FROM UML TOWARDS PETRI NETS TO SPECIFY AND VERIFY

Thouraya Bouabana-Tebibel
Institut National d'Informatique BP 68M, Oued-Smar 16270, Algiers, Algeria

Mounira Belmesk
Collège Edouard MonPetit, Longueuil, Canada

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Abstract: UML nowadays, has emerged as the industry standard for object-oriented modeling. However, it still lacks a well-defined semantic base enabling it to perform formal verification and validation tasks. Our goal being to provide system designers a life cycle of software development integrating conviviality and rigor, we propose a methodology to specify, verify and validate using UML. This methodology is based on a technique which derives colored Petri nets from UML class, statechart and collaboration diagrams. The approach that we propose associates the formalization of the object dynamics to the formalization of the object behavior. A case study is provided to illustrate this technique.

1 INTRODUCTION

UML (OMG, 2001) is currently considered as the universal notation for object-oriented specification of complex system artifacts, in graphic and documented form. Nevertheless, it lacks a well-defined semantic which allows the use of formal proof techniques guaranteeing the precision and the correctness of the modeling.

The class diagram models the static structure of a system, in terms of classes and relationships between these classes, where the objects represent the class instances and the associations represent the relation instances. The statechart diagram describes in a formal manner the behavior of the objects of a given class by way of states and events. The collaboration diagram shows the object interactions by emphasizing in particular, the static structure which allows the object group collaboration.

On the other hand, Petri nets (Jensen, 1992) are a formal and graphical appealing language that relies on a mathematical theory which permits abstract proof activities. Colored Petri nets are a generalization of ordinary Petri nets, allowing convenient definition and manipulation of object values. Because of its rigor and reliability, the use of formal specification is increasingly present in the world of modeling, in spite of its complex approach.

We are interested in this paper, in developing a methodology which will associate, the object-oriented modeling to the formal specification in order to compensate between the limits of one versus the constraints of the other. This methodology starts from a UML modeling to derive colored Petri nets from class, statechart and collaboration diagrams. The statechart diagram generates a Petri net translating the operational and dynamic behavior of the object. The collaboration diagram afterwards intervenes in the interconnection of the different object Petri nets, thus assuring their interaction. As far as the class diagram is concerned, its role is to precise the object roles and to provide the OCL invariants.

The remainder of the paper starts with a brief expose on the current trends on this research and works similar to the work presented herein. Then, we present the proposed methodology and the development of the technique upon which it is based. This technique is illustrated in a case study. We conclude with observations on the obtained results and recommendations of future research direction.

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2 RELATED WORK

Many studies and research works are being done in order to combine the UML notation and formalisms. A first approach consists in integrating formalisms in UML diagrams. Delatour and Paludetto (Delatour, 2003) present a methodology for analysis and development of real-time systems, supported by the ArgoPn tool. This methodology is based on the dual and complementary use of the UML interaction and activity diagrams on the one hand and Petri nets on the other hand. According to the same approach, Elkoutbi and Keller (Elkoutbi, 2000) develop a tool for prototyping, based on the UML use cases and Petri nets.

The formalization of the UML diagrams has been tackled in various works. In (Kim, 1999) the class diagrams are formalized by the Z language. Likewise, formal semantics of UML statecharts (Varro, 2002), (Kuske, 2001) and integration in the statecharts of languages state oriented (Z, B) (Meyer, 2001) and properties or axiomatic oriented (algebraic specification) (Attiogbé, 2002), were also investigated.

Another trend in the current research, consists in deriving formalisms from UML modeling. The *v*UML tool (Lilius, 1999) validates UML models by model checking. The UML Model is translated into PROMELA which constitutes the input language of the model checker SPIN. Likewise, a systematic derivation of a PROMELA/SPIN model from a rule-oriented model is tackled in (Attiogbé, 2004). As for the AGL Telelogic Tau tool (Telelogic, 2003), it allows the validation of UML real-time models by translating the model into SDL language and then validating it by model checking. The limit of these tools resides in the incapacity of the model checker to verify open reactive systems.

