Mapping Formal Results Back to UML Semi-formal Model

Vinicius Pereira[1], Luciano Baresi[2] and Marcio E. Delamaro[1]
[1]*Instituto de Ciencias Matematicas e Computacao, Universidade de Sao Paulo, Sao Carlos, SP, Brazil*
[2]*Dipartimento di Elettronica e Informazione, Politecnico di Milano, Milan, MI, Italy*

Keywords: UML, Formal Results, Traceability, Mapping, Model Verification.

Abstract: UML is a widely used modeling language and it has a semi-formal notation that helps the software developers with a set of modeling rules, but without the need to have expertise in formal methods. This semi-formalism encourages the use of UML in Software Engineering domain because the software engineers involved can understand UML diagrams easily. Whereas, formal methods are more accurate than UML and their formal models have a higher correctness than the UML models. Thanks to this correctness, over the years, researchers are seeking ways to assign a formal semantics to UML. Usually they focus on how to formalize UML diagrams, transform them into formal models (such as LISP) and use them in model checkers. However, few researches discuss the problem of how to present the formal results to an audience who has no knowledge of formal methods. In order to fulfil this problem, in this paper is presented a mapping responsible for making the correlation between the formal results and the UML semi-formal environment, allowing the developer to analyze the results without having advance knowledge of formal methods. Therefore, we hope that this work may contribute to the increased adoption of formal methods in the software development industry.

1 INTRODUCTION

Unified Modeling Language (UML) (Eriksson et al., 2004) is widely recognized and used in different computational domains, being the modeling language most adopted by the industry (Hutchinson et al., 2011). The modeling of a system using UML can be understood without problems among people working in software development. Such degree of understanding is possible because UML has a semi-formal notation. This notation encourages intercommunication among professionals without expertise in real formalism.

The lack of a well-defined formalism in UML makes its models less accuracy than a formal model. This lowest accuracy could be reflect later in an incomplete system. Depending on the system, it could be impossible or unfeasible to repair it. For example, a Web system can be repaired without major problems, but not a critical embedded system. On the other hand, the use of formal methods is not trivial. To one uses these methods is necessary to have a certain level of knowledge about formalism that the majority of professionals that works with UML do not have. Therefore, researchers seek ways to bring together the UML and the correctness of formal methods.

Thus, assigning a formal semantics for UML includes works that show how to add formalism to UML, transform the formalized UML model in a compatible model to be input for a model checker, and to obtain the formal results that show whether the modeled system satisfies or not the properties desired by developers or stakeholders. Among these proposals are the fUML[1] and studies that deal with the formal semantics of at least one UML diagram (Diethers and Huhn, 2004; Rossi et al., 2004; Snook and Butler, 2006; Bouabana-Tebiel, 2009; Grobelna et al., 2010; Micskei and Waeselynck, 2011; Kaliappan and Konig, 2012).

However, these formal results continues with a problem: an average professional in the Software Engineering domain might not be able to either read or analyse the output generated by model checkers, due to the difficulty of the formalism present in the results. Few researches deal with this problem, as for example the study of (Mayerhofer et al., 2012).

To fulfil this limitation, (Baresi et al., 2012) proposed the formalization of a subset of UML 2.x models for the development of critical embedded systems. Called MADES UML, this subset is part

[1]http://www.omg.org/spec/FUML/Current

of a larger research effort carried out in the MADES European project (Bagnato et al., 2010). MADES UML uses TRIO (Ciapessoni et al., 1999) to assign formal semantics to its subsets and the $\mathbb{Z}$ot[2] model checker (Pradella et al., 2007) to analyze the union between these models and TRIO.

In this context, we along with the MADES team have proposed a contribution to the MADES UML and deals with the problem of how analyze and use results obtained by the model checker. For this purpose, we present a mapping to support this activity to trace information contained in the results and include them within the UML model.

We claim that by means of our mapping, it is possible to correlate the formal results' information (trace) — such as timestamp, state, transition, lifeline, class, etc. — and the UML model, previously created with a modeling tool. Once the mapping is done, the developer might analyze which elements of the UML model are present in the trace, where the error is — if the result is unsatisfied — and when it occurred. The debug process, where a developer can follow the code during runtime and see what is happened with the program, inspires such process. In our case, the developer will follow the formal results by seeing what is happening in the UML model. A support tool, integrating our mapping with Eclipse IDE[3] is also shown.

This paper is structured as follows: Section 2 describes the related works. Section 3 describes the developed traceability technique and Section 4 details how works our mapping, which is responsible for link the UML 2.x model and the formal results. Section 5 there is a brief explanation of the possible transformations that formal results might have in the UML model. Section 6 presents an example of how the traceability technique and its mapping operate. Section 7 describes the lessons learned during this study. Concluding remarks and future works are made in Section 8.

2 RELATED WORKS

The major of reseachers that assign a formal semantics to UML focus only on a single type of diagram and neglect the integration of different modeling elements. Well-known formalization of types of single diagrams refer to Sequence Diagrams (Storrle, 2003; Lund and Stolen, 2006; Micskei and Waeselynck, 2011), State Machines (Paltor and Lilius, 1999; Hammal, 2005) and Activity Diagrams (Borger et al., 2000; Cengarle and Knapp, 2005; Eshuis, 2006; Bouabana-Tebiel, 2009) as can be seen in Table 1, where column SD stands for Single Diagram.

