DELAYS IN SYNCHRONIZED ELEMENTARY NET SYSTEMS

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ABSTRACT
Synchronized Elementary Net Systems (SENS) are a model for systems consisting of events, conditions and subject to generalized timing constraints. The constraints are quantified and are relative to some "reference events" such as clock ticks, meters, (multiform time). The partial ordering of event occurrences can be altered by the "timing" constraints which induce additional precedences. This paper provides algorithms which compute delays between event occurrences. The "dioid" algebraic structure is the underlying mathematical model. Applications of delays to some reachability problems are given.


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I. INTRODUCTION

The aim of this paper is twofold: modelling and analysis of concurrent systems with timing constraints.

The application of Petri nets modelling and analysis techniques to safety-critical real-time systems has been explored in a recent paper [LevSto87]. The central example, proposed by the authors, was "a simple railroad crossing". This example has been taken up again in another paper about modelling, specification and verification of real-time embedded systems [OstWon87]. In this case, Extended State Machines (ESMs) were preferred to Petri nets. As both papers dealt with real-time systems, they had to express some timing constraints. The former used Time Petri nets [Merlin75], the latter chose a "Real-time Temporal Logic". We tackle this problem with Synchronized Elementary Net Systems (SENS) [Andr688].

Chap.II is devoted to modelling. Taking the Railroad Crossing System as an example, we show that SENS are suitable for modelling multiform time. Few approaches, but some synchronous languages ([BeCo85]), offer such a possibility.

The dynamics of concurrent systems can be expressed by "(non-sequential) processes" [Petri77]. In a previous paper ([Andr88]), we explained how the notion of processes could be extended to SENS. In Chap.IV, we introduce a quantitative approach which is complementary to the former presentation. The central problem is the computation of delays between event occurrences. According to their values, delays can induce a temporal ordering between some event occurrences. This alteration, due to the "timing constraints" is characteristic of the system behaviour and cannot be ignored.

To cope with multiform time, a richer structure than natural numbers is needed. We introduce a dioid whose elements are sets of bags. The technical material about SENS and this algebra, is given in Chap.III.

Delays are related to "longest paths" in cycle-free graphs. But, due to the firing rule of SENS, their computation gives rise to several specific issues, analyzed in Chap.IV. Effective algorithms to compute delays are given. They are applied to the Railroad Crossing System in order to prove its correctness.

The computation of delays is restricted to conflict-free SENS. This simplification allows to shed light on the essential problems. The extension to general SENS is beyond the scope of this paper. It is more technical and does not involve new concepts.

II. SYSTEM WITH TIMING CONSTRAINTS

II.1. A SIMPLE RAILROAD CROSSING

We take the system proposed in [LevSto87]. This simplified Railroad Crossing System is made of events and conditions. The system is composed of a railway and a train, a level crossing with its gate and a controller for the gate. The train can be travelling ("Tr"), before the crossing ("Bc"), within the crossing ("Wc"), past the crossing("Pc"). The position of the train is given by sensors called pedals which are pushed down by the wheels. "pb" and "pp" are the pedals signaling that the train is approaching the