Like the Petri nets, the Object-Z formal specification has been derived from UML modeling in many works. In (Bittner, 2003) the results of analysis and development of the method Fusion/UML are translated in Object-Z. Object-Z is also derived from UML class diagrams incorporating OCL constraints in (Roe, 2003).

Much work on the formalization of UML, has been done however, it currently still lacks, a unified formalization which associates the dynamics of the objects, through the roles they play, to their operational behavior, from where emerges the theme of this paper.

3 METHODOLOGY OF SPECIFICATION AND ANALYSIS

We propose in this work a platform of construction and analysis of UML models (see figure 1). This platform offers a user a graphic interface for the edition of the class, statechart and collaboration diagrams. The statechart diagrams are converted into **O**bject colored **P**etri net **M**odels (*OPM*) that will be connected by derivation of the collaboration diagrams. The Petri nets resulting from the derivation are then analyzed using some adequate information on the class diagrams. The analysis is performed by way of a validator, PROD (Varpaaniemi, 1997). The results of the verification can afterwards be exploited for eventual corrections on the UML model which is likewise refined, verified and then corrected until reaching the level of detail sought for the final code generation.

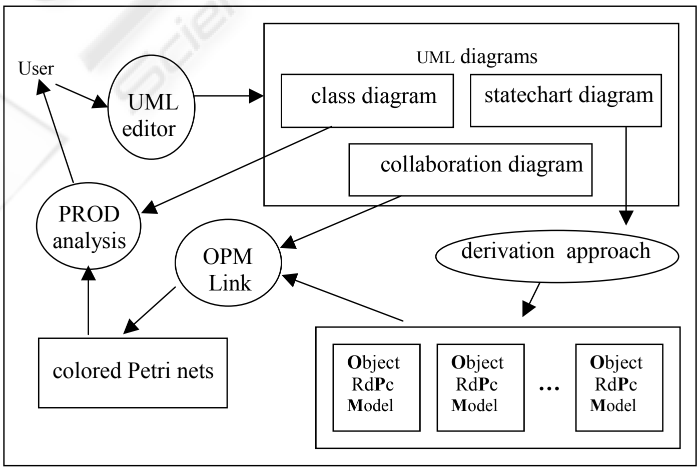


Figure 1: Methodology of modeling and analysis

3.1 Object behavior specification approach

Saldahana and Shatz (Saldhana, 2001) develop a method of derivation of Petri nets from UML modeling, based on statechart and collaboration diagrams. The generated Petri nets, allow the specification of the operational behavior of the system.

Such (Saldhana, 2001), we suggest to connect the statechart models translated into Petri nets, using the collaboration diagram information. However, we propose a different architecture of interconnection (see figure 2) and new rules of interaction. The resulting Petri net model is articulated in components whose generation is carried out as follows.

Any statechart diagram is converted into a Petri net called *DM* (Dynamic Model).

We distinguish on the statechart diagram, between five types of actions : the event causing the transition firing (***event***), the action executed on a transition at the entry of the state (***transition entry action***), the action generated on entering the state (***entry action***), the action generated on exiting the state (***exit action***) and the action executed on a transition at the exit of the state (***transition exit action***).

The action is modeled by a token of *event* type. This token can be internal or external. The external token symbolizes the inter-object communication. As for the internal token, it is generated for an internal use with the *DM*.

The communication between the objects of the system is relayed by the *Link* place. This connection is deduced from the collaboration diagrams. The *Link* place receives the external events coming from the different *DM* and poses in each *In-Event* place attached to *a DM* the events thrown to this *DM*.

The *In-Event* place constitutes, the reserve of the events that are sent to the *DM* whether they are external coming from the *Link* place or internal generated by the *DM* itself. It is an interface for the *DM* towards the events which occur within. The *DM* and this interface constitute an **O**bject **P**etri net **M**odel called *OPM*.