Table 1: Related Works comparison.

Paper	SD	MD	1w	2w
(Paltor and Lilius, 1999) (Borger et al., 2000) (Storrle, 2003) (Hammal, 2005) (Cengarle and Knapp, 2005) (Eshuis, 2006) (Lund and Stolen, 2006) (Bouabana-Tebiel, 2009) (Micskei and Waeselynck, 2011)	x	-	x	-
(Saldhana and Shatz, 2000) (Diethers and Huhn, 2004) (Broy et al., 2006)	-	x	x	-
(Goldsby et al., 2006) (Mayerhofer et al., 2012)	x	-	-	x
(Remenska et al., 2013) MADES UML + This study	-	x	-	x

Considering the multi-diagrams (MD in Table 1) UML models, the number of proposals is limited. Among them, one can find UML Semantics Project (Broy et al., 2006) working with Activity, State, and Interaction Diagrams; the Vooduu approach (Diethers and Huhn, 2004) which works with State and Sequence Diagrams; and (Saldhana and Shatz, 2000) works with State and Collaboration Diagrams.

All works mentioned so far have an "one-way" process of transforming the UML (and its semantics assigned) to a different notation that can be interpreted by formal verification tools (1w in Table 1). On the other hand, finding a study that shows the opposite — proposes a technique that takes the formal results and transforms them to be displayed in UML model ("two-ways", in Table 1 as 2w) — is more difficult, because the studies usually stop by the results provided by model checkers. They do not show how developers could analyze these results.

About researches that deals with both transformation (2w), the study of (Goldsby et al., 2006) is an example of how might be possible to show formal results' information to developers. They use model checking in State Diagrams and then present the formal results in a Sequence Diagram. Another example is the work of (Mayerhofer et al., 2012), which shows how to create an extension of the fUML and both transformations using a dedicate trace. Despite being interesting, the process presented by them can be applied only with Statecharts. Note that both studies deal with only one UML diagram.

Compared to these studies, MADES UML is a multi-diagrams, currently assigning formal semantic to five types of UML diagrams. The research

[2]http://home.deib.polimi.it/pradella/Zot/

[3]http://eclipse.org/

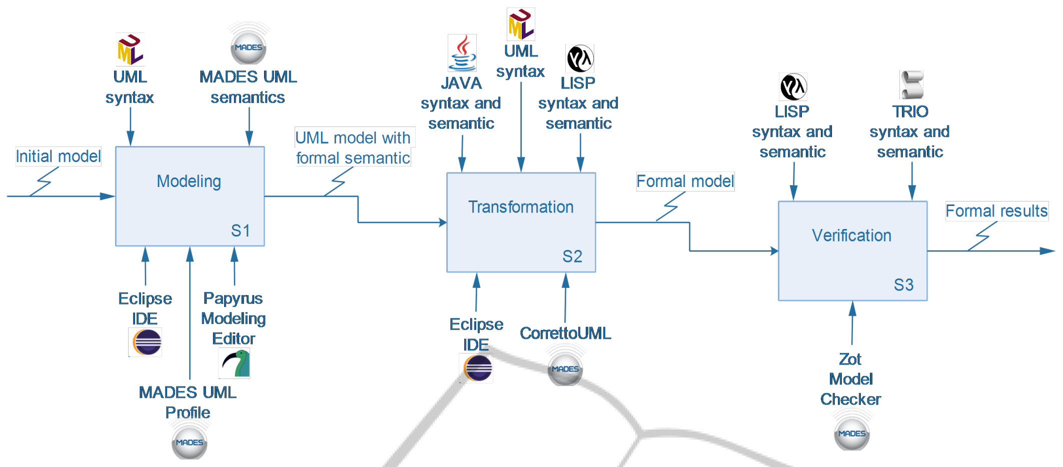


Figure 1: Relationship among MADES UML steps.

presented here aims to add in MADES UML the ability to present the formal results in the semi-formal UML model built with its five diagrams. Thus, as reported in the last line of the Table 1, the MADES UML is multi-diagram and now owns a "two-way" transformation, being able to show the formal results back to the UML model.

The study of (Remenska et al., 2013) is similar to the one present in this paper. They present a multi-diagram approach that uses Sequence Diagram to model the system and Activity Diagram to extract concurrency information. The authors present both transformations, but the way they present the formal results is different from what is proposed here. In their study, the formal results are displayed in a new model, also created using only Sequence Diagrams. In our study, the formal results are present in the "original" UML model itself, i.e. we use the same model that was created before the formalization. By doing this, we can use all the diagrams in the model to interact with the user. In fact, the debug process was the inspiration here. Instead of running the code and systematic follow what is happening during execution, here the user follows the trace "execution" and sees in the model — through highlights of UML elements — what the model checker tried to do and where it failed.

3 TRACEABILITY TECHNIQUE

While the process of assigning a formal semantic to UML is relatively well explored, the reverse process is not widely discussed. This paper proposes this reverse process for MADES UML, by using a mapping that allows the traceability of formal results back into the UML model. As can be seen in Figure 1, MADES UML is divided into three steps: (i) Modeling, (ii) Transformation, and (iii) Verification. Each step is described below.

