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An Automated Transformation Approach for Requirement Specification

Amel Benabbou[a*], Safia Nait Bahloul[a], Philippe Dhaussy[b]

[a]*Litio Laboratory, IDTW team, University Oran1 Ahmed Ben bella, BP 1524, El -M'Naour, 31000Oran, Algeria*
[b] *Lab-STICC Laboratory, MOCS team, ENSTA-Bretagne, France*

Abstract

Use cases are often useful in capturing requirements by defining goal-oriented set of interactions between the system and its environment. Formalization of precise requirement is then important for context-aware verification based on use cases scenarios in the form of contexts. In this paper, we propose a high-level formalism for expressing requirements based on interaction overview diagrams that orchestrate activity diagrams automatically transformed from textual use cases. Our approach is qualified as context-aware model-checking; it supposes the availability of the system model as concurrent communicating automata and a specification language for describing requirements. Specification of requirements is performed through transformation phases to generate intermediate artefacts able to reduce the semantic gap between informal and informal requirement. The transformation is based on meta-models implemented in Ecore environment, algorithm and rules are defined using QVT Relational language, and primarily illustrated on an example.

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Keyword: Model-checking, use case, context-aware verification, meta-models, Interaction Overview Diagram

1. Introduction

In design of complex systems, more time and effort are spent on verification task. Model-checking is a verification technique based on models that describe the possible behaviours of systems. Its inputs are the System Under study (SUS) model and a formal characterization of properties (requirements). The principle is to explore all the model behaviours and check whether such properties are true or not. An exhaustive exploration of the model behaviours leads to the problem of the state explosion problem [1]. The context-aware

* Corresponding author.
E-mail address: benabbou_amel@yahoo.fr.

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verification has been introduced [2] as a technique to reduce this problem. The idea is based on state space decomposition by closing the SUS with a well defined finite and acyclic environment described through particular use cases, called context (with which the system interacts). The objective is to guide the model-checker to concentrate its efforts on a relevant restriction rather on the whole of the model. This technique enables at least three different decomposition axes: a) the environment can be decomposed in contexts; b) contexts enable the automatic partitioning of the state-space into independent verification problems; c) the requirements are focused on specific environmental conditions in which they should be satisfied.

Based on this idea, our approach fits in a context-aware verification methodology based on a domain-specific language called CDL (Context Description Language) used for the specification of context in the form of use cases scenario [3]. A context *C* is defined as a simple MSC (*Message Sequence Chart*) [4] *M* composed of a sequence of emission events *a!* and reception ones *a?*. CDL structure is inspired from the *Use Case Chart* proposal [5] and is hierarchically constructed in three levels: Level-1 is a set of constructs which describes hierarchical activity diagrams where either alternative (alternative/merge) or concurrency (fork/join) (parallel *par*"||"), between several executions is available. Level-2 is a set of scenario diagrams organized in alternatives (*alt* "+"). Each scenario is fully described at Level-3 by sequence diagrams (*seq* ";"). For more description of CDL language, see the published articles [6, 7] available on http: //www.obpcdl.org. The CDL structure is given in Fig1 as follows:

```
cdl example_cdl is   // level-1
{
    main is { Dev1 || Dev2 || Dev3 }
}
activity Dev1 is {   //level-2
   {
event goIni tDev ; event login 1 } ;
   {
      event ackLog ; event operate ;
       {
        { event ackOperate ;  event
logout1    }
     [ ] event nackOperate ;  //Level-3
     }
[ ] event nackLog . . .
} }
```

