A UNIFIED APPROACH FOR SOFTWARE PROCESS REPRESENTATION AND ANALYSIS

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Abstract: This paper presents a unified approach for software process management which combines object-oriented (OO) structures with formal models based on (high-level timed) Petri nets. This pairing may be proved beneficial not only for the integrated representation of software development processes, human resources and work products, but also in analysing properties and detecting errors of a software process specification, before the process is put to actual use. The use of OO models provides the advantages of graphical abstraction, high-level of understanding and manageable representation of software process classes and instances. Resulted OO models are mechanically transformed into a high-level timed Petri net representation to derive a model for formally proving process properties as well as applying managerial analysis. We demonstrate the applicability of our approach by addressing a simple software process modelling example problem used in the literature to exercise various software process modelling notations.

1 INTRODUCTION

According to a recent study the software industry in US spends approximately 275 billion dollars every year in software development projects (Wallace and Keil, 2004). A major part of these projects (above 70 percent) are facing problems, since they exceed the initial cost/time estimates or, in the worst case, they fail by not providing those deliverables and services which have initially been proposed. There has been a great deal of concern in software process engineering community on developing satisfactory software within timing and resource constraints (Murch, 2001).

It is the task of a software process management approach to specify and represent what must be performed during each phase of a software development project (e.g., requirements definition, specification, design, implementation, testing etc.). The main objective of software process management is to ensure that all project deliverables are provided before project deadlines, all resulted software products satisfy end-user requirements and development costs are within the estimated budget (Murch, 2001; Royce, 1998).

Classical project modelling and planning techniques (network-based techniques such as PERT and CPM) have been found inadequate to describe all artefacts of a complex software process (Mehrez et al., 1995). Various techniques have been concentrating on relieving software project participants of difficulties in understanding the activities performed during software development. Software process modelling approaches try to clarify the concurrent, iterative and evolutionary characteristics embedded in software projects, by using either formal or informal modelling notations (Armenise et al., 1992). Formal modelling techniques, such as Petri net-based models (Gerogiannis et al., 1998; Murata, 1989), offer the advantages of simulation, decision making and powerful managerial analysis. As far as process modelling is concerned, formal techniques provide facilities to analyze the dynamic aspects of a software development process by examining, for example, the duration of each project activity and sources of possible resource conflicts (Min et al., 2000). Informal modelling notations, such as the Unified Modelling Language (UML) for object-oriented modelling (Cantor, 1998; Fowler, 2004), can be useful to represent not only the software system under development but also the processes performed within a project to develop a software system.

Recently, various object-oriented approaches in software process engineering domain have been unified in the so called Software Process Engineering Metamodel (for short SPEM) (OMG, 2005). SPEM is an adopted standard from the Object Management Group. It utilizes UML diagrammatic notations and provides means to describe, in abstract terms, any software development process and its components. Syntactic richness, user friendliness, simplicity and flexibility of SPEM notations, make them a promising tool for software project managers, usually not familiar with formal methods. SPEM adoption can be particularly useful to support the definition of those processes (e.g., the Rational Unified Process (Jacobson et al., 1999)) which involve or mandate the use of UML during the software development.

In this paper, instead of introducing a new model to represent and analyze software development processes, we propose the unification of UML models with Petri nets. The proposed approach is centered upon handling the inherent complexity and satisfying various requirements met in software development projects. The presented approach is currently under development in the context of the MISSION-SPM project (short for Model based Integrated Environment to Support Simulation in Software Project Management). MISSION-SPM is an R&D project that receives funding and support from the European Social Fund and the Greek Ministry of Education (in the context of the ARCHIMEDES national research programme). The main objective of the project is the definition of a unified architecture to support the graphical representation of software development processes and the process managerial analysis as well.

The next section of the paper presents the background of the MISSION-SPM approach. Then, in section 3, an experimental study is presented, modelling a part of a software process example with the use of UML diagrams. In section 4, a discussion is provided on the translation of UML process diagrams to a corresponding formal model, expressed in a high-level timed Petri net notation. Managerial analysis issues are briefly discussed in section 5. The paper concludes with ideas for possible directions for further research.