Modeling. This step involves the creation of an UML model with MADES UML semantics. In order to create this model, it is used Papyrus Modeling Editor[4], the official UML2 graphical modeler within Eclipse IDE, which provides the UML syntax. Together with Papyrus, it is used an UML Profile especially developed for MADES UML, which provides its semantics.

Transformation. Herein it is performed a transformation of UML model into a LISP script, by using a support tool called ℂorrettoUML (Motta, 2012b). ℂorrettoUML was developed as a plug-in for Eclipse IDE. This tool was developed to bring together the UML model (and MADES UML semantics) with the model checker.

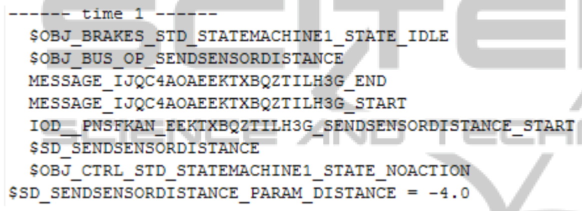
Verification. This step involves running ℤot model checker with the LISP script. ℤot was chosen because it can undestand TRIO syntax used in MADES UML. After the execution, the user should analyzes the formal result to check for possible problems.

Throughout this paper we have devised a running example. The chosen example is a car collision avoidance system (CCAS). The CCAS example is one of the case studies provided by industrial partners of the MADES European Project[5] (Motta, 2012a). The CCAS system analyzes the distance between a car A and car B, with car A behind car B. If the distance between them is less than the minimum distance allowed for a period of time, then the car A system slows it automatically until the minimum distance between them is respected again. Based on

[4]https://www.eclipse.org/papyrus/
[5]http://www.mades-project.org/

this scenario, a MADES UML model was created with eight diagrams contain Class, Object, State, Sequence, Interaction and Time Property Diagrams — the last one created for write the properties that user want to analyze.

To developed the mapping between formal results and UML model, we analyze the support tools provided by MADES UML and the formal results generated by ℤot. The Figure 2 shows an example of CCAS' formal results. The formal results' data presented in ℤot trace is not trivial for understanding. An expert must analyze it line by line and manually control where the information is going in the UML model. This is an error prone activity. In order to assist an expert we have created a traceability technique that uses our mapping. Also a support tool is under development[6].



```
------ time 1 ------
  $OBJ_BRAKES_STD_STATEMACHINE1_STATE_IDLE
  $OBJ_BUS_OP_SENDSENSORDISTANCE
  MESSAGE_IJQC4AOAEEKTXBQZTILH3G_END
  MESSAGE_IJQC4AOAEEKTXBQZTILH3G_START
  IOD__PNSFKAN_EEKTXBQZTILH3G_SENDSENSORDISTANCE_START
  $SD_SENDSENSORDISTANCE
  $OBJ_CTRL_STD_STATEMACHINE1_STATE_NOACTION
$SD_SENDSENSORDISTANCE_PARAM_DISTANCE = -4.0
```

Figure 2: Example of formal results generated by ℤot.

The traceability technique aims to add a fourth step to the MADES UML: (4) To enable the analysis of information contained in formal results within the UML model that was previously transformed, i.e., the transformation from "formal to UML model". The formal information should be represented in UML diagrams, so it might be understandable to the user who does not have (or have few) knowledge about formal verification, formal methods, model checkers, etc. The Figure 3 presents how our fourth step interact with MADES UML.

As can be seen in Figure 3, the traceability technique contains its support tool which includes two elements: the Mapping Checker and the Graphical Transformation Builder. Mapping Checker is responsible to make the correlation between formal and UML elements. Graphical Transformation Builder performs transformations in the UML model to represent each line in formal results inside the UML model. More information about Mapping Checker and Graphical Transformation Builder can be found in Sections 4 and 5 respectively.

The technique also contains three artifacts. The first one is the UML model created with MADES UML semantics. The next one is our mapping, which it is created when ℂorrettoUML transform the UML

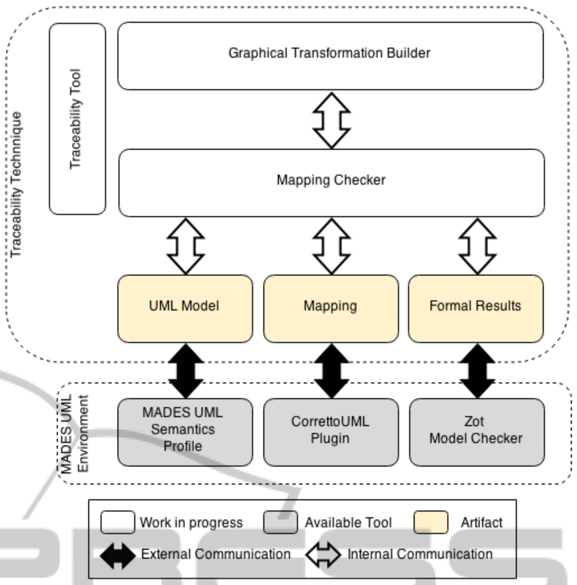


Figure 3: Traceability Technique and MADES UML.

model to the LISP script. New methods were created in ℂorrettoUML to make it possible create a mapping having information about both UML elements and their formal equivalent. Finally, the last element is the formal results generated by ℤot.

