Discrete Event Dynamic Systems: Theory and Applications, 11, 5–8, 2001.

Foreword

Y.C. HO

This special issue continues the tradition of this journal of highlighting particular interesting and timely topics. This time is for another useful model of discrete event systems, namely, Petri Nets (PN). However, particular attention is devoted to extension of PN to cover continuous systems. This issue thus complements the earlier 6/98 issue on hybrid system. We thank guest editors Professors Giua, Menga and Di Febbraro of Italy in putting together this worthy issue.

Guest Editorial

ANGELA DI FEBBRARO difebbraro@polito.it
Dip. di Automatica ed Informatica, Politecnico di Torino, Italy

ALESSANDRO GIUA giua@diee.unica.it
Dip. di Ingegneria Elettrica ed Elettronica, Università di Cagliari, Italy

GIUSEPPE MENGA menga@polito.it
Dip. di Automatica ed Informatica, Politecnico di Torino, Italy

Petri nets (PNs) were firstly introduced, and are still successfully used (Murata, 1989), to describe and analyze *discrete event systems*. Recently, however, several attempts have been made to extend the discrete PN formalism to also encompass *hybrid systems*, i.e., systems presenting both time-driven and event-driven dynamics. The first steps in this direction were taken in 1987 by David and Alla who introduced first a *continuous Petri net* (CPN) model (Alla and David, 1987), and then a *hybrid Petri net* (HPN) model (Le Bail et al., 1991; David, 1997). Since then, several hybrid net models have been presented by different researchers and a list of relevant references can be found on the web (Biblio on HPN, 2000).

The main motivation for using Petri nets as hybrid models is the fact that all those good features that make discrete PNs a valuable discrete-event model still apply to HPNs. Examples of these features are: PNs do not require the exhaustive enumeration of the state space and can finitely describe systems with an infinite state space; they allow modular representation where the structure of each module is kept in the composed model; the discrete state is represented by a vector and not by a symbolic label, thus linear algebraic techniques may be used for analysis.

There is so far no widely accepted classification of all the different HPN models that have appeared in the literature. We propose to distinguish between two main classes.

- *HPN with continuous places* (HPN-CP). In this class of models, the hybrid net contains two types of places: discrete places, containing tokens as in a discrete PN; continuous places, containing fluid, i.e., non negative real quantities of marks. Thus, the marking of discrete (continuous) places represents the discrete (continuous) part of the state. The time-driven dynamics are represented usually by continuous transitions, as in the case of the David and Alla model, or by continuous arcs, as in the *fluid stochastic Petri nets* introduced by (Trivedi and Kulkarni, 1993).

- *HPN with continuous variables* (HPN-CV). In this class of models, a discrete PN is used to describe the event-driven dynamics and the discrete part of the hybrid state is represented by the net marking. The continuous part of the state is described by additional variables, whose dynamics is ruled by differential algebraic equations (DAE) not represented in the net structure. Examples of this models are the DAE-nets of Valentin-Roubinet (1998) and Champagnat et al. (1998).

Models of the HPN-CP type are usually derived from timed discrete PNs by fluidification, i.e., by relaxing the condition that the marking be an integer vector. As an example, the constant-speed HPN model of David and Alla derives from deterministic timed PNs, while the fluid stochastic Petri net model of Trivedi and Kulkarni derives from *generalized stochastic Petri nets* (Ajmone Marsan et al., 1995). Models of the HPN-CP type can often be studied using standard discrete PN analysis techniques, such as incidence matrix and invariants, and so on. However, very simple time-driven dynamics can be captured with this kind of models and the continuous state variables cannot take negative values.

Models of the HPN-CV type are clearly inspired by *hybrid automata* (Alur et al., 1993; Puri and Varaiya, 1996). The main advantage of this class is that it can represent systems with arbitrary time-driven dynamics. The drawback is that the overall hybrid behavior cannot be studied with standard PN analysis techniques.

A possible extension of the HPN-CP model allows the marking of a place to take also negative real values, as in *differential Petri nets* (Demongodin and Koussoulas, 1998). Further extensions, based on the concept of high-level Petri nets, have also been defined: by associating colors to the transition firings and to the markings, arbitrarily complex time-driven dynamics can be modeled (Giua and Usai, 1998).

Another interesting family of HPN models, that is somehow between the two classes we have previously defined, is the class of *batch PNs*, that are well suited to describe production processes where single parts move on conveyors or require in some stages to be worked in batches. In this type of nets, we still have continuous and discrete places, but some additional continuous variables are introduced as well, to represent the batch processing (Caradec and Prunet, 1998).

The eight papers presented in this special issue cover a large spectrum of topics. The first five articles are all based on HPN-CP models; the sixth one deals with a HPN-CV model; the seventh one is on batch PNs; the last one uses PNs within the formalism of condition-event net systems (Krogh, 1993).

The article by David and Alla presents a survey of different models in the family they have defined and on which are also based the two subsequent papers. The paper by Balduzzi et al. compares a model called *First-Order HPN* with hybrid automata and shows that for restricted subclasses the marking reachability problem is decidable. The paper by Komenda, El Moudni, and Zerhouni shows how dioid algebra, a standard tool for the analysis of timed event graphs, may also be applied to a class of hybrid Petri nets, for which it is possible to extend the results on the input-output representation and time-optimal ("just in time") control known for timed event graphs.