2 BACKGROUND

The MISSION-SPM project focuses on exploiting the benefits of unified approaches for software process representation, analysis and simulation. Our research stem from two complementary perspectives for process representation: (1) UML based process representation, and (2) Petri net based modelling and analysis, respectively.

The complementary diagrammatic notations of UML can be used to represent different views of a complex software process. For example, UML use case or class diagrams can be used to represent the functionality and the static structure of a software process. These models provide appropriate constructs to define software processes and relevant artefacts, as well as various process performers involved in process activities. Other notations, such as UML sequential diagrams, state diagrams and collaboration diagrams, offer the means to represent the dynamic behaviour of process elements (i.e., the operational behaviour of process classes). These diagrams support the process planning, since they can define the process control flow (i.e., relationships among activities and artefacts). In MISSION-SPM, usage of UML notations is mandated by SPEM terminology for describing software processes (OMG, 2005). Roughly speaking, a software process is divided into phases. Phases contain activities that are performed by performers (e.g., architects, programmers etc.). Each activity has some input and produces some output. Following the SPEM terminology, inputs and outputs to and from activities are called work products.

Formal models can be utilized to gain the formality required to strongly support simulation and managerial analysis. For example, Petri nets are an interesting graphical model and they have been widely applied in various application areas (Murata, 1989). Their mathematical foundation, developed over the years, has made Petri nets a powerful, well-understood model, especially applicable to software process modelling (Liu and Horowitz, 1989; Chang and Christensen, 1999; Min et al., 2000). In MISSION-SPM, we have selected the formal modelling notation of Petri nets for the analysis of process models. Abstract process models, initially expressed by UML diagrams, are transformed into high-level timed Petri nets (Ghezzi et al., 1991) for the formalisation and analysis of their static/dynamic properties. As far as managerial analysis is concerned, simulation and rigorous analysis techniques from the Petri net analysis domain can be applied to examine some useful metrics and properties, such as the cumulative time consumption and the degree of concurrency of process activities at any process phase, the level of utilization of each process performer etc.

3 UML MODELS OF A PROCESS EXAMPLE

In this section, the MISSION-SPM approach is illustrated by using UML class and state diagrams. We use the class diagram presented in Figure 1 to describe the structure of a simple software process example.

The elements of this example constitute a subset of corresponding components met in ISPW-6 process core problem (Kellner et al., 1991), a general software process modelling problem used to study various software process modelling notations. The example refers to the design modification/review activity of a hypothetical software development project which involves four performers (one Design Engineer, one Quality Assurance Engineer and two Software Engineers) and one work product (the Software Design Document). The first project task, called "Modify Design", is carried out by the assigned Design Engineer. The subsequent task, called "Review Design", is performed jointly by a team including the Design Engineer, the Quality Assurance Engineer and the two Software Engineers. The class diagram in Figure 1 presents some of the main methods of these process elements (depicted as classes) and the possible associations among them. For the sake of simplicity, class attributes and stereotype names are not presented in the class diagram. The operational semantics of the process elements involved in this example can be captured by using four state diagrams, one for each process element respectively (Figure 2). State diagrams describe the states and state transitions of the process elements (classes) and interact through invocation of services. Services represent certain management decisions/responsibilities, as well as corresponding communication messages (notifications for start/completion of activities). Therefore, events and actions correspond to requests for services (e.g., execution of performers' activities), completions of services and acknowledgments of service completions.

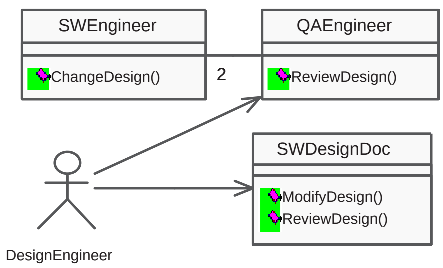


Figure 1: Class Diagram for the Example Process.