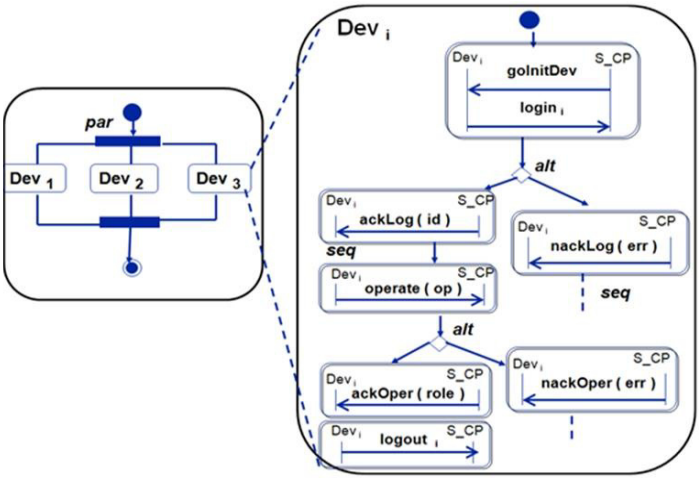

Fig. 1. An example of CDL Model: Textual and Graphical version

Within a CDL specification, the behaviour of each actor is considered as series of scenarios. Users are required to identify the behaviour of each actor to formalize it in the form of a CDL scenario. This is a manual process that requires a significant effort and good knowledge of CDL syntax and semantic. There is a semantic gap between the textual descriptions of use cases and CDL models. Moreover, produce an exhaustive description of events seems to be a complicated task. Although CDL has been evaluated to solve several state explosion cases [8], however, the industrial feedback reports that it is perceived as a low-level language, restrictive and difficult to grasp on complex models. Then, we need to express environmental scenarios at a higher level of abstraction that maps better to the specification engineers. The new UML interaction diagrams are suitable for high-level specifications. Interaction Overview Diagrams (IOD)s constitute a high-level structuring mechanism that we use to synthesize scenarios. In our approach, IODs are used to: i) capture the behaviour of the system, ii) describe the messages flow in the system and iii) describe the structural organization of CDL.

In this paper, we are concerned by the following contributions: 1) a process to generate in an automated

way an activity diagram from textual use case performed by a model transformation that conforms to UML meta-models, defined in this paper; 2) a process of transformation into IOD for each actor and using gates to relate IODs with system boundaries to facilitate interface specification; 3)The orchestration of several actors and related use cases are specified by the requirements engineer using IODs that are closely related to the CDL structure and easily transformed into CDL contexts. The objective of this work is to facilitate contexts elaboration by producing intermediate models between use cases and CDL. This allows the automatic generation of CDL models from IODs and then assists the specification engineer to accomplish his task.

The paper is organized as follows. Section 2 is an overall presentation of the methodology our context-aware approach. We give our meta-models and transformation rules in section 3 Orchestration and automation aspects are given in section 4 and 5. Related work and limits are presented in section 6. Finally, a conclusion closes the paper in section 7.

2. General overview of the context aware verification approach

In our model-checking approach, the SUS is modelled using the formal language Fiacre [9] through automata. The surrounding environment and requirements are specified using the CDL formalism. Properties are formalized and verified on the elaborated model by the model-checker OBP (Observer Based Prover) [14].

Our work focuses on context description based on informal use cases. The specification of these use cases should be controlled through a set of writing rules and instantiated from use cases meta-models. This control is performed so as to reduce ambiguity and facilitate the generation of behavioural models (CDL) from such instances. This allows precisely synthesizing the structure of our context description formalism as activity diagrams (with both actors and system partitions) by a set of transformation rules using interaction meta-model. Because contexts focus on the system boundaries, the system partition is replaced by gates connected to the actors' interactions. IODs express use cases coordination at the higher level. The whole set of interaction diagrams constitute the high-level specification point of view from which CDL contexts are generated. The generated CDL models are used directly by OBP tools to assess the context part of the model submitted for verification. The double arrows between meta-models transformations mean the ability to establish traceability links to ease the debugging process. Fig 2 schematizes the whole context-aware verification methodology [15].

