A Normative Language Approach to the Application of Petri Nets for Clinical Workflows

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Abstract: This contribution discusses the application of Petri nets for modeling workflow in healthcare based on a normative language approach. After a brief introduction, a framework of different abstraction levels covering clinical workflow representation to workflow implementation is presented. In order to use the object Petri nets formalism for clinical workflow representation at the conceptual level of the framework, a healthcare specific net interpretation of these Petri nets is introduced which maps healthcare terms to formal object Petri net elements.

1 Motivation

The application of Petri nets in healthcare has been conduced by a number of researches [GS04; Jø02]. However, the lack of an intuitive approach to Petri nets from the end-user perspective has been discussed as their major disadvantage [GrRo99]. This leads to difficulties to apply Petri nets at the conceptual modeling level where clinical workflows have to be designed and verified in cooperation with clinical personnel like practitioners and nurses.

This contribution attempts to develop an integrated approach which covers the end-user oriented clinical workflow [DRK00] modeling on the conceptual level as well as their technical implementation within clinical workflow management systems. In this context we propose to extend the normative language approach to requirements engineering introduced by Ortner [Or96] by the concept of net interpretation introduced by Petri [Petr75]. This leads to a systematic definition of relevant language terms of a domain and the allocation of these terms to formal net elements with an equivalent semantic. The main purpose of this approach is to overcome the language gap between end-users and IT experts and to ensure a smooth transition of relevant domain elements to reliable and formal conceptual workflow models.

The remainder of this paper is organized as follows. After this introduction, the next section will give a short overview of object Petri nets [Va04] which is the formalism we

propose to use for the healthcare domain. Then, a framework for different levels of abstraction from workflow modeling at the conceptual level to clinical workflow implementation is presented. A Petri net interpretation is introduced in section 4 in order to demonstrate how language terms of the upper abstraction layers can be mapped to the lower level where Petri nets are applied. The final section presents conclusions and future work.

2 Object Petri nets foundations

Petri net is a generic term for a number of modeling techniques, graphical representations and notational conventions that are all based on the concept of net formalism introduced by Carl Adam Petri [Pe62]. A significant difference between different types of Petri nets is their token concept [RR98]. Within elementary Petri nets, undistinguishable black tokens represent the availability of states, while at high-level Petri nets, tokens are passive data structures which were transformed by transitions. While the use of structured tokens permits the representation of more complex systems, they are still passive and have no dynamic behavior. With the emergence of object-orientation some research has been conducted to combine Petri net models with the object-oriented paradigm [GV03; ZH00]. The object Petri nets approach adds dynamic behavior to tokens by defining them again as Petri nets [Va04]. Hence, it allows a multi-level modeling technique whereby one or more object nets move through a so-called system net as ordinary tokens. The reader is referred to [Va04] for a more formal introduction to this notation.

Figure 1 gives an example of the three possible interaction relations between the system and object nets [Va98]. The object net (ON) illustrated on the left is located at the place p1 of the system net (SN). A label $<i_n>$ synchronizes steps between the respective transitions of the object net and system net; a missing label indicates mutually autonomous step. Since there is no such label at transition e1 and t1 an object autonomous step of the object net and a system autonomous step (also called transport) of the system net is possible. After theses steps, object and system net have reached a point where an interaction between the two levels at e2 and t2 as well as e3 and t4 are possible next steps.

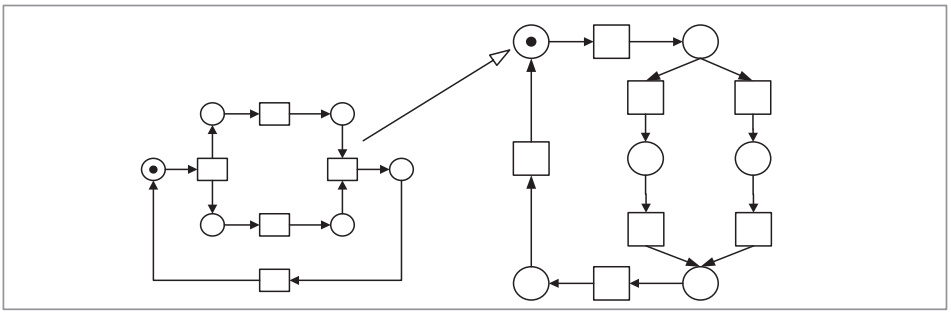

Figure 1. Object Petri net example [Va98]

3 A normative language framework for modeling clinical workflows

The application of object Petri nets for workflow modeling has been outlined by numerous contributions [Aa99; Va98]. But while the object Petri nets offer a powerful modeling notation for IT experts to accurately model and afterwards implement workflows within workflow management systems, the system lacks a solution on how this abstract and formal mathematical constructs can be used to communicate with practitioners and nurses.