The first task of the technique is identify the elements present in formal results. From them, by using the mapping, the traceability technique can move forward and backward through each time node within the results. Each of these nodes has one or more formal element that was previously transformed by ℂorrettoUML.

Next, the formal element can be one of the following eleven different types of UML elements identified on the five diagrams supported by MADES UML: *State Diagram* - State or Transition; *Sequence Diagram* - Lifelines, Message or Parameter; *Class Diagram* - Class, Attribute or Operation; *Object Diagram* - Object; and *Interaction Overview Diagram* - Actions or Control Flows.

Therefore, the element is analyzed and the formal element is mapped to its correct UML element (one of eleven above). Finally, through the UML element the traceability technique can access its UML diagram and shown the formal results in the graphical representation.

The main artifact is the mapping, for the reason that without it, becomes unfeasible knowing how the connection between formal and UML elements. With that in mind, it is necessary to define what should be present in the mapping and how it will be used by the traceability technique.

[6]https://bitbucket.org/vinpereira/tracetool

4 FORMAL TO UML MODEL MAPPING

To create the mapping, we assume that when doing the formal verification of the model, the user only have access to UML model and formal results. Thus, a third artifact is required to unite these two types of environments. In order to make such union, we foresee a mapping that contains information that correctly identify the elements in both environments. In addition, this information must show that an element X in the formal environment has its equivalent in an element Y in the semi-formal environment.

The file that contains the mapping is defined as a file with inputs which can be assigned without major problems and extensible for future works in expansion to others tools — for example, MADES UML could uses another formal verification tool than ℤot. The file is created in *Transformation* step (see Section 3) when ℂorrettoUML is performing its actions, because this is the best moment for gather useful information about both modeling and formal environment. Thus, when running ℂorrettoUML, besides performing its pre-defined functions, the tool is upgraded to be responsible for gathering the information that we need to use our technique.

ℂorrettoUML's upgrade involves creation of methods that capture — at the moment of transformation — information considered important for the right correspondence between the modeling and formal environments (see pseudo code in Algorithm 1).

```
Input: MADESModel madesModel, File
       mapping
1  begin
2      foreach StateDiagram std in
       madesModel.getStateDiagrams() do
3          foreach State state in std.getStates()
           do
4              CorrettoState cstate = new
               CorrettoState(state);
5              Predicate pred =
               cstate.getPredicate();
6              mapping.write(pred.getName() +
               "," + state.getUmlId());
7          end
8          foreach Transition trans in
           std.getStates() do
9              CorrettoTransition ctrans = new
               CorrettoTransition(trans);
10             Predicate pred =
               ctrans.getPredicate();
11             mapping.write(pred.getName() +
               "," + trans.getUmlId());
12         end
13     end
14 end
```

Algorithm 1: Getting data for Mapping.

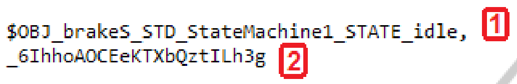
Algorithm 1 shows the core idea of collecting the required data from State Diagrams for our mapping. As ℂorrettoUML make the transformation from UML model to formal model, our method gather the ID and formal name for each element inside the State Diagram (Lines 2 to 13). At Line 2, the method iterate with each StateDiagram present in the UML model created with MADES UML semantics. In Lines 3 to 7, our method manipulate all states inside a State Diagram. At Line 3, our method gather each State in the State Diagram. Then, in Line 4 the method instanciate a *CorrettoState* (a semantic version of State, for MADES UML) with the given state. Line 5 also instanciate a variable, now a *Predicate* one that holds the TRIO temporal logic information for the state. Finally, both ID and formal name are written in the mapping file, as can be seen in Line 6, in order to be used later in the traceability technique. The ID cames from the UML state and the formal name is gather from the *Predicate*'s name, since the formal model created by ℂorrettoUML uses TRIO information. A similar process is done with all transitions inside a State Diagram (Lines 8 to 12). In addition, the same logic is applied for Class, Object, Sequence, and Interaction Overview Diagrams.

Thus, the new methods return a pair containing the formal name that the UML element assumes in LISP script and its unique identifier (ID) in the UML model. With an ID it is possible to recover the UML element in the graphical representation and in hierarchical treeview. Exceptions are the parameters of Sequence Diagram and attributes of Class Diagram, which do not exist in graphical representation of the model. Therefore, we decide that the mapping file must have a pair composed by the element "formal name" in formal environment and its ID in modeling environment.

It is important to understand that the mapping does not need all elements of each diagram. For example, when mapping the elements from a State Diagram, if does not exist two mapped transitions leading from state *A* to state *B*, then the transitions can be absent in the mapping. The same logic could be applied to elements from Sequence Diagram.

To assist in understanding our mapping, Figure 4 shows an example for State Diagram where it is illustrated how it is linked formal and semi-formal environments. The Figure 4 shows the "formal name"

(1) and the UML ID (2) for an element present both in formal results and UML model. This element is a representation of an object called *BrakeSystem* that has a State Diagram. Within this diagram exists a State Machine 1 and *Idle* is one of the states in the state machine. Thus, the *Idle* state has both information (formal name and ID) in mapping and our technique can represent *Idle* in the UML model when required.



```
$OBJ_brakeS_STD_StateMachine1_STATE_idle,
_6IhhoAOCEeKTXbQztILh3g
```

Figure 4: An example of mapping.

