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Using Adaptive Agents to Automatically Generate Test Scenarios from the UML Activity Diagrams

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Abstract

Test case generation is one of the most important issues in software testing research and industrial practice. Test scenarios are frequently used to derive test cases for scenario-based software testing. However, the generation of the test scenarios is usually a manual and labor-intensive task. It is desired that test scenarios can be automatically generated. In this paper, we propose an automated approach using adaptive agents to directly generate test scenarios from the UML activity diagrams.

1. Introduction

Software testing remains the primary technique used to maintain quality of the software products and to gain consumers’ confidence in software. Unfortunately, it is well-known that testing software is a time-consuming and costly process [4]. Therefore, techniques that support the automation of software testing will result in significant cost and time savings for the software industry. Automatic generation of the test data is essential for the automation of software testing.

Great attention has been given to effectively using UML, which is the industrial de-facto standard for modeling object-oriented software systems, in software testing (see, for example, [6] and the references therein). One of the focused research topics is using UML artifacts for scenario based testing.

Scenarios represent the sequences of executions in a software system. Properly generated test scenarios are essential for the scenario-based software testing to achieve the required test adequacy and to guarantee the software quality [8]. However, one major problem with the generation of test scenarios is that the generation procedures are either completely manual or can not be fully automated [2].

Currently, there is a research trend to apply artificial intelligence techniques in software engineering, especially in software testing research (see for example, [5][11][15] and the references therein). One of the much focused areas in applying artificial intelligent techniques to software testing is the automated generation of test data.

Results have been reported of using artificial techniques in test data generation for software testing. The focus of the techniques mainly involves the applications of the genetic algorithms and the Ant Colony Optimization algorithms, for examples, [12][15]. However, automation of the generation procedure, efficiency of the generation algorithms, and the feasibility of the generated test data are frequently concerned. Furthermore, the reported results mainly concern with the state-based testing problems. The problem of generating test scenarios for scenario-based software testing receives less attention.

Recently, an approach has been proposed in [13] to use so-called anti-ant-like agents to automatically generate test threads from the UML activity diagrams. It is shown in [13] that using agents provides a potential avenue to automate the generation of test scenarios for scenario-based software testing. However, the proposed algorithm in [13] may result in redundant exploration of the activity diagrams and hence reduce the efficiency of the generation process. Furthermore, the complexity of the activity programs which are explored in [13] calls for further research.

In this paper, we propose to use adaptive agents to
overcome the difficulties and limitations encountered in [13]. The algorithm proposed in this paper is more efficient, and is capable to deal with the UML activity diagrams which contain more complicated structures.

This paper is structured as follows. Section 2 provides an analysis of the UML activity diagrams. Section 3 presents an adaptive agent approach to test scenario generation. Section 4 briefly describes the tool support for the proposed approach. Section 5 briefly discusses the related work; and the conclusion is found in Section 6.

2. Analysis of the UML Activity Diagrams

In general, an UML activity diagram includes an initial state, the action states, the final states, the fork nodes, the join nodes, the branch nodes, the merge nodes, the transitions and their associated guard conditions, and the final nodes.

The following definition for the UML activity diagrams is modified from [16]:

**Definition 1** An activity diagram is a 8-tuple $AD = (A, B, M, F, J, K, T, a_0)$ where $A = \{a_1, a_2, \cdots, a_n\}$ is a finite set of action states of the UML activity diagram; $B = \{b_1, b_2, \cdots, b_n\}$ a finite set of branches; $M = \{m_1, m_2, \cdots, m_n\}$ a finite set of merges; $F = \{f_1, f_2, \cdots, f_n\}$ a finite set of forks; $J = \{j_1, j_2, \cdots, j_n\}$ a finite set of joins; $K = \{k_1, k_2, \cdots, k_n\}$ a finite set of final states and end flows; $T = \{t_1, t_2, \cdots, t_i\}$ a finite set of transitions which satisfies $\forall t \in T, t := c > e \vee t = e$ where $c \in C, e \in E, C = \{c_1, c_2, \cdots, c_n\}$ is a finite set of guard conditions. $E = \{e_1, e_2, \cdots, e_i\}$ is a finite set of edges of the activity diagram; and $a_0$ is the unique initial state.

