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Preface

The idea behind the series of volumes "Advances in Petri Nets" is to present to the general computer science community recent results which are the most representative and significant for the development of the area.

The main source of papers for the "Advances" is the annual International Conference on Applications and Theory of Petri Nets. Selected papers from the latest conferences are considered for the series. In addition, the "Advances" present also papers submitted directly for publication - potential authors are encouraged to submit papers directly to the editor of the "Advances". All contributions go through an independent refereeing process and, if accepted, they often appear in the "Advances" in a revised and extended form.

The main aims of the "Advances" are:

(1) to present to the "outside" scientific community a fair picture of recent advances in the area of Petri nets, and

(2) to encourage those interested in the applications and the theory of concurrent systems to take a closer look at Petri nets and then join the group of researchers working in this fascinating and challenging area.

"Advances in Petri Nets 1993" covers the 12th International Conference on Applications and Theory of Petri Nets held in Gjern, Denmark, in June 1991. I would like to thank the members of the program committee for their help in selecting papers from the workshop to be submitted to the "Advances".

Special thanks go to the referees of the papers in this volume who very often are responsible for considerable improvements of papers presented here. The referees were: M. Ajmone Marsan, C. André, F. Baccelli, G. Balbo, E. Best, R. Bhatia, J. Billington, G. Bruno, G. Chehaibar, L. Cherkasova, G. Chiola, F. de Cindio, R. Coelho, W. Damm, J. Desel, R. Devillers, M. Diaz, S. Donatelli, H. Ehrig, J. Esparza, C. Fernandez, A. Finkel, G. Franceschinis, H. Genrich, C. Girault, U. Goltz, R. Hopkins, P. Huber, M. Jantzen, K. Jensen, E. Kindler, M. Koutny, H.-J. Kreowski, M. Lindqvist, J. Martinez, G. De Michelis, T. Murata, S. Natkin, M. Nielsen, L. Ojala, C.-A. Petri, W. Reisig, U. Rhein, R. Shapiro, M. Silva, C. Simone, E. Smith, Y. Souissi, P. Starke, P.S. Thiagarajan, R. Valette, A. Valmari, W. Vogler, K. Voss, R. Walter. The editor is also indebted to Mrs. M. Boon-van der Nat for her help in the production of this volume.

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Editor

Contents

Replacement of Open Interface Subnets and Stable State Transformation Equivalence*

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ABSTRACT The aim of this paper is to provide a hierarchical design method, refinement by replacing place-bordered subnets, with a hierarchical analysis method based on equivalence and preorder. We consider nets with distinguised places (interface places) and distinguished states (stable states), called open interface nets (OI-nets); OI-systems are OI-nets such that the stable state set is a home space. Two equivalence notions are defined: $\equiv_{SF}$ on OI-systems and $\equiv_{SST}$ on OI-nets. We show that if $N_1 \equiv_{SST} N_2$ and N_2 is robust (robust OI-nets are a subclass of OI-nets) then $N[N_1 \leftarrow N_2] \equiv_{SF} N$. Since an equivalence is too restrictive in hierarchical design and it is only possible to replace subnets of N whose border is a subset of the interface of N, an interface expansion operation is defined giving rise to a preorder $\preceq_{SF}$ such that $\preceq_{SF} \cap \preceq_{SF}^{-1} = \equiv_{SF}$.

KEYWORDS Place-Transition Nets, Hierarchical Design and Analysis, Open Interface Nets and Systems, Stable State Transformation Equivalence and Preorder, Replacement, Expansion, Robust Open Interface Nets

Contents

*This work is part of BULL's contribution to DEMON (ESPRIT BRA 3148)

1 Introduction

Refinement and abstraction are complementary methods in system design and analysis. Within hierarchical design, one starts with an abstract model and refines it stepwise by replacing some parts of the model by more detailed submodels. The inverse operation (abstraction) is useful when we want to analyse and understand an implemented system by building an abstract model of its behavior. Such hierarchical design method must be supported by a hierarchical analysis method: if $\mathcal{M}$ is transformed by a well defined operation *op*, the properties of $op(\mathcal{M})$ should be deduced from those of $\mathcal{M}$ and *op*.

