Development of a Tool for Extended Place/transition Net-Based Mutation Testing

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Abstract
This paper shows a tool for EPN (Extended Place/transition Net)-based mutation testing to evaluate and improve the quality of a test suite for concurrent software. The tool includes functions for (1) construction of an original EPN that represents the expected behavior of concurrent software under test, (2) construction of mutant EPNs by applying mutation operators to the original EPN, (3) execution of a test suite on each mutant EPN in order to calculate its mutation score, and so on.

Keywords: Software Testing, Mutation Testing, Model-Based Testing, Vienna Development Method

1. Introduction
The techniques to create a test suite (a set of test cases) based on formal models that represent specifications of SUT (Software Under Test) is called MBT (Model-Based Testing), and they can be introduced into a software testing process in order to systematically evaluate and improve the reliability of large SUT. The effects of MBT depend on the quality of a test suite, that is, the capacity of a test suite to find possible failures in SUT. MBMT (Model-Based Mutation Testing) was proposed as a technique to evaluate and improve the quality of a test suite of MBT.

In MBMT, mutant models are created by inserting an intentional failure into a formal model of SUT, and then the ratio of killed mutant models (that is, mutant models whose failures have been found by a test suite) is calculated to evaluate the quality of the test suite. The ratio is called a mutation score, and it can be improved by modifying the test suite based on designs that have not been killed.

For example, some studies showed MBMT using directed graphs or automata as their formal model. On the other hand, we have been investigating PNBMT (PN-Based Mutation Testing), that is, MBMT using a PN (Place/transition Net) that can represent concurrent behavior of SUT. However, a PN cannot represent actions (data processing that should be executed with state transitions of SUT) and guards (conditions to get transitions fireable). The actions and guards play an important part especially when MBMT (also MBT) is applied to SUT including complex data processing.

In this paper, we propose an EPN (Extended Place/transition Net), that is, a PN that is extended by...
introducing VDM++ (a formal specification description language for VDM (Vienna Development Method))⁶ in order to define actions and guards, and then, we show a tool that we have been developing to support EPNBMT (EPN-Based Mutation Testing). The tool is supposed to be used by test engineers. This study is based on the idea that the effectiveness of PNBMT will be improved by achieving (a) the higher representation power of a PN by actions and guards, and (b) the semi-automation by our tool.

The rest of this paper is organized as follows. In section 2, we propose an EPN. Section 3 shows the principal functions of our tool according to the procedure of EPNBMT. Section 4 gives a conclusion and future work.

2. EPN (Extended Place/transition Net)

In this section, we propose an EPN, that is, a PN that is extended by introducing VDM++ (a formal specification description language for VDM) in order to define actions and guards.

An EPN consists of a PN and VDM specifications. The PN is a traditional formal model suitable for representing expected state transitions of SUT including concurrent behavior. It consists of places to represent the states of components of SUT, transitions and arcs to represent the change of states of SUT, and tokens to represent current states or resources of the components. The VDM specifications are a set of VDM++ codes to represent actions and guards that are given to transitions of the PN if necessary. The actions can represent data processing that should be executed with state transitions of SUT, and the guards can represent conditions to get transitions fireable.

In an EPN, a state of SUT corresponds to a set that consists of a marking (that is, a distribution of tokens on a PN) and values of instance variables (that is, variables that are defined in VDM specifications and are used in actions and guards), and a state transition of SUT corresponds to the change of a marking and values of instance variables that results from the firing of a transition of a PN.

A simple example of an EPN is shown in Fig. 1. The initial marking of the EPN is expressed as \([0,1,1,0, v=0]\). The action "\(v:=v+1;\)" is attached to the transitions \(t_1, t_2, t_3\), and it is executed by the firing of each transition. Additionally, the guards "\(v \mod 2=0\)" and "\(v \mod 2=1\)" are attached to \(t_1\) and \(t_3\), respectively. \(t_1\) and \(t_3\) can be fired when there are tokens for their ingoing arcs and their guards are satisfied. For example, only \(t_1\) is fireable in the initial state of the EPN of Fig. 1.

