Stochastic Process Algebras for the Analysis of Internet Protocols

Alessandro Aldini, Marco Bernardo, Roberto Gorrieri, and Marco Roccetti

Università di Bologna, Dipartimento di Scienze dell'Informazione
Mura Anteo Zamboni 7, 40127 Bologna, Italy
{aldini, bernardo, gorrieri, roccetti}@cs.unibo.it

In the last decade a new formal approach to the integration of performance aspects in the modeling and analysis of concurrent systems has emerged with Stochastic Process Algebras (SPAs for short). Like classical process algebras, they are algebraic languages endowed with a small set of powerful operators whereby it is possible to construct algebraic models from simpler ones. The main advantages of this approach are summarized with the motto: *integration* and *compositionality* (see e.g. [2]). There are several forms of integration supported by SPAs, including those illustrated below:

- *functionality and performance*: both aspects are to be described in the unique specification model, called integrated model. This has the advantage of ensuring coherence of the functional and performance (sub-)models as they both originate by projection from the same integrated model. Moreover, the integrated model is justified also because it allows the analysis of mixed properties (e.g., mean time to deadlock) and makes easier proof of functional properties for which the probabilistic aspect may be relevant.
- *(stochastic) process algebras and (stochastic) Petri nets*: the system, represented abstractly as a process term, can be automatically mapped to an equivalent (yet more concrete) representation in the form of a stochastic Petri net. The net representation may be advantageous from the analysis standpoint as, e.g., it often yields more compact state space or even avoids constructing the state space; it is also useful whenever it allows for the application of efficient solution techniques to derive performance measures.
- *verification tools and performance evaluation (or simulation) tools*: having the two integrations above, it is possible to exploit many available tools for either functional (e.g., CWB) or performance analysis (e.g., MarCA). This can be easily achieved by simply generating the suitable inputs for the specific tools starting from the integrated model.

There are also several forms of compositionality, including those described below:

- *compositional modeling*: SPAs provide a linguistic support to describe complex systems componentwise; each component is defined in isolation and then composed to the component it has to communicate with; this feature is very useful for designers from a pragmatic point of view.

– *compositional manipulation*: process algebras are usually equipped with equivalence notions that are congruences w.r.t. the operators, hence supporting the substitution of equals for equals in any context; in this setting, it is interesting to study which semantic congruences ensure that systems are equated if and only if they have the same functionality performing in the same (stochastic) time; it turns out that the integrated model is the right model on which solving this problem.
– *compositional solution*: in order to cope with the problem of state space explosion, aggregation and decomposition techniques have been investigated in order to efficiently solve the performance models, possibly exploiting the compositional structure of terms.

In this talk we shall provide a short overview on SPAs, on the available results and on the challanges for the future.

In order to show the usefulness of the approach, we have tested our technology on two interesting case studies about the measurement of the quality of service (QoS) of different soft real time applications concerning audio transmission over the Internet. In the former case study [4, 3], the technology has been used during the development of a novel adaptive mechanism for trasmitting audio packets over the Internet in order to predict the performance of several possible implementations of the synchronization phase of the mechanism. In the latter case study [1], we have compared the QoS of such a novel adaptive mechanism with earlier ones. Many are the factors that affect the QoS for real time audio applications over the Internet (such as, e.g., codec, access, operating system, sound card delays) but probably the most important metric that influences the user perception of audio is represented by the average packet audio playout delay vs. the packet loss rate. This is precisely the metric we have used to compare the QoS of such protocols.

References

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