The formal name presented in Figure 4 could be understand without major problems but some transformations made by ℂorrettoUML are not so easy to understand. For example, a message (from Sequence Diagram) usually is transformed to *Message_FoVpUAOCEeKTXbQztILh3g*, where the second part (after the underline) is a serializable value. If we have two or more messages, then it is difficult to identify each message in the UML model. This problem is one good example that make us to use the ID as a par for the formal name.

Algorithm 2 presents a pseudo code that assists to illustrate our mapping. Our traceability technique first reads the line that user wants to analyze (Line 2) and extract the formal name from it (Line 3). If there is a formal name in the line, then Mapping Checker searches into mapping file for the formal name and returns the associated ID (Lines 4 and 5). Once the Mapping Checker has the ID then it searches in UML model for an element with the same ID (Line 9). Finally, our technique sends the necessary commands for Eclipse IDE to open the UML element that matches the trace line (Lines 10 and 11). At the end of this process, the UML element is selected and displayed both in graphical representation (Line 10 - editor) and in hierarchical treeview (Line 11 - view) to the software developer.

```
Input: File trace, StyledText viewer, String
       umlId, MappingChecker
       mappingChecker, EObject umlElement,
       Resource umlResource,
       IMultiDiagramEditor editor,
       ModelExplorerView view
1  begin
2      String lineText =
       viewer.getLineText(traceLine);
3      String formalName =
       trace.extractFormalElement(lineText);
4      if formalName.length() != 0 then
5          umlElementID =
           mappingChecker.getUmlId(formalName);
6      else
7          message("There is no formal element
           here!");
8      end
9      EObject umlElement = umlResource
       .getEObject(umlElementID.trim());
10     editor.openElementService(umlElement);
11     view.revealElement(umlElement);
12 end
```

Algorithm 2: Mapping TraceLine to UML Element.

5 FORMAL TO UML REPRESENTATIONS

The presentation of the formal results within the "original" UML model (the one that was initially transformed to LISP) involves different types of representations. An example of how this can happen is using colors in a State Diagram to represent the state accesses that occur at each instant of time. Another example is the use of stereotypes in a Class Diagram or the creation of comments in a Sequence Diagram to illustrate input and output values for a particular parameter.

Currently the traceability technique can select and shows the trace element in graphical representation (UML Model Editor) and in hierarchical treeview (Model Explorer View) using Papyrus[7] in Eclipse IDE. It is also possible to change colors in graphical representation.

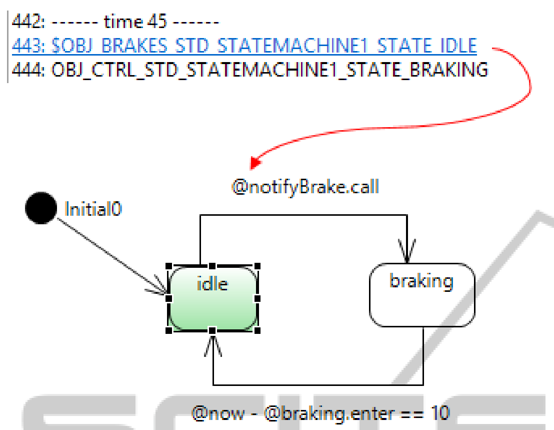
Once identified the element, the technique invokes a Graphical Transformation package that calls the format method and its representation type. The format can be a shape, an edge or a connector. The representation type options are color, stereotype, and symbol. The last two should be added in future versions.

We developed a Graphical Transformation Builder to perform the representation process of formal elements in their respective UML elements. This builder is responsible for finding the Papyrus format of the element under analysis. The UML elements can have the following three formats: (i) Shape, for classes, operations, attributes, states, objects, lifelines, and actions; (ii) Connector, for transitions; and (iii) Edge, for messages and control flows.

Based on which type of representation must be done (color, stereotype or symbol), the right method is called and perform the change in UML element. This

[7]https://www.eclipse.org/papyrus/

change occurs only in graphical representation and not in hierarchical treeview. The Figure 5 shows an graphical example for our traceability technique with a CCAS' State Diagram using MADES UML.



```
442: ------ time 45 ------
443: $OBJ_BRAKES_STD_STATEMACHINE1_STATE_IDLE
444: OBJ_CTRL_STD_STATEMACHINE1_STATE_BRAKING
```

Figure 5: Graphical example using CCAS' State Diagram.

In Figure 5, the user clicks on "state line" at time 45 in formal results. After that, the traceability technique — using our mapping — selects to him the right UML element, in this case a state called *Idle* in a State Diagram. The technique also changes the color of this state to help the user to understand what is happening. After this process, the user have a colored state in a State Diagram which represent the "state line" clicked before.

6 FROM TRACE TO UML MODEL

This section presents a resume of how the traceability technique is applied to CCAS example modeled using MADES UML. The Figure 6 shows a Class Diagram for the CCAS example.

