Efficient non-anonymous composition operator for modeling complex dependable systems

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Abstract—A new model composer is proposed to automatically generate non-anonymous model replicas in the context of performability and dependability evaluation. It is a state-sharing composer that extends the standard anonymous replication composer in order to share the state of a replica among a set of other specific replicas or among the replica and another external model. This new composition operator aims to improve expressiveness and performance with respect to the standard anonymous replicator, namely the one adopted by the Möbius modeling framework.

I. INTRODUCTION

Stochastic model-based evaluation is widely used to analyze the performability, dependability and performance of complex systems. A convenient technique to make model construction easier, and to promote an efficient solution process, is based on the hierarchical submodels composition [1], [2]. To overcome the heavy and error prone manual definition of many submodels, automated procedures are currently available to assist the modeller in generating the hierarchical composed model representing the specific instance of the system. A general approach is based on the definition of primitives, such as the Rep operator proposed in the Möbius framework [3], which can be used to represent different components, behaviors or characteristics of a system, automatically replicating a single template model. Each replica is indistinguishable by other replicas and then it is anonymous. Although satisfactory in general terms, such Rep operator shows limitations from the efficiency point of view when employed in the modeling of systems composed of a (large) population of similar, but non-anonymous, components.

In this paper, a new composition operator, called NARep, is introduced to deal with efficient non-anonymous replication inside the Möbius framework. The new operator characteristics are identified and presented in the context of performability and dependability evaluation.

II. THE CONTEXT

The Möbius modeling framework [3] is a powerful modular environment that supports multiple modeling formalisms and solution techniques. Among the others, it supports the Stochastic Activity Network (SAN) formalism, composition operators Rep and Join [1], performance variables based on rate and impulse rewards (used also to define performability and dependability measures), analytical and simulative solvers.

Join operator is a state-sharing composer that brings together two or more submodels. Rep operator is a special case of Join that constructs a model consisting of identical copies (replicas) of a submodel. Rep and Join operators are defined at level of Abstract Functional Interface (AFI) [3], [4], a common interface between model formalisms and solvers that allows formalism-to-formalism and formalism-to-solver interactions. At AFI level, places and activities (transitions) of SAN correspond to state variables and actions. In the following, for sake of simplicity, we will use SAN models and SAN notation (places and activities) also to describe Rep and Join operators. The state of a model is represented by the current value of all the places defined in the model. A place of a replicated SAN model can be local (assume, at the same time, different values in different replicas) or shared (same place, with only one value, that can be read or updated by each replica). The Rep operator can be used to represent multiple components, behaviors or characteristics of a system having identical definition and parameters.

A. Non-anonymous replication in Möbius

Non-anonymous replicas of a single SAN model can be automatically generated through Rep operator via a sophisticated use of local places and immediate activities as shown in [5]. Local places, representing replica indexes, are set up so that each replica becomes self-aware of its index. The specific state, number of “tokens” or “marks” in Petri nets dialects, of the ith non-anonymous replica is represented by the ith entry P—I>Mark(i) of a shared array-type extended place P, i.e., an extended place defined as an array of states, that is shared among all the replicas. Thus, each replica has read and write access to the state of all the other replicas of the same SAN. In addition, a different submodel that shares the place P with a Rep has read and write access to the state of each specific replica.

This approach allows to cope with dependability analysis of complex critical systems, with a variety of interconnected components organized according to sophisticated topologies, such as electrical or transportation systems. In [6], which focuses on Smart Grids, a stochastic modeling framework has been proposed, which uses the Rep operator as described above to quantitatively assess representative indicators of the resilience and quality of service.

B. Motivations for an enhanced replication operator

Using an anonymous replicator to produce non-anonymous replicas sounds unnatural, while on the other hand the Join op-
The proposed NARep operator has the following advantages:

- Automatic generation of non-anonymous indexed place and SAN replicas transparent to the modeler; this feature enlarges the framework expressive power.
- A significant reduction of the connectivity lists generation time overhead can be obtained exploiting only actually existing dependencies instead of the assumed complete graph of dependencies. Therefore, the $n^2$ checks currently performed by the Rep operator constitute the worst case for NARep, when full connection is considered.
- Symmetries exploitation via the state-space lumping remains possible.

Future work will include:

- NARep formalism definition,
- integrate NARep into Möbius framework,
- evaluate the actual impact of NARep on the connectivity lists generation time overhead; in particular, a significant improvement is expected for the Smart Grid model presented in [6], being the electrical and communications networks sparse.

References

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