An Integrated Approach for the Specification and Analysis of Stochastic Real-Time Systems (Short Abstract)

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Two approaches for expressing and analyzing time properties of systems have been developed which are based on formal description paradigms: (i) the real-time approach, mainly concerned with the expression of time constraints and the verification of exact time properties, and (ii) the probabilistic-time approach, mainly concerned with the probabilistic quantification of durations of system activities via exponential distributions and the evaluation of system performance.

The different aspects of time expressed by the real-time and probabilistic-time approaches can be seen as being *orthogonal*. According to the probabilistic-time approach the possible values for the duration of an activity are quantified through probabilistic (exponential) distributions, but no time constraint is expressible: all duration values are possible with probability greater than zero. According to the real-time approach some interval of time is definable for doing something, but the actual time the system spends in-between interval bounds is expressed non-deterministically. A specification paradigm capable of expressing both aspects of time should be able of expressing both time constraints and a probabilistic quantification for the possible durations which satisfy such constraints. We can obtain such an expressive power by considering models capable of expressing *general probability distributions* for the duration of activities. In this way time constraints are expressible via probability distributions that associate probability (density) greater than zero only to time values that are possible according to the constraints. Technically, the set of possible time values for the duration of an activity is given by the *support* of the associated duration distribution. This idea of deriving real-time constraints from distribution supports, that we have introduced in [2], was subsequently applied also in [3] and [4].

Representing real-time and probabilistic-time in a single specification paradigm allows us to model a concurrent system more precisely by expressing and analyzing the relationship between the two aspects of time. Moreover, the capability of expressing general distributions gives the possibility of producing much more realistic specifications of systems. System activities which have an uncertain duration can be represented by more adequate distributions than exponential ones (e.g. Gaussian or experimentally determined distributions).

Process algebra with generally distributed time offer the possibility of an integrated approach for the modeling and analysis of stochastic real-time concurrent/distributed systems [1]. In particular, specifications made with the calculus of Interactive Generalized Semi-Markov Processes (IGSMPs) [1] can be directly analyzed through standard discrete event simulation and by means of the techniques in [1]: minimization via bisimulation based congruence abstracting from internal system activities and derivation of the performance model (a GSMP).

Besides performing combined analysis, we have now introduced formal techniques for compositionally deriving, from an IGSMP specification: (*i*) a pure probabilistic-time (Markovian) specification in the form of a term of the calculus of *Interactive Weighted Markov Chains* (IWMCs) – an extension of Interactive Markov Chains (IMCs) with *weight* transitions expressing probabilistic choices –, by approximating general distributions with *phase-type* distributions, i.e. combinations of exponential distributions (as a consequence all duration values for delays get probability greater than 0 and the information about time constraints, related to the real-time behavior of the system, is lost); and (*ii*) a pure real-time specification in the form of a parallel composition of *Interactive Timed Automata* (ITA) – a variant of Timed Automata where action executions, events enabled on the basis of clock constraints and clock reset events are expressed by means of separate transitions –, by considering the support of general distributions and by turning probabilistic choices into non-deterministic choices (as a consequence the information related to the probabilistic-time behavior of the system is lost).

Deriving a pure Markovian representation (the IWMC) and a pure real-time representation (the ITA) is very important from a practical viewpoint in that it gives the possibility of reusing existing techniques and tools already developed for performance evaluation and model-checking of non-probabilistic real-time properties. Moreover, the advantage of deriving an IWMC and an ITA from the same initial IGSMP specification (w.r.t. generating them independently) is that they are guaranteed to be consistent, in that they represent different aspects of the same initial system specification. Both mappings can be found in [1].

The mapping into IWMCs is significant in that: (*i*) it shows process algebra to provide exactly the machinery necessary for approximating GSMPs with CTMCs through phase-type distributions, and (*ii*) it confirms ST semantics to be the adequate semantics for generally distributed time (as claimed in [1]) in that approximation of activity durations with phase-types is a form of action refinement. Moreover, w.r.t. the mapping in [4], which solves a problem in [3], the mapping into ITA does not cause an exponential growth of the state space.

References

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