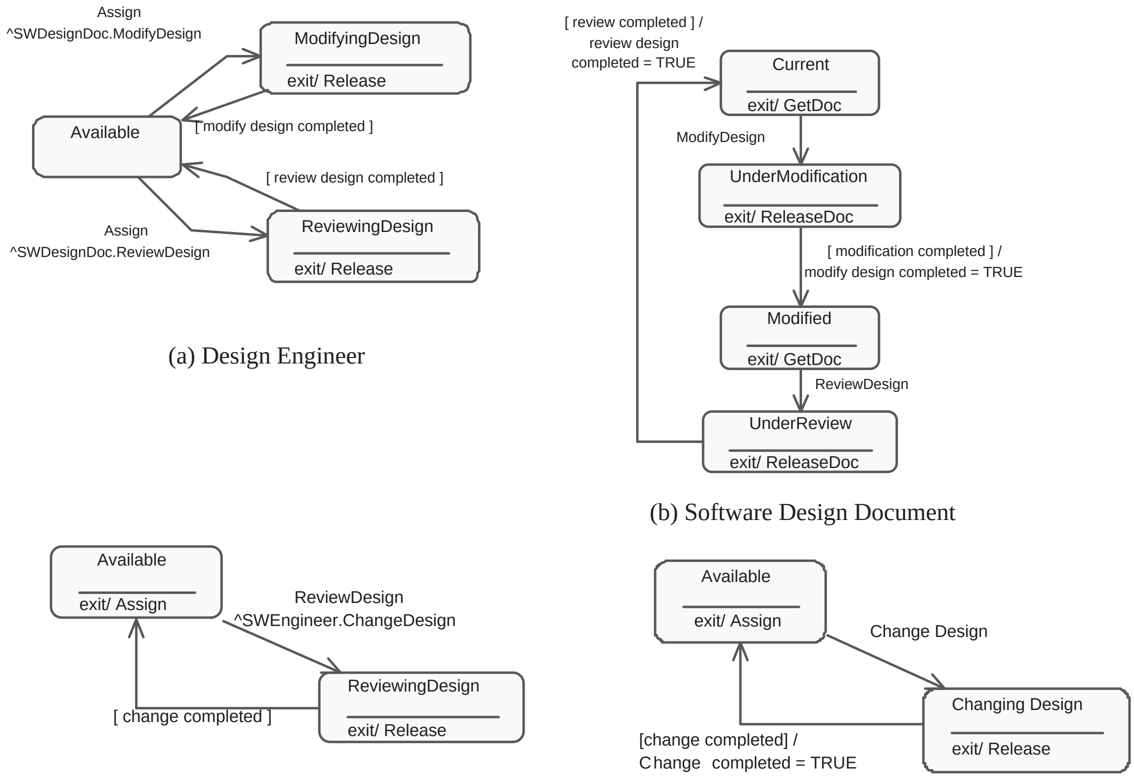
4 TRANSFORMING UML MODELS INTO PETRI NETS

Various approaches have been proposed for the formalisation of UML diagrams with Petri net models in different application domains. For example, state diagrams and collaboration diagrams have been translated into stochastic Petri nets to apply performance analysis (Pooley and King, 1999). Activity diagrams have been augmented with the operational semantics of Coloured Petri nets (Jensen, 1995) to represent complex workflow structures (Eshuis and Wieringa, 2001). Class diagrams have been formalised with object-oriented Petri nets (Delatour and Paludetto, 1998) to analyse the timing behaviour of real-time systems. In other approaches, class and state diagrams have been transformed into high-level Petri nets (Baresi and Pezze, 2001b; Baresi and Pezze, 2001a) to reason on the dynamic aspects of software systems by applying simulation and reachability analysis.

In general, all these translation schemes from UML diagrams into Petri nets follow two alternative approaches. According to the first alternative, states of activities are mapped into Petri net places. The second option is to associate states with Petri net transitions. In MISSION-SPM, we have followed the first approach, since it is more natural, according to the original Petri net semantics (Murata, 1989), to associate states and activities with Petri net passive components (places) and spontaneous actions, denoting start/end of activities, with Petri net active components (transitions).

The adopted approach is based on the transformation rules presented in (Baresi and Pezze, 2001b; Baresi and Pezze, 2001a) which aim to automate the production of a high-level Petri net by taking as input UML class and state diagrams. The advantage of this selection is the generation of a highly expressive formal notation augmented with data structures for modelling net tokens, as well as with predicates, actions and timing parameters for describing net transitions. We attempt to further exploit the adopted approach by introducing relevant semantics from the software process management domain. Tokens play the role of the artefacts of a certain software process. Thus, a high-level timed Petri net model is automatically produced to provide a highly condensed representation of a software process.