A test scenario is defined as follows:

**Definition 2** Let $AD = (A, B, M, F, J, K, T, a_0)$ be an activity diagram. Denote $TS$ the set of test scenarios for $AD$. $\forall TS \in TS, ts$ is a sequence of action states and transitions, i.e. $ts = a_0, a_1, \cdots, a_n, k \land a_i \in A \land t_i \in T \land k \in K, i = 1, 2, \cdots, n$.

A directed graph is defined as $G = (V, E)$ where $V$ is a set of vertices of the graph and $E$ a set of edges of the graph. A UML activity diagram can be viewed as an activity graph where the vertices are the activity nodes, the object nodes, the branch nodes, the fork nodes, the join nodes, and the initial node, while the edges are the activity edges in the activity diagram. An activity graph is a directed, dynamic graph in which the activity edges may become accessible only after the evaluation of their associated guard conditions.

The fork-join pairs in the UML activity diagrams represent concurrent executions. Due to the concurrency contained in fork-join pairs, it is difficult to derive test scenarios for an UML activity diagram which contains fork-join pairs. Furthermore, in complicated UML activity diagrams, the fork-join pairs can have complicated structures, namely, they may contain nested fork-join pairs, and they may include branches or loops between the fork and the join.

To our knowledge, there is no systematic approach reported in literature to automatically generate all test scenarios for the UML activity diagrams which contain complicated fork-join structures. For example, the approach in [16] generates only incomplete test scenarios for an UML activity diagram under the assumption that the activity diagrams contain forks which only have two outgoing edges. Although the approach reported in [13] does not constrain the outgoing edges of the forks, the generated test scenarios for a fork-join pair only contain the combination of the sequentially connected execution paths between the fork and the join, therefore, may miss some test scenarios for the fork-join pair.

This paper further extends the approach reported in [13] to tackle more complicated UML activity diagrams. In particular, the approach proposed in this paper aims at providing a solution to generate complete test scenarios for the UML activity diagrams which may contain complex fork-join structures.

First of all, we present a simple classification of the fork-join pairs considered in this paper.

2.1 A simple classification of the fork-join pairs

The fork-join pairs considered in this paper can be classified as four types, namely, the Atomic-Fork-Join (AFJ) type, the Simple-Fork-Join (SFJ) type, the Simple-Nested-Fork-Join (SNFJ) type and the Branch-Nested-Fork-Join (BNFJ) type. Note that it is possible that the fork-join pairs in the UML activity diagrams may contain other structures. Research is currently being carried out to investigate the fork-join structures which are not covered here.

Before we provide the definitions for each of the types, we give the following definition:

**Definition 3** Let $ID$ denote the incoming degree of a node in the activity diagram, $OD$ denote the outgoing degree of a node. $ID(x)$ and $OD(x)$ denote the number of incomings and outgoings of the node $x$, where $x \in A \vee x \in B \vee x \in M \vee x \in F \vee x \in J \vee x \in K$. 
Especially, $\text{ID}(a_0) = 0$, $\text{OD}(a_0) = 1$, $\text{OD}(k) = 0$, $\forall k \in K$.

Now, we are ready to give a definition for the Atomic-Fork-Join type:

Definition 4

An AFJ is a 4-tuple $\text{AFJ} = (A, T, f, j)$ where $A$ and $T$ are the set of action states and the set of transitions, respectively; $f$ is the unique fork in the AFJ; $j$ is the unique join in the AFJ; $\text{OD}(a) = 1 \land \text{ID}(a) = 1, a \in A$ which means that each action state has one incoming and one outgoing exactly; and $\text{OD}(f) = 2 \land \text{ID}(j) = 2$ which means that the unique fork only has 2 outgoings, and the corresponding join has 2 incomings. The sequence $f \xrightarrow{1} a_1 \xrightarrow{1} a_2 \cdots \xrightarrow{1} j$ is called an execution path of this fork-join.

