Time Petri Nets with Action Duration: A True Concurrency Real-Time Model

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ABSTRACT

The design of real-time systems needs a high-level specification model supporting at the same time timing constraints and actions duration. The authors introduce in this paper an extension of Petri Nets called Time Petri Nets with Action Duration (DTPN) where time is associated with transitions. In DTPN, the firing of transitions is bound to a time interval and transitions represent actions which have explicit durations. The authors give an operational semantics for DTPN in terms of Durational Action Timed Automata (DATA). DTPN considers both timing constraints and durations under a true-concurrency semantics with an aim of better expressing concurrent and parallel behaviours of real-time systems.

Keywords: Actions Duration, Durational Action Timed Automata (DATA), Maximality Semantics, Real-Time Systems, Time Petri Nets with Action Duration (DTPN)

INTRODUCTION

Petri Nets are a well-established formal model for the specification of distributed and concurrent systems. This model is very attractive by its ability to capture causal and parallel behaviours of these systems. Since its introduction, timed models based on Petri Nets have been extensively studied for the specification and verification of real-time systems.

The two main extensions of Petri Nets with time are Timed Petri Nets (TdPN) and Time Petri Nets (TPN) (Ramchandani, 1974; Merlin, 1974). In TdPNs, delays were first
associated with transitions (T-TdPN) and then to places (P-TdPN) (Ramchandani, 1974; Sifakis, 1977). The two corresponding subclasses namely T-TdPN and P-TdPN are expressively equivalent (Ramchandani, 1974; Sifakis, 1977) and are a subclass of TPNs. Thus, a time delay can represent a minimum duration of firing or a minimum residence time of a token in a place. Informally, the TdPN uses the notion of duration as opposed to the notion of period of TPN.

In TPNs, temporal extension is expressed as an interval associated mainly to transitions (T-TPNs), to places (P-TPNs) or arcs (A-TPNs) (Merlin, 1974; Khansa, 1997; Walter, 1983). Regarding the expressiveness of T-TPN and P-TPN, Khansa et al. (1996) showed that these two models are incomparable. A-TPNs and P-TPNs are similar; however, the only difference concerns the strong semantics of P-TPNs and the lazy semantics of A-TPNs (Boyer, 1997).

At last, T-TPNs form a subclass of Time Stream Petri Nets (Emerson, 1990) that have been introduced to model multimedia applications.

TPNs are primarily used for performance analysis. In these models the firing of transitions is of null duration. They natively express specifications in time. In explaining beginnings and ends of actions with specification of time progress, they can also express specifications in duration. However, this manner of modelling the action durations has many disadvantages. First, the size of the associated semantic structure is increased. This phenomenon is known as the state space combinatorial explosion problem. Second, the obtained specification structurally keeps out the statement of system to be specified. Third, the underlying semantics, usually the interleaving semantics, suppose structural and temporal atomicity of actions, i.e., actions are indivisible and have null duration. Moreover, this semantics gives abstracts to the parallel execution of actions.

With the assumption that the firing of each transition corresponds to the execution of a divisible action with duration, our goal is to exploit a model which permits expressing true-concurrency in a natural way without splitting actions into their start and end events. To do this, we propose at first an extension of TPN model called Time Petri Nets with Duration Action (DTPN). In this model, two annotations are associated to each transition, namely its timing constraint that restricts the date at which it can be fired and the duration of its corresponding action. Consequently, DTPNs can be considered as a generalization of Merlin’s TPNs, T-TdPNs and P-TdPN (Merlin, 1974; Ramchandani, 1974; Sifakis, 1977). Then, we give true-concurrency semantics to DTPN in terms of maximality semantics (Devillers, 1992; Courtiat & Saïdouni, 1995; Saïdouni & Courtiat, 2003; Saïdouni Belala & Bounab, 2008; Saïdouni, Belala & Bounab, 2009). This semantics has been proven necessary and sufficient for the action refinement and for action durations (Saïdouni, 1996). The underlying model is a Durational Action Timed Automaton (DATA) (Saïdouni & Belala, 2006).

DATA provides an abstract model for real-time systems based on true concurrency semantics. It is very near syntactically to Timed Automata (Alur & Dill, 1994) on which transitions are specified in terms of two related conditions (guard and deadline) expressing respectively, possibility and forcing of execution by stopping time progress. As a main result, DATA allows the verification of new properties related to simultaneous progress of actions at different states of the system.

The paper is organized as follows. First, we introduce the Time Petri Nets with Action Duration model. Next, we recall Durational Action Timed Automata with its semantics. In the follow section, we show the operational construction of DATA associated to DTPN, illustrative examples and DATA generation algorithm. Then, a case study of multimedia document modelled with DTPN is presented. After, we discuss the advantages of the proposed model. Finally, we give some conclusions and perspectives of our work.