3. Tool for EPNBMT (Extended Place/transition Net-Based Mutation Testing)

This section shows the functions of the tool that we have been developing to support EPNBMT, according to the procedure of EPNBMT. The functions (the procedure) consist of (1) construction of an original EPN, (2) construction of mutant EPNs, (3) conversion of a test suite, and (4) execution of a test suite.

3.1. Construction of an original EPN

First, test engineers need to construct an original EPN based on specifications of SUT. The original EPN is an EPN that represents the expected behavior of SUT; it is called "original" in order to distinguish it from mutant EPNs that will be constructed on the next step. The EPN has been discussed in the previous section. Our tool provides the function to construct an original EPN. Fig. 2 gives the screen image in the execution of the function. The GUI (Graphical User Interface) for the function consists of (A) a pane to edit a PN and (B) a pane to edit VDM specifications for actions and guards. Additionally, (B) consists of five code editors to edit values, types, instance variables, operations, and functions of the VDM specifications, and one of them can

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Fig. 1. Simple example of an EPN (initial state).
be selected by a tab. Test engineers can define not only the PN of an original EPN but also the actions and guards of an original EPN.

3.2. Construction of mutant EPNs

After completing constructing an original EPN, test engineers need to construct mutant EPNs. The mutant EPN is an EPN that intentional failure(s) has been inserted into by the use of mutation operators. In this study, the following mutation operators are supposed to be utilized.

- Model-based mutation operators: the addition and deletion of an element of a PN (that is, a place, a transition, an arc, or a token) can be performed in order to insert an intentional failure. They were proposed in our previous study.\(^1\)

- Code-based mutation operators: the grammar of VDM++ is somewhat similar to those of general procedural programming languages. Therefore, in order to insert an intentional failure, traditional code-based mutation operators (for example, replacement of operators, variables, and constants) can be applied to actions and guards that have been implemented as VDM specifications.

Our tool provides the function to construct mutant EPNs. Fig. 3 shows the screen image in the execution of the function. The GUI for the function consists of (A) a list of mutant EPNs that have been constructed, (B) a pane to edit a PN of a mutant EPN by the use of model-based mutation operators, and (C) a pane to edit VDM specifications for actions and guards by the use of code-based mutation operators.

(A) enables test engineers to select one of existing mutant EPNs and show it on (B) and (C). Additionally, it enables to add and remove a mutant EPN. (B) highlights a part that a mutation operator has been applied to in order that test engineers can easily confirm a result of application of a mutation operator. (B) also gives test engineers the way of manual and automatic construction of a mutant EPN. When performing manual construction, test engineers select a model-based mutation operator from the menu, and then specify a part of a PN that it should be applied to. When executing automatic construction, a model-based mutation operator is randomly selected, and then a part that it will be applied to is randomly determined by our tool. (C) consists of five code editors to edit values, types, instance variables, operations, and functions of VDM specifications, and one of them can be selected by a tab. These code editors enable test engineers to manually apply a code-based mutation operator.

3.3. Conversion of a test suite

After the construction of an original EPN, a test suite to be evaluated needs to be converted to execution paths (that is, sequences of successive markings, transitions, and values of instance variables) on the original EPN. It is a preparation for automatic execution of the test suite in the next step. Our EPNBMT accepts an arbitrary format and design technique of the test suite.

Our tool provides the function to manually convert an arbitrary test suite to execution paths on an original EPN. Fig. 4 shows the screen image in the execution of the function. The GUI for the function consists of (A) a list of test cases that a test suite consists of, (B) a list to edit
transitions of a test case selected on (A), and (C) a pane to show an original EPN and edit a test case.