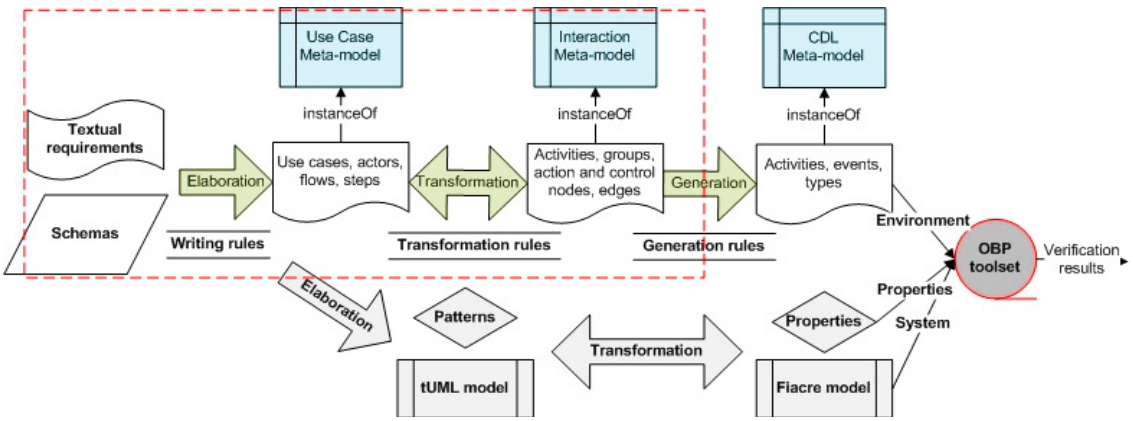

Fig. 2. Methodology for a context-aware verification process

It's out of the scope of this paper to illustrate the whole verification process; rather we focus on application of our proposal of automated transformation rules to generate contexts (area squared with red in Fig 2).

3. Context elaboration

In this section, we give our meta-models, transformation rules, resulting diagrams and generated IODs.

3.1. Meta-models

We need to have meta-models conforming to the UML meta-models in order to ease the exchange of models produced by various UML tools. But we need also to keep the meta-models concise and sound. Hence, our use case and activity diagram meta-models borrow as much as possible constructs and hierarchy from those in UML 2.4.1[10]. However, we have simplified and tuned them for our own purposes. In Fig4, a use case is associated to one or many scenarios, called *BehaviourFlow*, some of them are main scenarios. A *BehaviourFlow* is made of an ordered sequence of *Step*s: *StepGroup* contains an ordered sequence of *Step*, including other *StepGroup*s recursively. A *Step* may be also *TriggerStep* (the condition triggering a *BehaviourFlow*), *IncludeStep* (the step contains another *BehaviourFlow*), *ReturnStep* (a return to another *Step*). A *StepGroup* is a *LoopGroup* or a *ConditionalGroup*. A *BehaviourFlow* can have extension(s), which are alternatives that describe different steps than those in a success scenario, and it applies recursively. A *child BehaviourFlow* refers to a *parent BehaviourFlow* and states the branching point where the extension condition (a *TriggerStep*) should be checked: a *single* branching point or a *bounded* interval; in the latter case, the condition can occur at any steps within the bounds and triggers the *child BehaviourFlow*.