3.2 Object dynamic specification approach

Our approach, contrary to Saldhana and Shatz's technique is not limited to the specification of the system operational behavior ; it also aims at the modeling of the dynamics of the objects through the roles they play. Thus, diagrams translating the structural schematics of the objects as well as their movement, must be used to generate Petri nets supporting a precise specification of these objects. To this end, we propose to introduce on the one hand, the class diagram which represents the structural links between the objects of the system, by emphasizing the roles they play, and to insert on the other hand, in the statechart diagram, the evolution expression of the objects. This expression will be in charge of the role updates by insertion or suppression of objects. It will appear as a tagged value that follows the operation causing the update of the role. This tagged value will translate the insertion (+ role) / suppression (- role), of a given object in the role (see figure 3).

The role is a pseudo-attribute of the source class; so, it is important to observe the principle of its encapsulation in the source class, in order to remain in conformity with the object interconnection scheme of figure 2 ; the role updates of a source class can accompany only the operations of this class.

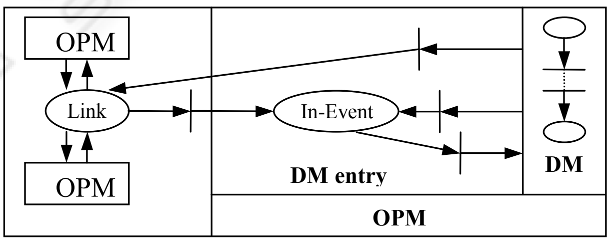


Figure 2: Architecture of a colored Petri net derived from UML

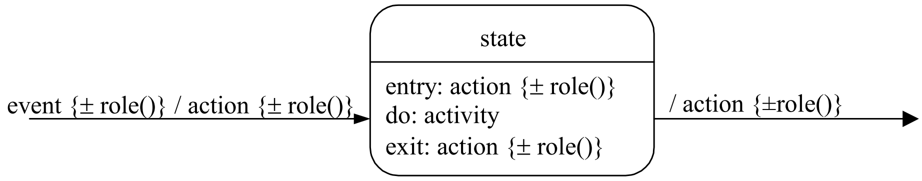


Figure 3: Role update expression on the statechart diagram

This approach strongly supports a precise verification/validation of the modeling. The validation can be obtained by way of the awaited properties of the system, written by the modeler in the OCL language. OCL is a formal language mainly based on the handling of collections in order to specify object invariants. However, these collections correspond to a specification of roles. So, the use of OCL implies inevitably, the use of the role concept modeling. This makes it possible to say that the validation allows the checking of the object operational and interactive mode as well as the object movement through the system, by means of the roles it plays.

The properties are then translated into the PROD validator syntax to be checked. The translation of OCL specification in temporal logic properties, constitutes the subject of a study which is being presented into another article. For a deeper validation, we also propose in that study to introduce temporal logic operators into OCL.

We present in section 4 some properties of the system, specified in OCL language and then translated into PROD temporal logic syntax. The establishment of the system properties will rely on the class diagram structure.

3.3 Derivation technique

The derivation of UML modeling to the Petri net specification, is introduced on : the class diagram for getting the OCL invariants, the statechart diagram to translate the object behavior and dynamics and finally, the collaboration diagram for connecting the interactive objects of the system.

3.3.1 Derivation from the collaboration diagram

UML object is modeled by a colored token in the Petri nets. The various colors of the token correspond to the object arguments. We distinguish between two types of objects : interactive objects, of *object* type, and exchanged objects, of *event* type. The exchanged objects are signal or call events. Therefore, any interactive object is a prototype object modeled by the token <*obj*>, where *obj* is the object identifier. As far as the event object is concerned, its source and destination must always appear in the specification, in order to precise the entity involved in the interaction. These arguments are drawn from the collaboration diagram. Thus, the «send» event is identified by the source object (*srce*), the target object (*targ*), the event identifier (*ev*) and the object which undergoes the action (ex*obj*). It is modeled by the token <*srce, targ, ev, exobj*>.