(A) enables test engineers to select one of existing (already converted) test cases and show its execution path representation on (B) and (C). (C) highlights a transition that is selected on (B), and shows a marking and values of instance variables just after the firing of the transition. Additionally, (A) enables to add and remove a test case. When adding a test case (converting a test case and entering it into our tool), test engineers input required information (successive markings, transitions, and values of instance variables) via (B) and (C). (B) enables to add and remove a transition of a test case selected on (A). When a new transition is added, (C) can highlight fireable transitions based on a current marking and values of instance variables, and then selecting a highlighted transition brings the automatic updating of the current marking and values of instance variables, which will save test engineers' labor.

3.4. Execution of a test suite

Finally, test engineers need to apply the converted test suite to all of the constructed mutant EPNs, and then calculate a mutation score as the ratio of killed mutant EPNs to all of the constructed mutant EPNs. If the mutation score is not good, the test suite can be improved based on mutant EPNs that have not been killed. Our tool provides the function to execute a test suite. Fig. 5 shows the screen image in the execution of the function. The GUI for the function consists of (A) a control panel to start executing a test suite, (B) a list of mutant EPNs with the results of testing, (C) a list of test cases with the results of their application to a mutant EPN selected on (B), (D) a list of transitions of a test case selected on (C), (E) a pane to show markings and values of instance variables of an original EPN (the upper part) and the selected mutant EPN (the lower part) just after the firing of the selected transition in the selected test case, and (F) a pane to show a detailed log of test suite execution, including a mutation score. (B)-(F) enable test engineers to easily confirm the result of test suite execution invoked by (A).

Each test case is executed as follows:

(i) A mutant EPN is initialized based on an initial marking and initial values of instance variables of a test case.

(ii) In the mutant EPN, transitions are fired from the top of the test case. Each of firings is performed by the following (a)-(c).

(a) The pre-conditions to fire a transition, that is, the existence of tokens for ingoing arcs of the transition, and the guard of the transition are checked. When they are not satisfied, it is found that the mutant EPN is killed by the test case.

(b) The transition is fired, and the action attached to the transition is executed. As a result, a current marking and values of instance variables are updated.

(c) If the transition includes post-conditions, and they are not satisfied, it is found that the mutant EPN is killed by the test case.

(iii) When the firing of the final transition of the test case has been completed, the test result (that is, a final marking and values of instance variables in the mutant EPN) is compared with the expected result.
included in the test case (that is, a final marking and values of instance variables in the original EPN). If there are differences between the test result and the expected result, it is found that the mutant EPN is killed by the test case.

4. Conclusion and Future Work

This paper has shown a tool for EPNBMT (Extended Place/transition Net-Based Mutation Testing) to evaluate and improve the quality of a test suite for software including concurrent behavior. The EPN proposed in this paper is a PN extended by introducing a formal specification description language for VDM, in order to represent actions and guards. The tool consists of the following four functions: (1) an original EPN can be created to define the expected behavior of SUT, (2) mutant EPNs including intended failures can be created by applying mutation operators to the original EPN, (3) an arbitrary test suite to be evaluated can be converted to execution paths on the original EPN, and (4) a mutation score can be calculated by applying the converted test suite to all the mutant EPNs. If the mutation score is not good, the test suite can be improved based on mutant EPNs that have not been killed.

In the tool, model-based mutation operators are automatically applicable, but code-based mutation operators are only for manual application. The latter will be automated in order to save test engineers’ labor in our future work. Additionally, if the tool can generate mutant EPNs intensively including failures that are possible in operational environments, a degree of precision of a mutation score would be improved. Thus we will plan to develop the techniques for modeling of actual failures and for strategical application of mutation operators based on the model.

Another approach to improve the degree of precision of a mutation score is to utilize fault-proneness information that can be derived from software metrics, in order to adjust a mutation score. In the previous study, we proposed a technique in which the weights based on fault-proneness information and usage distributions are given to a PN in order to calculate an adjusted mutation score5. Extending this technique for EPNs is also included in our future work.

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