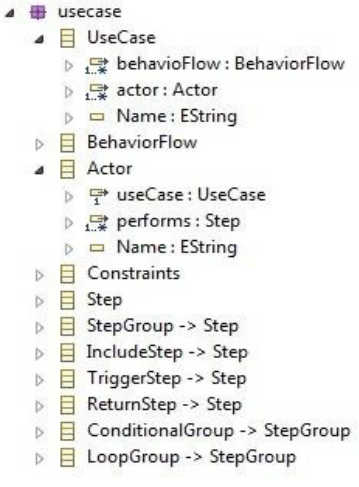

Fig. 3. Use case Meta-model elements in Ecore

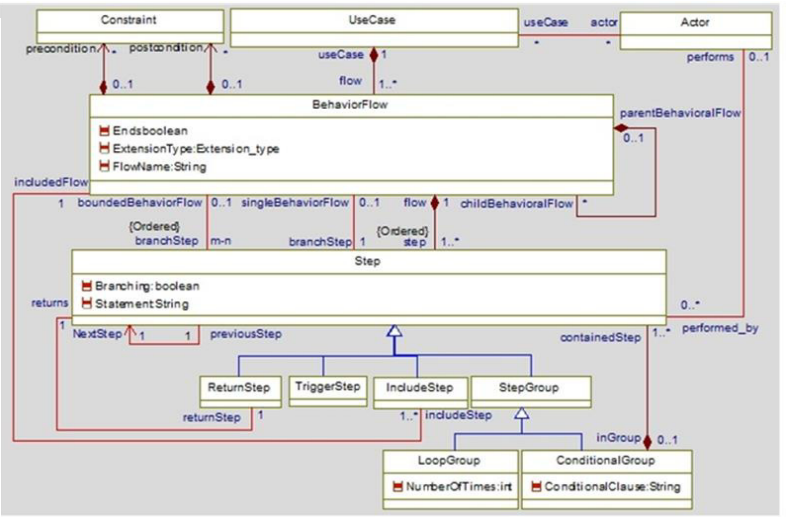

Fig. 4. Use case Meta-model

The second meta-model that we use is that of activity diagram. In this meta-model, *Activity* is a generalization of *ActivityNodes* and *ActivityEdges* for linking between them. *ActivityNode* is either a simple *action*, a *ControlNode (decision, fusion, etc)* or some specialization of groups of *StructuredActivity* in *looped* and *conditional* forms. An *ActivitygGroup* generalizes also the *partition* notion that gathers activities for each actor. See Activity meta-model given as follows:

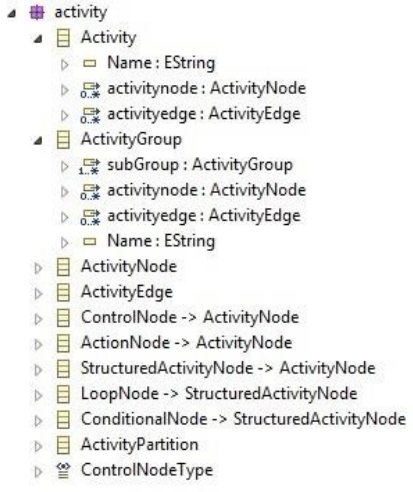

Fig. 5. Activity Meta-model elements in Ecore

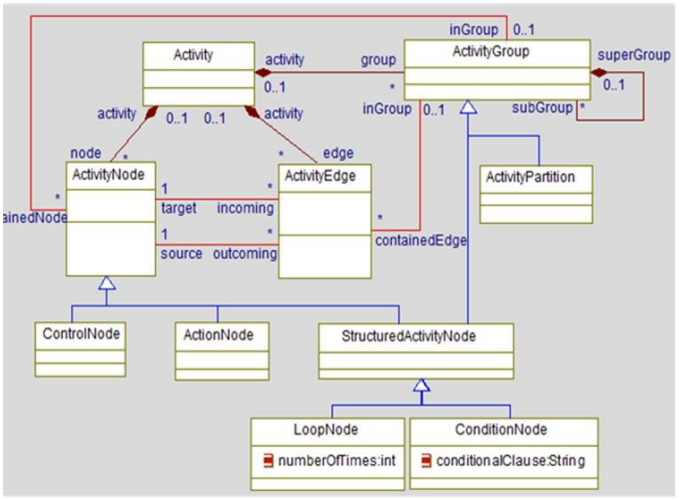

Fig. 6. Activity Meta-model

3.2. Transformation process

Transformation of textual use cases to activity diagrams is realized in three phases as follows:

1) *Basics creation (BCRi rules)*: a use case generates an activity diagram, each actor generates a partition and a partition for the system is added.
2) *Activity node creation (ANRi rules)*: control nodes, structured nodes and action nodes are created from corresponded element in use case. For example, in this phase steps are transformed to actions.
3) *Activity edge creation (AERi rules)*: connecting activity nodes with control flows. For example, linking initial node to the first element.