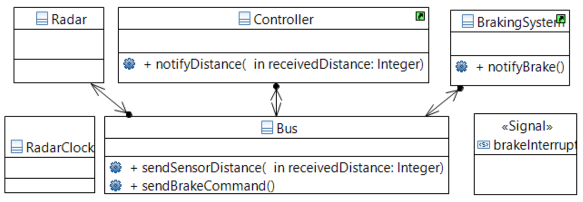

Radar
Controller
+ notifyDistance(in receivedDistance: Integer)
BrakingSystem
+ notifyBrake()
RadarClock
Bus
+ sendSensorDistance(in receivedDistance: Integer)
+ sendBrakeCommand()
«Signal»
brakeInterrupt

Figure 6: Class Diagram for the CCAS example.

The CCAS model go through a transformation into a LISP script using ℂorrettoUML tool and then a verification by ℤot model checker. Finally, the ℤot trace file — with the formal results — is opened in the prototype plug-in for this traceability technique together with the mapping and UML model. Figure 7 shows the CCAS example in Eclipse IDE with our plug-in.

As can be seen in Figure 7, the user clicks in line 926 at time 94 which contains an element called *OBJ_BUS_OP_SENDBRAKECOMMAND*. The user does this action in Trace Checker View (1). The action expands a node that contains an operation *sendBrakeCommand*() and select it in hierarchical treeview (2). Then, the equivalent Class Diagram (see Figure 6) is displayed and the respective operation (to the node) is also selected in the graphical representation (3). Therefore, now the user have a better understanding about line 926 in formal results.

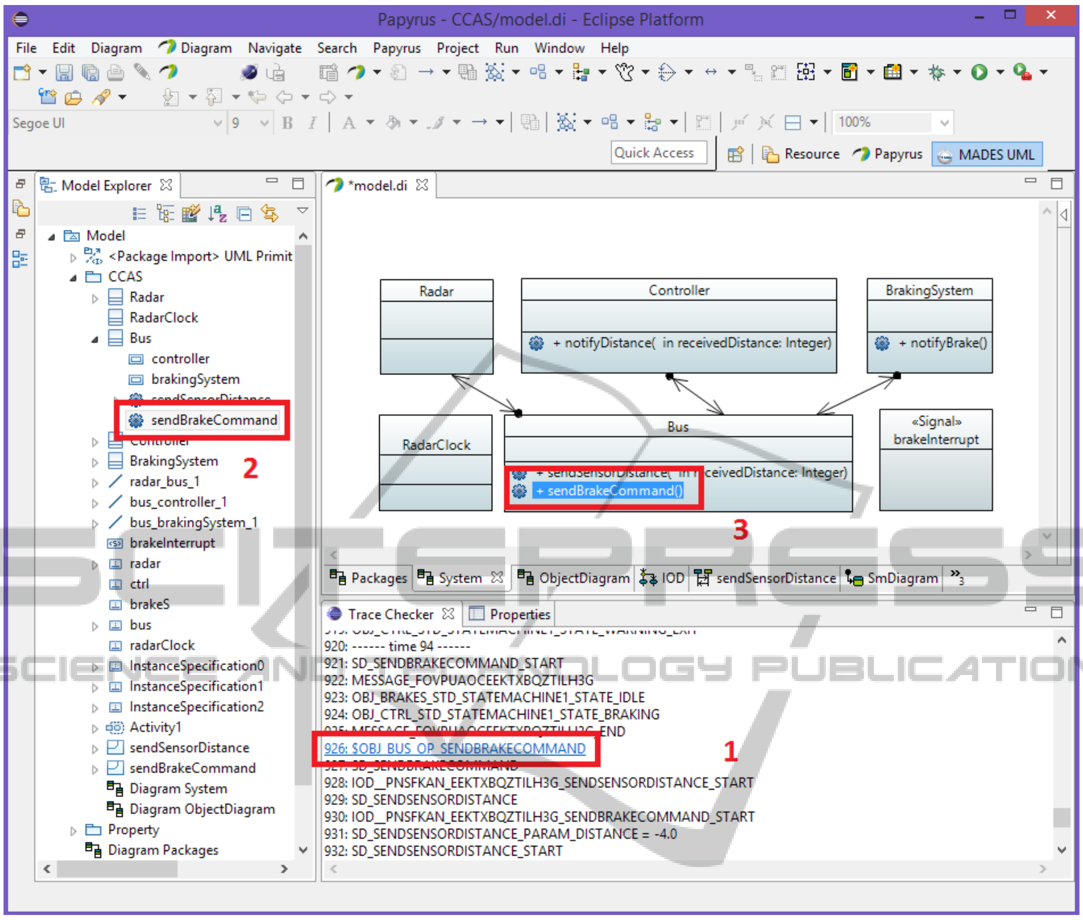
The visualization of the formal results and its manipulation through the act of clicking on the desired line is our way to guarantee that the mapping is correct. All this process could be transparent to user if required. To the user is important to see where the data is passing through the UML model, similar to what happens in the debug process. The current state is just a way to ensure that mapping is doing its working correctly.