The operation considered in this paper is the replacement of a place-bordered subnet (open subnet) with a net: if the replacement net is more detailed than the subnet it is a refinement otherwise it is an abstraction. If $N[N_1 \leftarrow N_2]$ is the net obtained by replacing the subnet N_1 with the subnet N_2 in N, we want to deduce $N[N_1 \leftarrow N_2] \equiv N$ from $N_1 \equiv' N_2$, for some equivalence relations $\equiv$ and $\equiv'$.

These equivalences are not based on labelling transitions and comparing the behaviors of nets expressed in terms of observable events. We adopt the dual point of view: the state transformation equivalences. Therefore, we label places and we distinguish "observable" states: two systems Σ_1 and Σ_2 are equivalent if there exists a correspondence between their observable states, and any transformation from an observable state to another one in Σ_1 is possible between the corresponding states in Σ_2. But we call these states "stable" rather than observable because they are not recognizable by an external observer (cf. the introductory example in the next section); the "observable" places are called interface places. So, the notions defined in this paper are not observational but they have to be considered a hierarchical analysis and proof method of net-based hierarchical design.

Open subnets naturally appear when a distributed system is modelled as a set of actors communicating through buffers by message passing. For instance, this analysis method may be applied to HOOD Nets [7] which have a place interface, or to the hierarchical design method based on "abstract actors" [8] where an abstract server is a net having a place interface and refinements are done by replacing such nets.

An open subnet is generated by a subset of transitions while a closed subnet (transition bordered) is generated by a subset of places. Replacement of closed subnets and composing nets by merging transitions have been widely studied by means of labelled-transition-based equivalences ([1, 2, 3, 16, 18] and see [11] for an overview of such equivalence notions). These notions are most of the time inspired from algebraic models like CCS and CSP, have elegant mathematical properties and are nicely handled; while replacing open subnets and composing nets by merging places are a bit more tricky and are not free operations since restrictions are necessary to obtain closure properties or to ensure the existence of some mathematical constructs [23] (when you compose two nets by merging transitions, the behavior of the whole net can be deduced from those of the two nets; this is not the case when composing nets by merging places).

Refinement of transition is a particular case of replacement of open subnet: you replace the subnet generated by this transition. This operation has been studied by [15, 14, 19, 9] either considering property preservation or considering equivalence notions which are congruences for such refinements. We are not looking for an equivalence notion which is preserved by such refinements but for an equivalence between a net and its refinement. In [17] a subnet generated by one transition is replaced with particular nets called "modules": we consider a more general replacement operation, and the equivalence notion of [17] is inspired from [1] and then based on labelling transitions. In [4] we have studied the subnet replacement from a more practical viewpoint: we have defined a restricted class of colored nets—reentrant nets—and an equivalence notion—OII-equivalence—with transition and place labelling to compare a net N with $N[N_1 \leftarrow N_2]$, where N_1 and N_2 are equivalent reentrant nets; but now we give up transition labelling and we reconsider the whole problem more generally and more theoretically.

This paper is organized as follows. In the second section, we give the basic definitions and an introductory example to motivate the notions studied in the paper. The point is that we do not consider plain PT-nets, but nets with a distinguished place subset called interface places, and a given set of "inner place" markings called stable states: these objects are called open interface nets (OI-nets). These OI-nets have not enough behavioral properties, so we define open interface systems (OI-systems) to be OI-nets with an interface marking such that the stable state set be a home space.

In the third section, we define two state transformation equivalence notions: when you refine actions you change the level of abstraction of events, and if you are seeking an equivalence between a net and its refinement, it is more relevant to compare the state transformations performed by the action with those performed by its refinement than comparing their behaviors expressed in terms of observable transitions (which is suitable when refining states and replacing closed subnets). Thus you are led to label places and study state transformation equivalences [13]. Stable functionality equivalence (SF-eq) is defined on OI-systems, and the preservation in a restricted sense of deadlock and home space property is shown. SF-equivalence being insufficient to do replacements, a stronger equivalence notion, stable state transformation equivalence (SST-eq), is defined on OI-nets. These two equivalences are bisimulations relating only stable states.