We present in a pseudo-code form, the algorithm (implemented yet in QVT-Query View Transformation- relational language) of the transformation process where variables are typed as model elements in the use cases meta-model (*ucMM*::) and the activity meta-model *acMM*::). A summary of rules is given bellow, but the complete transformation list is given in [11].

Algorithm Transform (uc): activity
Input uc: *ucMM::UseCase* //The use case to be transformed into activity
Output activity: *acMM::Activity* //The result generated activity from the input use case
declare
behaviourFlow : ordered sequence(*ucMM::Step*) // The main flow of the use case
extentionFlows : Set(*ucMM::BehaviourFlow::childBehaviourFlow*) // The flows extensions of the use case
groups:Set(*acMM::ActivityGroup*) // the group of sub activities in activity
initialNode : *acMM::ControlNode::InitialNode* // The initial node of the activity
partitions: Set(*acMM::ActivityPartition*) // The partitions of the activity
finalNode: *acMM::ControlNode::ActivityFinalNode* // The final node of the activity
edge: *acMM::ActivityEdge* // The link that rely elements in activity.
Begin
activity := *ucMM::Activity*.create // rule **BCR 1**: a *use case* generates an *activity diagram*
activity.name := uc.name

partitions.add(CreatePartitionForEachActor(uc)) // **rule BCR 2**: an *Actor* generates a *Partition*
partitions.add(CreatePartitionForSystem(uc)) // a system partition is added
activity.partition.addAll(partitions)
groups.add(CreateGroupFor Each *BehaviourFlow*(uc)) // **rule BCR3** : *BehaviourFlow* generates an *ActivityGroup*
activity.group.addAll(groups)
initialNode: = *acMM::InitialNode*.create // **rule BCR 4:** a main *BehaviourFlow* generates an *InitialNode*
activity.node.add(initialNode)

For all *behaviourFlowStep* (stp : ucMM::Step) {

Rule ANR3: A *Step* in a *BehaviorFlow* generates, generally, an *ActionNode* (in the *ActivityGroup* generated from the *BehaviorFlow*) with the following exceptions:
if (stp.isInstanceOf(ucMM::Step) **then** invoke **ANR3** (uc, stp, activity)

if (stp.isInstanceOf(*ucMM::TiggerStep*) **then** invoke_rule_ A**NR3.1** (uc, stp, activity) **end**
Rule A**NR3.1:** Generates a *DecisionControlNode* associated to the *ActivityGroup* and an *ActivityEdge* having as a source this *DecisionControlNode* and as a pending target the first *ActivityNode* of the *ActivityGroup.*

if (stp.isInstanceOf(*ucMM::StepGroup*) **then** invoke_rule_ A**NR3.2** (uc, stp, activity) **end**
Rule ANR3.2: A *StepGroup* (either a *LoopGroup* or a *ConditionalGroup*) generates a *StructuredActivityNode* (either a *LoopNode* or a *ConditionalNode*), then rule ANR3 is applied recursively to the *StepGroup*.

if (stp.isInstanceOf(*ucMM::ReturnStep*) **then** invoke_rule_ A**NR3.3** (uc, stp, activity) **end**
Rule ANR3.3: The first *ReturnStep* to a given *Step* generates a *FusionControlNode* and an *ActivityEdge* having as source this *FusionControlNode* and as target the *ActivityNode* generated from the given *Step*; another *ReturnStep* to the same *Step* does not generate anything else.