Note that only two parallel execution paths are contained in an AFJ. We use $ES$ to denote the set of the execution paths $ES = \{es_1, es_2\}$, then $|ES| = 2$. If $S_1 = \{a \mid a \in A, a \text{ occurs in } es_1, es_2 \in ES\}$, $S_2 = \{a \mid a \in A, a \text{ occurs in } es_2, es_1 \in ES\}$, then $S_1 \cap S_2 = \emptyset$. Moreover, if $U_1 = \{t \mid t \in T, t \text{ occurs in } es_1, es_1 \in ES\}$, $U_2 = \{t \mid t \in T, t \text{ occurs in } es_2, es_2 \in ES\}$, then $U_1 \cap U_2 = \emptyset$. Therefore, each action state and each transition in an AFJ only appear in one of the two execution paths.

For example, the fork-join pairs shown in Figure 1 and Figure 2 are both AFJs. Denote the number of test scenarios as NTS. For the fork-join pair in Figure 1, $\text{NTS} = C_1^1 = 3$. For the fork-join pair shown in Figure 2, $\text{NTS} = C_4^1 + C_4^4 = 4 + 4 \times 3/2 = 10$.

Next, we provide a definition for SFJ:

Definition 5

A SFJ is a 4-tuple $\text{SFJ} = (A, T, f, j)$ where $A, T, f$ and $j$ are the set of action states, the set of transitions, the unique fork, and the unique join in the SFJ, respectively; $\text{OD}(a) = 1 \land \text{ID}(a) = 1, a \in A$ which means that each action state has one incoming and one outgoing exactly; and $\text{OD}(f) = n \land \text{ID}(j) = n$ where $n \geq 2 \land n \in N$, $N$ is the set of natural numbers; the sequence $f \xrightarrow{1} a_1 \xrightarrow{1} a_2 \cdots \xrightarrow{1} j$ is called an execution path of this fork-join.

Obviously $n$ parallel execution paths are contained in a SFJ. Hence, $ES = \{es_1, es_2, \cdots, es_n\}$ and $|ES| = n$.

If $S_1 = \{a \mid a \in A, a \text{ occurs in } es_1, es_1 \in ES\}$, $S_2 = \{a \mid a \in A, a \text{ occurs in } es_2, es_2 \in ES\}$, ..., $S_n = \{a \mid a \in A, a \text{ occurs in } es_n, es_n \in ES\}$, then $S_1 \cap S_2 \cap \cdots \cap S_n = \emptyset$. Moreover, if $U_1 = \{t \mid t \in T, t \text{ occurs in } es_1, es_1 \in ES\}$, $U_2 = \{t \mid t \in T, t \text{ occurs in } es_2, es_2 \in ES\}$, ..., $U_n = \{t \mid t \in T, t \text{ occurs in } es_n, es_n \in ES\}$, then
\[ U_1 \cap U_2 \cap \cdots \cap U_n = \emptyset. \] Therefore, each action state and each transition in an SFJ only appear in one of the \( n \) execution paths. The fork-join pair shown in Figure 3 is an SFJ. Its NTS is:

\[
\text{NTS} = \prod_{i=1}^{n-1} \sum_{j=0}^{m_{i+1}-1} (C_{j+1}^{m_{i+1}} \times C_j^{m_i}) ,
\]

where we assume that \( m_1 \geq m_2 \geq \cdots \geq m_n \geq 1, n \geq 2 \land C_0 = 1. \)

Obviously, the SFJ is an extension of the AFJ. In general, most of the fork-join pairs in the UML activity diagrams belong to the SFJ type. The NTS formula shown above can be deduced easily, and hence the derivation procedure is omitted. The NTS formula can be used to verify whether a proposed method is capable to generate all test scenarios for a SFJ in an activity diagram.

