to solve interesting problems proposed by industry. With GTE Labs scientists we have worked on the performance analysis of a polling system and that of a vacation queueing system [3, 4]. One of the requirements that database systems have to satisfy is that the response time not exceed a give threshold. Due to an impetus provided by NCR researchers, we considered the problem of computing response time distribution (as opposed to just the mean response time) [7]. Our ideas have been applied by the Software Productivity Consortium in the performance analysis of large Ada designs.

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