if (stp.isInstanceOf(ucMM::*IncludeStep*) **then** invoke_rule_ A**NR3.4** (uc, stp, activity) **end**
Rule ANR3.4: The first *IncludeStep* to a given *BehaviorFlow* generate a *FusionControlNode* and an *ActivityEdge* having as source this *FusionControlNode* and as a target the first *ActivityNode* from the Activity Diagram; another *IncludeStep* to the same *BehaviorFlow* does not generate anything else.
}
For all extentionFlows {invoke _rule_**ANR1**

Rule ANR1: Generate *FusionControlNode* for the *ParentBehaviorFlow* (from a *DepartureStep m* to an *ArrivalStep n*) at the first place of the *ActivityGroup* generated from the *c h i l d BehaviorFlow* and an *ActivityEdge* having as source this *FusionControlNode* and as a pending target the second *ActivityNode* of this *ActivityGroup*.

For all extentionFlowsStep stp:ucMM::Step invoke _rule_**ANR.2**

Rule ANR2: If N extension, generate N *DecisionControlNode* for each step in the interval [*m, n*] of the *p arentBehaviourFlow*, N (*n-m+1*) *DecisionControlNode* are generated in total.
Generate N*(n-m+1) ActivityEdge, hence each* having as source its corresponding *DecisionControlNode* and as a pending target the first *FusionControlNode* of the *ActivityGroup* generated from the *c h i l d BehaviorFlow*).
}
ResolvePending(uc, activity) invoke _rule_**ANR4**

Rule ANR4: Resolve all pending targets of any *ActivityEdge* thanks to the completion of the *ActivityGroup.*

finalNode := ucMM::ActivityFinalNode.create // Apply rule **ANR5:** generate an *ActivityFinalNode* for each *BehaviourFlows* that ends (Ends=true) such as each *ActivityFinalNode* is added to its corresponding *Activity-Group*
activity.node.add(finalNode)
invoke_rule_ENR (uc, activity) // rules **AER**
edge : = createEdge(uc, activity)

AER1*: Generate* an *ActivityEdge* having as source the *InitialNode* and as target the first *ActionNode* from the *ActivityGroup* generated from such *BehaviourFlow*.

AER2: Generate an *ActivityEdge* having as target its *ActivityFinalNode* and as source the last *ActivityNode* of the *ActivityGroup* generated from such *BehaviourFlow*.

AER3: generate one or N *ActivityEdge* for linking together the generated *DecisionControlNode*. The N-th *ActivityEdge* links the last *DecisionControlNode* to the *FusionControlNode* associated with the *Step* in question if this *FusionControlNode* exists else to the *ActivityNode* generated from such *Step* (either an *ActionNode* or a *StructuredActivityNode*)

AER4: For each *ActionNode* generated from a non-ending *Step* (being not followed by a *ReturnStep* or *End*), generates an *ActivityEdge* having as source the *ActionNode* and as target, either the next *ActionNode* if no *DecisionNode* or *FusionControlNode* are associated to, or the first of these *ControlNode*s.

return activity
End

3.3. A running example

We use a famous concurrency problem to illustrate a typical model-checking process to introduce our proposal: Lamport's problem of two neighbours *Alice* and *Bob* that share a yard in an exclusive manner [12]. This problem is presented within the following algorithm:

Alice :

```
while ( true )          {
flagAlice = up ;
            while      ( flagBob == up)  skip ;
catInYard ;
flagAlice = down ;

}
```

Bob :

```
while ( true ) {
flagBob = up ;
            while      ( flagAlice == up)          {
            flagBob = down ;
                        while ( flag Alice==up)        skip ;
    flagBob = up ; }
    dogInYard ;
    flagBob = down ; }
```

According to our context-aware verification approach, we need the following artefacts: i) the system is translated in the form of automata. ii) Contexts are given through use cases for example "*Alice's cat comes home*" (given in Fig7). iii) A property to be checked, formalized using CDL, for instance the mutual exclusion property of the simultaneous existence of *Alice*'s cat and *Bob's* dog in the yard.