The collaboration diagram is used to connect, with the *Link* place (see figure 2), the interactive objects which it represents and which are translated into *OPM* models. The exchanged messages are external events. All of them forward through the *Link* place.

Thus, for each *OPM* model, an oriented transition from the *Link* place to the *In-Event* place is built. The transition firing is conditioned by the external events in entry of the object, on the collaboration diagram.

Furthermore, all the events exchanged between two objects are inserted in the In-Event place of the *OPM* corresponding to the source object.

Algorithm

– create the *Link* place,
– for each *OPM* model deriving from the object *obj* :
  - create an *In-Event* place,
  - put in the *In-Event* place all the events <srce, targ, ev, exobj>, in exit of the object *obj*,
  - create a transition t,
  - create an arc *Link*→t such that Pre(*Link*, t) = <srce, obj, ev_1, exobj> + … + <srce, obj, ev_n, exobj> where ev_i is an entry event of the object obj,
  - create an arc t→*In-Event* such that Post(t, *In-Event*) = <srce, obj, ev_1, exobj> + … + <srce, obj, ev_n, exobj>.

3.3.2 Derivation of the statechart diagram

Since statechart diagrams may contain hierarchical or nested states, effective conversion to Petri nets requires that the nested states be flattened. So, for a given statechart diagram which models the lifetime of an object, one can generate a Shlaer-Mellor object life cycle (Shlaer, 1992), which is a flat state machine (contains just simple states and arcs). This transformation is given in (Saldhana, 2001). Then the flat state machine can be converted into a colored Petri net that forms the *DM* of the *OPM* model. This derivation is performed conforming to the conversion rules that we define below.

The colored Petri net is defined by <P, T, Pre, Post, M_0, C> where P is the set of *state* or *role* type places, T is the set of transitions, and C is the set of colors. Pre and Post are functions related to the transition firing. M_0 is initial marking.

We indicate in what follows by : e_i a state i, <obj> an interactive object, <exobj> the object which undergoes the action, srce the source object and targ the target object.

Algorithm

Conversion of a state *e*
- if final state, nothing to do,
- else create a place of state type,
- if initial state, create a token <obj> defining the initial marking M_0.

Conversion of a transition between the e_1 and e_2 states (e_1–t→e_2)
- create a transition t,
- create an arc e_1→t such that Pre(e_1,t) = <obj>,
- if e_2 not final state, create an arc t→e_2 such that Post(t, e_2) = <obj>.

Conversion of an event *ev* on the transition t
- create an arc In-Event→t such that Pre(In-Event, t) = <srce, targ, ev, exobj>.

Conversion of an internal/external entry action *act* inside e_2 such that e_1–t→e_2
- create an arc In-Event→t such that Pre(In-Event, t) = <srce, targ, act, exobj>,
- create an arc t→In-Event/Link such that Post(t, In-Event/Link) = <srce, targ, act, exobj>.

Conversion of an internal/external exit action *act* inside e_1 such that e_1–t→e_2
- create an arc In-Event→t such that Pre(In-Event, t) = <srce, targ, act, exobj>,
- create an arc t→In-Event/Link such that Post(t, In-Event/Link) = <srce, targ, act, exobj>.

Conversion of an internal/external transition entry/exit action *act* on t such that e_1–t→e_2
- create an arc In-Event→t such that Pre(In-Event, t) = <srce, targ, act, exobj>,
- create an arc t→In-Event/Link such that Post(t, In-Event/Link) = <srce, targ, act, exobj>.

Conversion of an insertion in the role *r*, on the transition t
- create a place of *role* type, if the place does not exist,
- if the role indicates an interactive object and it follows an event, create an arc t→r such that Post(t, r) = <srce>,
- if the role indicates an interactive object and it follows an action, create an arc t→r such that Post(t, r) = <dest>,
- if the role indicates the object which undergoes the action, create an arc t→r such that Post(t, r) = <exobj>.