Actually, these equivalences follow the research line investigated by [5] where Exhibited Functionality equivalence (EF-eq) is defined on "S-observable systems", and by [12] where state transformation preorder and equivalence are defined. The stable states are a generalization of the observable markings. A similar result to the one aimed at in this paper was established for 1-safe superposed automata nets and EF-equivalence [6] (functional refinement of 1-safe superposed automata nets is a particular case of replacing an open subnet). The main difference between SST-equivalence and EF-equivalence is how the simulation of a state transformation is done (cf.Definition 8); and EF-equivalence is defined by means of an isomorphism between algebras (generated by the observable markings) while SST-equivalence is defined by means of a bisimulation.

In the fourth section, the replacement operation is defined on OI-nets and OI-systems: $rep(N)$ indicates the resulting object after replacing a subnet of N by an SST-equivalent net. For an OI-net OIN, $rep(OIN) \equiv_{SST} OIN$, but the set of OI-systems is not closed by rep. A restricted operation—robust replacement (rep_r)—is defined such that the set of OI-systems is closed by rep_r and $rep_r(OIS) \equiv_{SF} OIS$ if OIS is an OI-system. In the fifth section, an interface expansion operation is defined on OI-systems, giving rise to the definition of a preorder associated to SST-equivalence; property preservations are established. In the sixth section, we give an example of using these notions in hierarchical design.

2 Open Interface Nets

2.1 Preliminary Definitions

Throughout this paper we consider place-transition nets (PT-nets) with weighted arcs and unbounded capacities. First we recall the basic definitions about PT-nets, and the notations used. Some symbols are overloaded but this should not be confusing.

Definition 1 *Here are the basic definitions and notations.*

PT-nets *A place-transition net is a tuple $N = (P, T; W)$ where P and T are finite sets (set of places and set of transitons), $P \cap T = \emptyset$ and $W : (P \times T) \cup (T \times P) \rightarrow \mathbf{N}$ is the weight function. The incidence matrix is $C : P \times T \rightarrow \mathbf{N}$ defined by $C(p,t) = W(t,p) - W(p,t)$. W and C are extended to $(P \times T^*) \cup (T^* \times P)$ and $P \times T^*$ in the usual way; $\sigma \in T^*$, $t \in T$ and λ is the empty word:*

$$C(p,\lambda) = 0 \bigwedge C(p,\sigma t) = C(p,\sigma) + C(p,t)$$

$$W(p,\lambda) = 0 \bigwedge W(p,\sigma t) = \max\left(W(p,\sigma), W(p,t) - C(p,\sigma)\right)$$

$$W(\lambda,p) = 0 \bigwedge W(\sigma,p) = C(p,\sigma) + W(p,\sigma)$$

The preset (resp. postset) of a set of nodes X is denoted ${}^\bullet X$ (resp. $X^\bullet$), and ${}^\bullet X^\bullet = {}^\bullet X \cup X^\bullet$. We assume there exist two sets $\mathcal{P}$ and $\mathcal{T}$ such that $\mathcal{P} \cap \mathcal{T} = \emptyset$, and all the PT-nets considered in this paper satisfy $P \subseteq \mathcal{P}$ and $T \subseteq \mathcal{T}$: then we can speak of the set of PT-nets satisfying some property.

PT-systems *A marked PT-net or a PT-system is a pair $(N; M_0)$ where $M_0 \in \mathbf{N}^P$ (the initial marking). We adopt the weak sequential firing rule:*

$$M \xrightarrow{\sigma} M' \text{ iff } \forall p \in P, M(p) \geq W(p,\sigma) \text{ and } M'(p) = M(p) + C(p,\sigma)$$

The reachability set is:

$$R(N; M_0) = \{M \in \mathbf{N}^P : \exists \sigma \in T^*, M_0 \xrightarrow{\sigma} M\}$$

Sum of markings *If $M_i \in \mathbf{N}^{P_i}$ for $i = 1, 2$ then $M = M_1 + M_2$ is such that $M \in \mathbf{N}^{P_1 \cup P_2}$, $M(p) = M_i(p)$ if $p \in P_i \setminus P_j$ and $M(p) = M_1(p) + M_2(p)$ if $p \in P_1 \cap P_2$.*