Main success scenario

1. Alice's cat asks for coming home.
2. Alice asks the system to lower her flag.
3. Alice asks the system to lower her flag.
4. The system lowers Alice's flag.

The use case ends.

Extensions:

1a. Phone call

1. The phone rings.
2. The system provides Alice with a phone call.
3. Alice talks on the phone.
   Return to step 2.

2a. Silly cat

1. Alice's cat goes back to the yard.
   The use case ends.

Extensions

1-3a. Cancelling

1. Alice cancels the use case.
   The use case ends.

```
<UC:UseCase
    xmi:version="2.0"
    xmlns:xmi="http://www.omg.org/XMI"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:UC="http://fr.ensta.amel.usecase"
    xsi:schemaLocation="http://fr.ensta.amel.usecase
usecase.ecore"
    Name="Alice's cat comes home">
  <behavioFlow
      ends="true"
      FlowName="Main"

branchStep1="//@behavioFlow.0/@childBehaviorflow.2/@step.1"
      Type="main">
    <step xsi:type="UC:TriggerStep"
        Branching="true"
        Statement="Alice's cat asks for coming home"
        performedBy="//@actor.0"
        nextStep="//@behavioFlow.0/@step.2"/>
    <step Branching="true"
        Statement="Alice's cat asks for coming home"

boundedBehaviorFlow="//@behavioFlow.0/@childBehaviorflow.2"
        performedBy="//@actor.0"/>
    <step Statement="Alice opens the door to her cat"

boundedBehaviorFlow="//@behavioFlow.0/@childBehaviorflow.2"
```

Fig. 7. "*Alice's cat comes home*" use case and a part of generated XMI file within Ecore environment

After applying our transformation rules on the running example, we show in Fig 8 the generated activity diagram as follows:

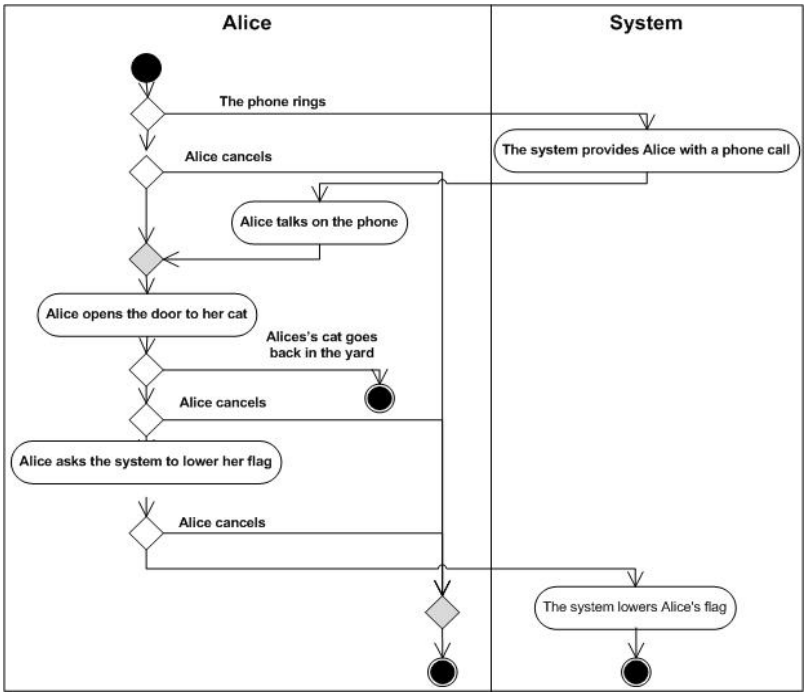

Fig. 8. The generated activity diagram for "*Alice's Cat goes home*" use case

3.4. Specification of the system boundaries and Orchestration of activity diagrams with IODs

The resulting activity diagrams are transformed into IODs, focusing only on the actor's partition and its interactions with the system. To do this, we need to use boundaries to establish the interface (focusing on exchanged messages) between the system and its environment. Our IODs are established as follows: first, we recommend writing actions with simple sentences having a subject, a verb, and eventually an object. Actions without the system as a subject or an object (such as *Alice opens the door to her cat*) are out of the scope and will be discarded. Compound actions (such as *Alice releases her cat* and *warns the system*) have to be split in simple actions (such as *Alice releases her cat* - out of the scope - and *Alice warns the system*) - within the scope). When the simple sentence rule is applied, it is easy to process *ActionNodes* and recognize if the system is a subject or an object and eventually discard the *ActionNode* from the system scope. The same rule applies to *DecisionControlNodes*: if the condition includes any reference to the system, the *DecisionControlNode* will be kept, else discarded. Any incoming or outgoing *ActivityEdges* to a discarded *ActivityNode* (*Action* or *Decision*) will be discarded too, and the pending *ActivityEdge* reconnected to the following *ActivityNode* (that might be discarded later, forcing the *ActivityEdge* to be reconnected). At the end, a set of nodes are discarded. Moreover, there are *ActivityEdges* crossing the boundary and because the system partition is not included, such *ActivityEdge* will be cut and replaced by a pair of related gates, one is the actor's model and another is the system model. The IOD generated from the activity diagram of the use case "*Bob releases a dog*" is given in Fig. 9.

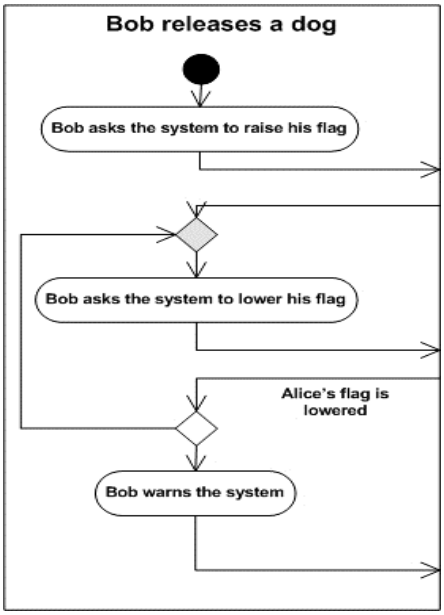

Fig. 9. IOD corresponding to the use case "*Bob releases a dog*" and System Boundaries

After this step, the specification engineer has to identify and gather all gates pair in the Interface Requirements Specification Document. We expect to have an interface specification including types, messages and events. For our purposes, the interface specification has to be abstracted as a list of UML Messages whose semantic is simply the trace <*sendEvent, receiveEvent*>.

The last step towards elaborating contexts is to organize all interactions in higher-level diagrams. Our second type of IODs fits for this purpose. Such IODs focus on the overview of the flow of control where the nodes are (inline) *Interactions* or *InteractionUses*. The specification engineer is free to orchestrate the interactions of all actors from different system viewpoints or according to his engineering needs. He should be aware of the structure of the CDL language: using concurrency at the higher level, corresponding to CDL Level-1 and fully describe scenarios by sequence diagrams, corresponding to CDL Level-3, for example. With these recommendations, there will be no difficulties to generate CDL diagrams from these IODs.

4. Conclusion and future work

We have presented an overview of a part of a methodology aiming to facilitate formal verification from informal requirements. Thanks to elaboration and transformation activities, the semantic gap between informal and formal requirements is reduced and engineers are helped towards formal verification. We have implemented our rule transformation and applying it on a famous academic example. However, what it remains in the future is the validation purpose on an industrial case study to check completeness and correctness of our transformation rules. We will also invest the theoretical soundness of the transformation and our team started a research thread using the Coq theorem prover in order to express assertions on the transformations and checks proofs on. As future work, we plan to continue towards the fully automation of the subsequent phases in the verification methodology presented in this paper until the automatic generation of CDL models.

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