Preliminary tests shows that this traceability technique can be used also with others UML diagrams (e.g. Component Diagram) and SysML, since their elements have ID like UML elements in MADES UML — at least when modeling in Papyrus. In addition, future works include the creation of mapping methods for other transformation tools besides ℂorrettoUML. Finally, ℤot trace is a textual file so in theory a formal result in textual format can be analyzed by the traceability technique and its mapping methods.

Another functionality for this mapping is a type of "model search". Here, the technique can find other occurrences of the UML element in analysis and show them to the user. For example, the user can see that a message in Sequence Diagram has a link to a particular operation in Class Diagram. For this to happen, first the model should allow this type of association. Then, the technique checks for any ID (in mapping) associated with the current UML element which user is looking. If there is then a "model search" view shows all occurrences and allows the user to navigate between them.

7 LESSONS LEARNED

During this study, several observations were noticed. Although *Papyrus Modeling Editor* is a robust graphical editing tool for UML in Eclipse IDE and provides a well-documented API, it is still under strong development. As result, some implementations



```
919: OBJ_CTRL_STD_STATEMACHINE1_STATE_WARNING_EXIT
920: ------ time 94 ------
921: SD_SENDBRAKECOMMAND_START
922: MESSAGE_FOVPUAOCEEKTXBQZTILH3G
923: OBJ_BRAKES_STD_STATEMACHINE1_STATE_IDLE
924: OBJ_CTRL_STD_STATEMACHINE1_STATE_BRAKING
925: MESSAGE_FOVPUAOCEEKTXBQZTILH3G_END
926: $OBJ_BUS_OP_SENDBRAKECOMMAND
927: SD_SENDBRAKECOMMAND
928: IOD__PNSFKAN_EEKTXBQZTILH3G_SENDSENSORDISTANCE_START
929: SD_SENDSENSORDISTANCE
930: IOD__PNSFKAN_EEKTXBQZTILH3G_SENDBRAKECOMMAND_START
931: SD_SENDSENSORDISTANCE_PARAM_DISTANCE = -4.0
932: SD_SENDSENSORDISTANCE_START
```

Figure 7: Traceability Example.

regarding transformation in UML elements may need to be updated in a near future. A new version of *Papyrus* — available during this study — helps to minimize this issue, but the problem still exists.

Another issue related with *Papyrus* is that the process to control UML elements in both graphical representation and hierarchical treeview is not trivial and it was necessary the collaboration of Papyrus' development team when they were available. In fact, this is a limitation of MADES UML, because it only works with *Papyrus*. The only way to model a system with MADES UML is through *Papyrus*, so anyone that wishes to work with MADES UML need to learn how to work with *Papyrus* and its possible issues.

One more limitation of MADES UML could be the fact that to properly model a system, one should learn about TRIO and its temporal logic operators, which it is not trivial. This knowledge is necessary if one wants to write properties and check if the model holds them or not. MADES UML provides a more simple approach to write these properties, by using a Time Property Diagram, but even with this diagram, it is still required to know temporal logic.

In terms of design, we have sought the simplicity. For example, the mapping file created in this study is intuitive to manage by people that may maintain the tool. Even if MADES UML were updated, such as adding a new diagram or the use of another model checker, make changes in our technique tends to not be complicated due to this simplicity.

The traceability technique works direct with diagrams present in UML model and the trace with formal results. Due to this, if UML model has a many diagrams or the diagrams have too much elements, or even the trace is a big file, then it will take more time to represent everything in the UML model for the user. Nevertheless, it will be less time consuming than the manual analyzes performed so far by the user. Therefore, scalability is a point of interest that should be examined in future work.

8 CONCLUSION AND FUTURE WORKS

This paper presented a traceability technique for MADES UML and its support tools. The technique focused on map the formal results produced by MADES UML tools to the "original" UML model. The paper described how the technique was defined, the requirements to use it, how to create and apply the mapping, as well as an example of how graphical representations may help the users to understand the information of the formal results.

The traceability technique presented here aims to assist MADES UML and its formal semantics filling the gap in how to trace back formal results to UML model. We achieve this by guiding the user through the analysis of formal results present by MADES UML formal verification tool. This enhances the users' understanding level about the results and thereby he/she can find possible defects more easily, fixing them and improving the UML model.

In spite of, the traceability technique has been presented together with MADES UML, theoretically our technique may be expanded to work with other UML diagrams and different model checkers. In addition, it could work with other studies on formalization of the UML semantics.

Regarding the technique improvements, the following topics are currently under development or analysis: ((i)) Improvements in traceability technique and its plug-in; (ii) Development of the Graphical Transformation Builder to display the data from formal results to user through graphical representations in the UML model; (iii) Application of the technique on case studies; (iv) Analysis of the possibility of using other tools besides $\mathbb{C}$orrettoUML and $\mathbb{Z}$ot; and (v) Feasibility of extending the technique and use it outside MADES UML environment.

We believe that with this technique, the user can obtain information concerning the formal results without having high knowledge about temporal logic, LISP, model checking, etc. The whole process exists, but the complexity can be decreased or even omitted from users, making "transparent" (if possible) any formal aspect.

ACKNOWLEDGEMENTS

The Brazilian funding agencies CAPES (Grant. No.: DS-7902801/D) and CNPq, through Science without Borders program (Grant. No.: 245715/2012-6), support this research.