More specifically, based on the transformation algorithm described in (Baresi and Pezze, 2001a), each process class, already defined in a UML class diagram, is represented by a high-level timed Petri subnet, in which there are two places for each identified service, one representing the service request and another indicating the service completion. This way, we can describe various kinds of conceivable interactions between the process elements, including methods' invocations, either parallel or sequential, requiring acknowledgment or not (i.e., synchronous or asynchronous interactions). States for each process class, already specified in a UML state diagram, are translated into net places in the corresponding Petri net; state exit actions are transformed into net transitions,



(a) Design Engineer

(b) Software Design Document

(c) Quality Assurance Engineer

(d) Software Engineer

Figure 2: State Diagrams for the Elements of the Example Process.

while state transitions are translated into arcs between corresponding places and transitions in the resulted Petri net. Instances of process performers and work products (i.e., the individual objects of each process class) are modelled with (typed) tokens accumulated in the corresponding places.

Considering the ISPW process example, we use one token to represent the Design Engineer, one for the Quality Assurance Engineer, one for the SW Design Document and two tokens representing the two Software Engineers. The resulted subnets can be merged together in one final net by fusing places. Places are merged together when there is a pair of places for the same service, one asking for the service and the other offering it. The application of this transformation method to the example process results in the high-level timed Petri net of Figure 3, where type definitions of tokens as well as transitions' predicates, actions and enabling intervals (Ghezzi et al., 1991) are not listed, for the sake of simplicity. For example, the enabling predicate of transition SWEngineer.Assign requires both tokens in SWEngineer.Available place to be active. By applying this transformation procedure, the final net has the structure of a marked graph (Murata, 1989) (i.e., each place has exactly one input transition and exactly one output transition), thus it allows the specification of synchronisation structures. The final net is composed of four subnets, which correspond to the original elements of the process example, respectively (i.e., the Design Engineer subnet, the SW Design Document subnet, the Quality Assurance Engineer subnet and the Software Engineer subnet). The Design Engineer subnet invokes the modify design method of the SW design document subnet. After the acknowledgment receipt (i.e., the notification that design modification is completed), the Design Engineer subnet performs a parallel method invocation to the SW design document and the QA Engineer subnet, requiring from them the design review. The QA Engineer subnet, in turn, requires from both SW Engineers to perform possible design changes.