Conversion of a decrementation of the role *r*, on the transition t
- if the role indicates an interactive object and it follows an event, create an arc r→t such that Pre(r, t) = <srce>,
- if the role indicates an interactive object and it follows an action, create an arc r→t such that Pre(r, t) = <dest>,
- if the role indicates the object which undergoes the action, create an arc r→t such that Pre(r, t) = <exobj>.

4 CASE STUDY

We illustrate our approach with an application in which we model the behavior of an object by the statechart of figure 6. We then, apply to this diagram the derivation rules we have enunciated, in order to generate the corresponding colored Petri net, represented on figure 7.

The treated application is a message server whose main role is to manage the communication between the connected stations. All the exchanged messages must go through it, to be forwarded to the receiver.

A station can at all times, connect or disconnect itself from the server. Its connection request is carried out by sending the *connection* event. Its disconnection is required by the *disconnection* event (see figure 5). The server confirms the station connection or disconnection by the *okconnection* or *okdisconnection* events, respectively.

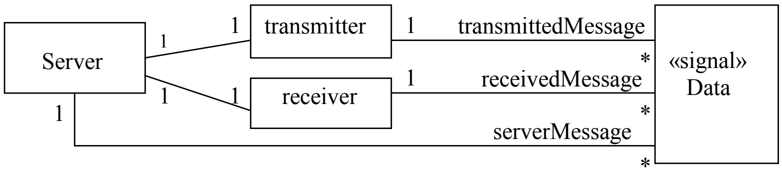


Figure 4: Class diagram of the message server

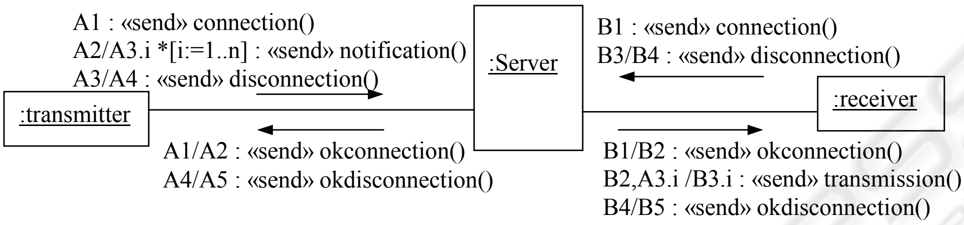


Figure 5: Collaboration diagram of the message server

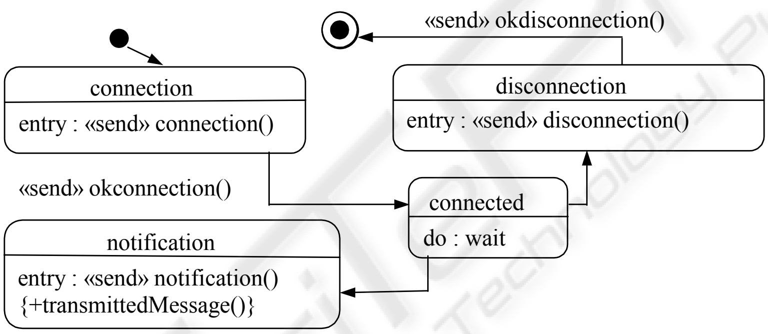


Figure 6: Statechart of the transmitter class

Connected, a transmitter can notify a message by way of the «send» *notification* event. The message entity is modeled by the signal stereotyped class *Data*. After receiving a client notification, the server transmits it by the «send» *transmission* event, to the receiver.

As far as the role updates are concerned, we will be interested particularly in the *transmittedMessage*, *receivedMessage* and *serverMessage* roles. The *transmittedMessage* role is updated by including an object, {+*transmittedMessage*()}, after the «send» *notification* action, in the transmitter statechart (see figure 6). The *receivedMessage* role is updated, {+*receivedMessage*()}, after receiving the «send» *transmission* event, in the receiver statechart. As for the serverMessage, it is incremented of an object {+serverMessge()}, in the server statechart, when receiving the «send» *notification*, and decremented of an object {-serverMessage()}when transmitting this notification («send» *transmission*) to the receiver (see figure 5).

