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Quantitative
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Performance Prediction of Behavioural Descriptions with Temporal Logics

Holger Hermanns
Universität Erlangen-Nürnberg
Informatik VII, Martensstr. 3
91058 Erlangen, Germany

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Abstract Stochastic Process Algebras (SPA) allow the integration of performance evaluation into early design phases of distributed systems. However, due to their *behaviour oriented* description, the definition of performance characteristics is difficult. In classical performance evaluation, these characteristics are usually defined in a *state oriented* manner, because the notion of *state* is an essential part of the concept of queueing networks, (generalized) stochastic Petri nets as well as stochastic automata networks. In this deliverable we

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will sketch some ideas to bridge the gap between state and behaviour oriented description by means of a simple temporal logic. This approach can be adapted to various existing behaviour oriented specification languages. Especially for LOTOS this bridge to classical performance evaluation is important, because the formal foundation of SPA can be extended to Basic-LOTOS straightforwardly.
This document is an extended abstract.

1 Introduction

Formal specification techniques bear the potential to greatly enhance the confidence in functional correctness properties of distributed systems. The ISO standardized specification language LOTOS [Bri89] seems to be especially well suited for formal verification of functional properties, because of strict formal semantics based on process algebras, like CCS [Mil89] and CSP [Hoa85].

The analysis of *performance* properties of distributed systems is usually separated from their formal specification and is carried out in a later design phase. This discrepancy may sometimes enforce costly redesign of a system that works correctly but does not fulfil certain performance requirements. In recent years, different approaches have been proposed to tackle this problem [Rud83, LL88, Her91]. Common to all these approaches is that they propose to integrate temporal information into a formal specification technique, in order to allow an early prediction of performance properties.

2 Stochastic Process Algebras

In recent years, the introduction of stochastic extensions of process algebras [GHR93] has initiated a lively research area. These *Stochastic Process Algebras* allow one to explicitly specify stochastic timing aspects in an algebraic framework. Various case studies have shown that this concept allows integrated performance modelling of LOTOS like specifications, (e.g. [HR94]).

The semantic model of SPA is a labelled transition system where the labels are enriched with stochastic timing information. More precise, every activity of the system is supposed to happen after a duration that is exponentially distributed with a specific parameter. Therefore, the analysis of temporal properties starts with the derivation of a *continuous time Markov chain*, that is subsequently analysed by means of standard algorithms. Some polished equivalences support the efficient analysis [Hil94, HHH+94].

Finally, the evaluation of performance properties relies on the definition of *Markov reward models*. These models assign weights (rewards) to dedicated sets of states in order to allow the calculation of interesting performance results. For example, the mean queue length of a system is obtained by assigning to every state of the system the current number of jobs in the queue as a reward.

This *state oriented* view is usual for classical performance evaluation, but it is a fundamental problem for the evaluation of SPA specifications. Process algebras are *per se* dedicated to a behaviour oriented characterisation of systems. Processes with the same behaviour are considered to be equivalent, even though their states might differ. Therefore, the definition of rewards models for SPA essentially relies on bridging the gap between state and transition oriented descriptions.

3 Defining Rewards with Temporal Logics

Typically, temporal logics are used to verify functional correctness of complex systems [Sti92]. This *model-checking* approach basically aims to formally prove that the *whole* system has certain properties,e.g. liveness or fairness. In contrast, we use a temporal logic to split the semantic model of a system in several disjoint partitions, each of them exhibiting a certain characteristic behaviour. The specification of such a behaviour is effected by means of temporal logic formulae. A Markov reward model is then defined as a function that for every partition associates a unique reward to all elements belonging to this partition.

As an example, let us consider the behaviour of a simple queue. At any instant in the systems life, the number of jobs inside the queue is equal to the number of jobs the queue can pass to the environment before this is no longer possible and without accepting inputs in the meantime. Therefore, the current filling degree of the queue can be deduced only by looking at the behaviour that is observable. This observation is the basis for a *behaviour oriented* definition of rewards to calculate the mean queue length. The reward 0, for example, is assigned to all states that fulfil a temporal logic formula that informally means: *No job can be taken out of the queue before a job has been inserted.*

This paper sketches the algebraic foundations of TIPP, an SPA developed as part of the QMIPS project, and emphasizes the affinity to Basic-LOTOS. Then we outline how performance evaluation is carried out in this calculus and focus on problems in defining Markov reward models. Subsequently, we give a short, intuitive introduction to the temporal logic CTL^* and show how this logic is applied in the definition of Markov reward models. These ideas are demonstrated by means of an example, a simplified version of the multiprocessor mainframe investigated in [HHM95]. Finally we discuss some problems and shortcomings of the approach.

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