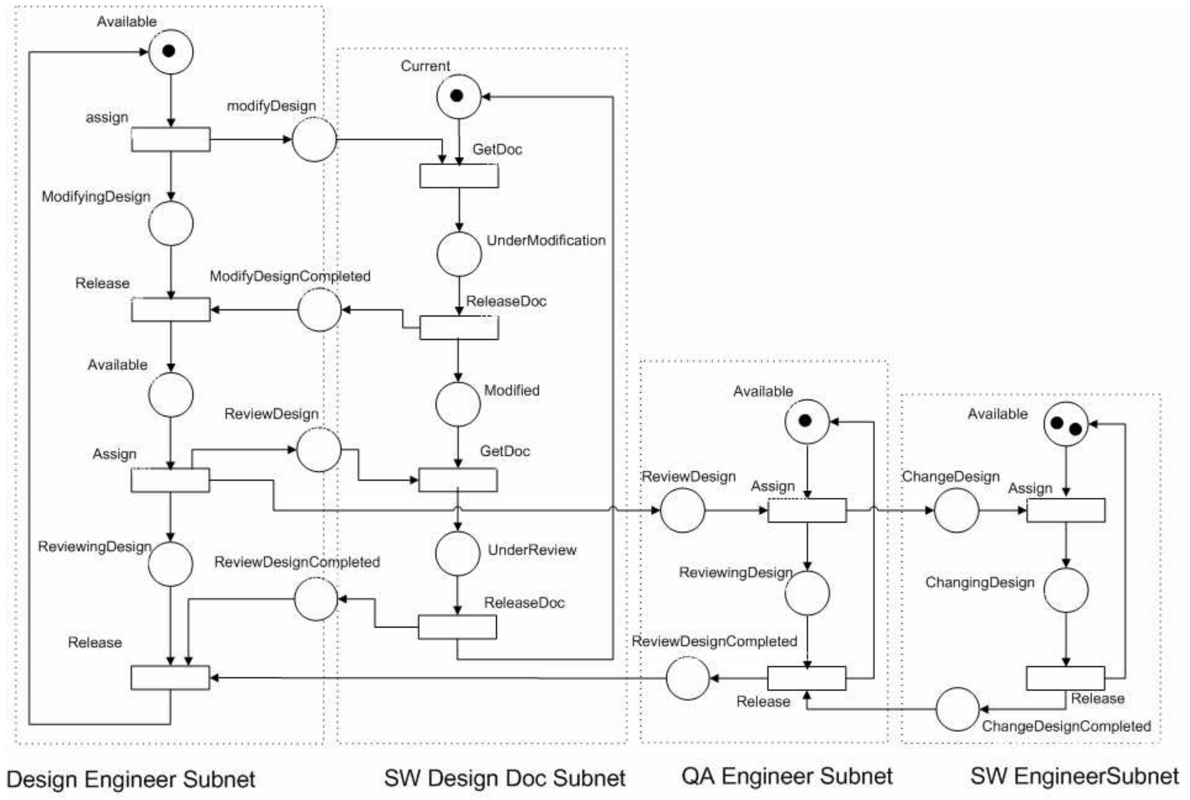


Figure 3: High-level Timed Petri Net for the Example Process.

5 MANAGERIAL ANALYSIS ISSUES

The resulted formal representation of process elements can be analysed and verified by various Petri net based analysis techniques, such as simulation, reachability analysis, model checking and verification of structural net properties (Murata, 1989). Analysis on the resulted marked graph structure may be particularly helpful to detect possible structural failures, such as deadlocks of the whole process. As far as analysis of dynamic properties is concerned, we can assign timing information to the resulted Petri net by associating timestamps with tokens and enabling time intervals with transitions. Then, simulation to the resulted high-level timed Petri net can be conducted to examine some important decision making elements, such as the cumulative time consumption and the degree of concurrency of process activities, at any process phase, the level of utilization for each process performer etc. Moreover, the use of automated tools, such as CPN tools (Jensen, 1995), can facilitate the process of modelling and analysis.

The simplest analysis technique is to apply simulation (i.e., execute all transition firings) on the net of Figure 3, in order to discover possible delays in the software modification and review process. For example, when the timestamps of the two tokens in place SWEngineer.Available have different values, the one with the greater timestamp (say SW Engineer 2) will delay the other (say SW Engineer 1). This situation can be solved by further decomposing the SW Engineer subnet in two other subnets, representing explicitly the two SW Engineers. Then, the QA Engineer can request, in sequence, from the two SW Engineers to perform possible design changes.

6 CONCLUSIONS

In this paper, we have briefly discussed the unification of object-oriented structures of software development processes with (high-level timed) Petri nets. This “pairing” may be proved beneficial not only for the integrated modelling of software development processes, involved performers and work products, but also in analysing properties and detecting errors of a software process specification, before the process specification is put to actual use. UML based diagrammatic representations of processes facilitate software project managers/engineers in understanding the elements of a software process model, while the direct executability of the resulted Petri nets provides the means for simulation support. We have demonstrated the applicability of our approach by describing a part of a standard software process modeling example problem with UML diagrams. The subsequent analysis can be performed on a mechanically generated Petri net representation.

The further development of our approach is an ongoing task that takes place within the context of MISSION-SPM project. Our current efforts concentrate on:

- exploitation of existing techniques to transform other dynamic UML models of software processes (e.g., activity diagrams) to equivalent formal representations, expressed in terms of high-level timed Petri nets (Eshuis and Wieringa, 2001),
- experimentation of various types of analysis techniques on the resulted nets, in order to assist the managerial decision process (Min et al., 2000), and
- specification of a fully compliant implementation of our approach with the modelling constructs of the SPEM metamodel; such a compliance will make the MISSION-SPM approach general enough to express and analyse various scenarios met in a range of software development processes.

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