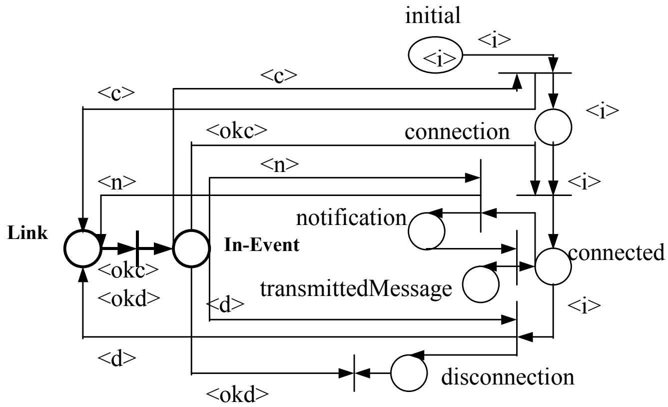
These treatments allow the expression of the following OCL invariant that translates the paraphrased property : a receiver r receives all the sent messages by a transmitter t.

Property expression in OCL

- {«invariant»
  r.receivedMessage→includes (obj) implies
  t.transmittedMessage→includes (obj)}
- {«invariant»
  t.transmittedMessage→size ==
  r.receivedMessage→size +
  s.serverMessage→size}

Property expression in PROD

- henceforth (eventually
  (transmittedMessage >= <obj>))
  implies (eventually
  receivedMessage >= <obj>))



Légende : i = transmitter ; c = transmitter, server, «send» connection, obj1 ;
okc = server, transmitter, «send» okconnection, obj2 ; n = transmitter, server, «send» notification, obji ;
d = transmitter, server, «send» disconnection, obj3 ; okd = server, transmitter, «send» okdisconnection, obj4 ;

Figure 7: OPM of the transmitter class

– henceforth (card(transmittedMessage) == card(receivedMessage) + card(serverMessage))

The first invariant means that every object that belongs to the role transmitterMessage will belongs to the role receivedMessage.

The second invariant means that the cardinality of the t*ransmittedMessage* role is always equal to the sum of the *receivedMessage* and *serverMessage* cardinalities.

5 CRITICAL DISCUSSION

The current research works deal only with the behaviour and the interactions of generic objects. They do not go yet in details of the object dynamics and identification. The methodology which we propose, offers to the user the opportunity of carrying out a meticulous validation of its modeling by checking the dynamics of the objects through the various roles they play. The checking of objects identified by their roles is allowed by means of the expression of the awaited properties of the system, written by the modeler in the OCL language. The properties are then translated into PROD language to be verified. This enhances the degree of the validation/verification but it remains insufficient, as long as it does not permit the specification and the validation of multiple class instances, identified by attribute values. We develop this subject in (Bouabana-Tebibel, 2004), where we show the benefits of such an approach.

6 CONCLUSION

This paper introduces a methodology to specify with UML, and then to systematically verify and validate modeling without having to master the techniques of formal checking. This methodology is founded on a derivation technique of colored Petri nets from UML models. The verification and validation are not only about the object's behavior, as presented in (Saldhana, 2001) but also on the object dynamics. For this purpose, we integrated the class diagram in the derivation technique and then we proposed to introduce the modeling of the objects into the statechart diagram.

To test the practical implementation of our derivation approach, we built a translator whose semantic functions are drawn from the rules we have enunciated. We also developed a graphic interface for the construction of the class, statechart and collaboration diagrams. These diagrams constitute the entry of the translator whose exit results into colored Petri nets, specified in PROD syntax. PROD is then executed to verify the modeling.

Among the prospects of this work, the analysis of the validation/verification results and their feedback to the user are explored. These results must be presented to the designer in an interpreted form, where the error in modeling is simply and clearly pointed out. Since the methodology calls for UML to provide the input specifications, it is only reasonable for the output results to be meaningful to the user. We also project to derive Petri nets specifying the operational and dynamic behavior of the objects from the activity diagrams.

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