Two articles are based on fluid stochastic Petri nets. The article by Tuffin, Cheng, and Trivedi shows several modeling examples and discusses the relationship with hybrid automata, whereas the paper by Gribaudo et al. extends this formalism introducing flush-out arcs whose firing may instantaneously empty a continuous place.

The article by Champagnat et al. deals with simulation and validation issues for DAE-nets in the context of batch production systems.

In the paper by Demongodin, Generalised Batches Petri nets are introduced through the definition of the model, the enabling and firing rules, the time analysis methods, and two examples to illustrate these notions.

Finally, in the paper by Chen and Hanisch, hybrid net condition/event systems are shown to be suited to model large and complicated hybrid systems in a modular way, also allowing their algorithmic analysis.

References

Ajmone Marsan, M., Balbo, G., Conte, G., Donatelli, S. and Franceschinis, G. 1995. *Modelling with Generalized Stochastic Petri Nets*, John Wiley & Sons.

Alla, H. and David, R. 1987. Continuous Petri nets. *Proc. 8th Int. Work. on Applications and Theory of Petri Nets*, Zaragoza, Spain, pp. 275–294.

Alur, R., Courcoubetis, C., Henzinger, T. A. and Ho, P. H. 1993. Hybrid Automata: an Algorithmic Approach to the Specification and Verification of Hybrid Systems. *Hybrid Systems 1993* LNCS, Vol. 736, Springer-Verlag, pp. 209–229.

Alur, R. and Dill, D.L. 1994. A theory of timed automata. *Theoretical Computer Science*, 126, pp. 183–235.

Bibliography on Hybrid Petri Nets. `http://www.diee.unica.it/~hpn`.

Caradec, M. and F. Prunet, 1998. Modelling of Hybrid Flexible Production Systems by Coloured Batches Petri Nets. *European Journal of Automation APII-JESA*, Special Issue on automation of mixed processes and hybrid dynamical systems, 32(9–10), pp. 1255–1269.

Champagnat, R., Esteban, P., Pingaud, H. and Valette, R. 1998. Petri net based modeling of hybrid systems. *Computers in Industry*, 36(1–2), pp. 139–146.

David, R. 1997. Modeling of hybrid systems using continuous and hybrid Petri nets. *Proc. 6th Int. Work. Petri Nets and Performance Models*, PNPM97 St-Malo, France, pp. 47–57.

Demongodin, I. and Koussoulas, N. T. 1998. Differential Petri nets: Representing continuous systems in a discrete-event world. *IEEE Trans. on Automatic Control*, 43(4), pp. 573–579.

Giua, A. and Usai, E. 1998. Modeling hybrid systems by high-level Petri nets. *European Journal of Automation APII-JESA*, Special Issue on Automation of mixed processes and hybrid dynamical systems, 32(9-10/98): 1209–1231.

Krogh, B. H. 1993. Condition/event signal interfaces for block diagram modeling and analysis of hybrid systems. *Proc. 8th Int. Symposium on Intelligent Control Systems*, pp. 180–185.

Le Bail, J., Alla, H. and David, R. 1991. Hybrid Petri nets. *Proc. 1st Int. European Control Conference*, ECC91 Grenoble, France, pp. 1472–1477.

Murata, T. 1989. Petri Nets: Properties, Analysis and Applications. *Proceedings IEEE*, 77(4), pp. 541–580.

Puri, A. and Varaiya, P. 1996 Decidable hybrid systems. *Computer and Mathematical Modeling*, 23(11/12), pp. 191–202.

Trivedi, K. S. and Kulkarni, V. G. 1993. FSPNs: Fluid stochastic Petri nets. *Proc. 14th Int. Conf. on Applications and Theory of Petri Nets* (Chicago, IL, USA), Lecture Notes in Computer Science, Vol. 691, M. Ajmone Marsan, ed., pp. 24–31.

Valentin-Roubinet, C. 1998. Modeling of hybrid systems: DAE supervised by Petri nets. The example of a gas storage. *Proc. of 3rd Int. Conf. on Automation of Mixed Processes*, ADPM98 Reims, France, pp. 142–149.

List of Reviewers

Knut Åkesson	(Sweden)
Hassane Alla	(France)
Marco Bernardo	(Italy)
Dong S. Chen	(USA)
Haoxun Chen	(USA)
Isabel Demongodin	(France)
Angela Di Febbraro	(Italy)
Rainer Drath	(Germany)
Luca Ferrarini	(Italy)
Jean-Marie Flaus	(France)
Reinhard German	(Germany)
Marco Gribaudo	(Italy)
Hans-Michael Hanisch	(Germany)
Kevin X. He	(USA)
Monika Heiner	(Germany)
Jan Komenda	(Czech Repuclic)
Nick T. Koussoulas	(Greece)
Mike Lemmon	(USA)
Bengt Lennartson	(Sweden)
Geer Jan Olsder	(The Netherlands)
Jörg Raisch	(Germany)
Simona Sacone	(Italy)
Matteo Sereno	(Italy)
G. Soto y Koelemeijer	(The Netherlands)
Miklós Telek	(Hungary)
Bruno Tuffin	(USA)
Claire Valentin-Roubinet	(France)
Robert Valette	(France)
Xiaolan Xie	(France)
Nourredine Zerhouni	(France)