REFERENCES

Bagnato, A., Sadovykh, A., Paige, R., Kolovos, D., Baresi, L., Morzenti, A., and Rossi, M. (2010). MADES: Embedded systems engineering approach in the avionics domain. In *HoPES'10*.

Baresi, L., Morzenti, A., Motta, A., and Rossi, M. (2012). Towards the UML-based formal verification of timed systems. In *FMCO'12*, volume 6957 of *LNCS*, pages 267–286. Springer Berlin/Heidelberg.

Borger, E., Cavarra, A., and Riccobene, E. (2000). An ASM semantics for UML activity diagrams. In *AMAST'00*, pages 293–308. Springer-Verlag.

Bouabana-Tebiel, T. (2009). Semantics of the interaction overview diagram. In *IRI'09*, pages 278–283, Piscataway, NJ, EUA. IEEE Press.

Broy, M., Crane, M. L., Dingel, J., Hartman, A., Rumpe, B., and Selic, B. (2006). 2nd UML 2 semantics symposium: formal semantics for UML. In *MoDELS'06*, pages 318–323. Springer-Verlag.

Cengarle, M. V. and Knapp, A. (2005). *Operational semantics of UML 2.0 interactions*. Technical Report TUM-I0505, Technische Universitt Mnchen.

Ciapessoni, E., Coen-Porisini, A., Crivelli, E., Mandrioli, D., Mirandola, P., and Morzenti, A. (1999). From formal models to formally-based methods: an industrial experience. *ACM TOSEM*, 8(1):79–113.

Diethers, K. and Huhn, M. (2004). Vooduu: Verification of object-oriented designs using UPPAAL. In *TACAS'04*, volume 2988 of *LNCS*, pages 139–143.

Eriksson, H. E., Penker, M., and Lyons, B. (2004). *UML 2 Toolkit*, volume 1 of *OMG Series*. Wiley Pub.

Eshuis, R. (2006). Symbolic model checking of UML activity diagrams. *ACM TOSEM*, 15:1–38.

Goldsby, H., Cheng, B. H. C., Konrad, S., and Kamdoum, S. (2006). A visualization framework for the modeling and formal analysis of high assurance systems. In *MoDELS'06*, volume 4199 of *LNCS*, pages 707–721.

Grobelna, I., Grobelny, M., and Adamski, M. (2010). Petri nets and activity diagrams in logic controller specification - transformation and verification. In *MIXDES'10*, pages 607–612.

Hammal, Y. (2005). A formal semantics of UML statecharts by means of timed petri nets. In *FORTE'05*, pages 38–52, Berlin, Heidelberg. Springer-Verlag.

Hutchinson, J., Whittle, J., Rouncefield, M., and Kristoffersen, S. (2011). Empirical assessment of MDE in industry. In *ICSE'11*, pages 471–480.

Kaliappan, P. and Konig, H. (2012). On the formalization of UML activities for component-based protocol design specifications. In *SOFSEM'12*, volume 7147 of *LNCS*, pages 479–491. Springer Berlin-Heidelberg.

Lund, M. S. and Stolen, K. (2006). A fully general operational semantics for UML 2.0 sequence diagrams with potencial and mandatory choice. In *FM'06*, volume 4085 of *LNCS*, pages 380–395.

Mayerhofer, T., Langer, P., and Kappel, G. (2012). A runtime model for fUML. In *MRT'12*, pages 53–58.

Micskei, Z. and Waeselynck, H. (2011). The many meanings of UML 2 sequence diagrams: a survey. *Software and Systems Modeling*, 10:489–514.

Motta, A. (2012a). *Logic-Based Verification of Multi-Diagram UML Models for Timed Systems*. PhD thesis, Politecnico di Milano - Dipartimento di Elettronica e Informazione.

Motta, A. (2012b). Towards the verification of multi-diagram UML models. In *ICSE'12*, pages 1531–1534. IEEE Press.

Paltor, I. P. and Lilius, J. (1999). Formalising UML state machines for model checking. In *UML'99*, pages 430–445, Berlin, Heidelberg. Springer-Verlag.

Pradella, M., Morzenti, A., and Pietro, P. S. (2007). The symmestry of the past and of the future: bi-infinite time in the verification of temporal properties. In *ESEC-FSE'07*, pages 312–320. ACM.

Remenska, D., Templon, J., Willemse, T. A. C., Homburg, P., Verstoep, K., Casajus, A., and Bal, H. (2013). From UML to process algebra and back: An automated approach to model-checking software design artifacts of concurrent systems. In *NFM'15*, volume 7871 of *LNCS*, pages 244–260. Springer Berlin Heidelberg.

Rossi, C., Enciso, M., and de Guzman, I. P. (2004). Formalization of UML state machines using temporal logic. *Software and Systems Modeling*, 3(1):31–54.

Saldhana, J. A. and Shatz, S. M. (2000). UML diagrams to object petri net models: An approach for modeling and analysis. In *SEKE'00*, pages 103–110.

Snook, C. and Butler, M. (2006). UML-B: Formal modeling and desing aided by UML. *ACM TOSEM*, 15:92–122.

Storrle, H. (2003). Semantics of interactions in UML 2.0. In *HCC'03*, pages 129–136. IEEE Computer Society.