Figure 2 is an approach to integrate the mentioned abstraction levels from workflow representation to implementation in healthcare in a conceptual framework. The proposed framework is based on the normative language approach introduced by Ortner [Or96]. The framework has four levels of abstraction. At the lowest level it represents the technology oriented specification of workflows for implementation purposes in workflow management systems. The next higher abstraction level describes processes in a formal manner independent from technology. In our case, object Petri nets were used at this level. The next level of abstraction is a domain specific and end user oriented representation of workflows at a conceptual modeling level. At this stage a normative language which consists of systematically reconstructed domain terminology is used in order to overcome the gap between natural language of end-users and artificial and constructed formal expert language. This attempt made by Ortner has its methodological basis within the linguistic-critical approach on constructivism [Lo87]. By extending the construction of a normative language by the concept of net interpretation, the set of the main language terms has to be mapped to corresponding Petri net elements of the next abstraction level within the framework illustrated in figure 2. The next section introduces such an approach in the healthcare domain for the application of object Petri nets.

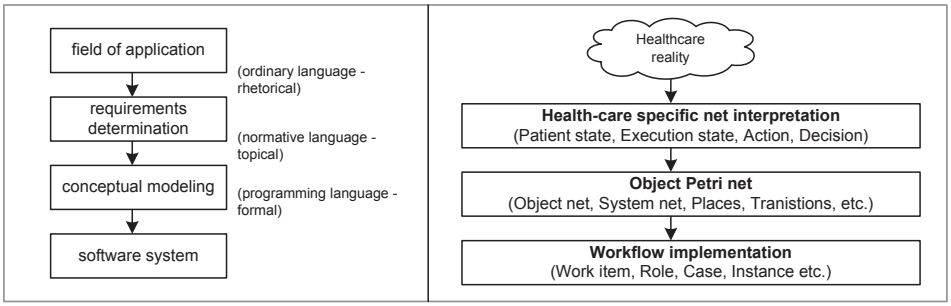

Figure 2. Normative language approach [Or96] (left) and its proposed application in healthcare (right)

4 Object petri net interpretation for clinical workflows

Basically the terms of the healthcare domain which have to be mapped to corresponding net elements are *action*, *decisions*, *patient states* and *execution states* [Wa02]. Actions are used to represent clinical or administrative tasks like intervention or data collection

during workflow execution. A decision is the selection of an alternative from a set of clinical alternatives. A patient state reflects the individual status of a patient during a treatment process. For example, this could be the status of a patient who has received the first dose of medicine and is eligible for the second dose. In contrast, the execution state reflects the system and organizational situation during the workflow execution at a specific time. For example, the transport of a patient from one organizational unit to another or an administrative task is a transition of the system state but does not affect patient state.

The underlying semantic of this Petri net formalism - whereby the object nets are tokens inside a system net with their own dynamic behavior - offers the opportunity to distinguish between state of the object net (patient state) and state of the system net (execution state). It can be argued that this leads to much more accurate representation of a patient as the workflow case then the use of colored Petri nets since a patient as a living organism can change its state spontaneously or over a certain period of time even when no task has been executed upon it. These thoughts lead to the object Petri nets interpretation summarized at table 3.

Object Petri nets	**Clinical workflow interpretation**
Object net	
States	Patient states
Transitions	Tasks transforming patient state
Marking of states	Current patient state
System net	
States	Workflow execution / decision states
Transitions	Tasks Transforming execution state
Marking of states	Current execution state
Dynamic behavior	
System autonomous (transport)	Execution of a workflow task which has no impact on patient state
Object autonomous	Change of the patient state independent from the workflow execution
Interaction	Execution of workflow task which changes also the patient state

Table 3. Object Petri net interpretation for the healthcare domain

5 Conclusion and future work

This contribution has discussed the application of object Petri nets in the healthcare domain based on a normative language approach. A framework on different abstraction levels from workflow representation to workflow implementation as well as a net interpretation for the application of object Petri nets in healthcare has been proposed. In this contribution the used terms were introduced very briefly. The next step is give an in depth definition of the terms and to investigate on other relevant terms. The mapping of the decision term to equivalent net elements need special attention since not all decisions

within the medical domain are rule based and can be represented by straight forward petri net element or patterns. Recent development on petri net based workflows patterns [MA05] need to be investigated to find an accurate way to deal with such decisions.

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