Now, we define the SNFJ type as follows:

**Definition 6** A SNFJ is a fork-join pair which contains a nested SFJ inside. If the nested SFJ is replaced with one of its test scenarios, and as a consequence the host fork-join pair becomes a SFJ, we call such fork-join a SNFJ.

For example, the fork-join pair shown in Figure 4 is a SNFJ. It can be decomposed into 2 SFJs shown in Figure 4.1 and Figure 4.2 respectively. Obviously, the NTS of a SNFJ = \( \sum \) the NTS of the decomposed SFJs. Therefore, the NTS of a SNFJ can be calculated using the above formula for a SFJ.

Finally, we give the definition for the BNFJ type:

**Definition 7** A BNFJ is a fork-join which contains a branch-merge pair inside. If the branch-merge is replaced with one of its test scenarios, and as a consequence the host fork-join pair becomes a SFJ, we call such fork-join a BNFJ.

For example, the fork-join pair shown in Figure 5 is a BNFJ. A BNFJ can be decomposed into two SFJs shown in Figure 5.1 and Figure 5.2 respectively. Obviously, NTS of a BNFJ = \( \sum \) NTS of the two decomposed SFJs.

Since the SFJ type forms the basis of the decomposition for the SNFJ type and the BNFJ type, we clearly need to investigate how to generate test scenarios for the SFJ type. In the following, we present an algorithm, called the SFJ algorithm, to generate the test scenarios for a SFJ type.

### 2.2 The SFJ algorithm

Suppose the SFJ is the one shown in Figure 3. The pseudo codes of the SFJ algorithm are given below.
Step 5: Generate test scenarios for the SFJ by traversing the scenario tree. Each path from root to a leaf forms a test scenario for the SFJ.

Note that the NTS formula can be used to verify that all test scenarios for a SFJ have been generated.

By using the SFJ algorithm, 10 test scenarios can be generated for the fork-join pair shown in Figure 2, and the generated test scenarios are exactly the same as those listed in Table 2. However, only 6 test scenarios can be generated using the algorithm proposed in [16].

3. Generate Test Scenarios from the UML Activity Diagrams

In this section, we will describe the complete algorithm of using adaptive agents to automatically generate test scenarios from the UML activity diagrams.

3.1 Adaptive Agents and Their Behavior

We consider the problem of sending adaptive agents to search an activity graph which corresponds to a UML activity diagram. The objective of the agent’s exploration is to build the test scenarios from the corresponding activity diagram.

The adaptive agents proposed exhibit similar behavior of some bacteria, for example the type of bacteria called Maxococcus xanthus. Maxococcus xanthus is a type of myxobacterium which lives in soil. A Maxococcus xanthus can move around the ground to search for nutrients. As it moves, the bacterium can lay down a slime trail which may play the role of greasing the path to easy the movement. Therefore, if a bacterium finds a slime trail, it has a better chance to follow that trail to make its movement easier [14].

Like Maxococcus xanthus bacteria, our agents move around in the directed activity graph to search for nutrients. As these agents move, they also lay down slime trails to mark their paths. However, unlike Maxococcus xanthus, bacteria, our agents actually exhibit opposite behavior with regard to the use of slime trails, namely, too strong slime concentration will turn our agents into stationary spores. A spore can not move around further to search for nutrients. Therefore, once an agent is turned into a spore, it will be removed from the search process.

Like many bacteria, our agents can adapt to the environment. Namely, if nutrients are sufficient at a place such that the workload of an arriving agent is too high, the agent will simply clone itself to easy the workload it has to take. The cloned agents will then be dispersed to different directions to cover the nutrients.

When our adaptive agents are dispatched to search an activity graph, they observe the following rules:

Rule 1: An agent can only move in the directions of the edges at a fixed speed.
Rule 2: An agent can lay down fixed amount of slime over an activity edge when it arrives at the edge.
Rule 3: An agent is turned into a spore if it arrives at an activity edge which possesses too high slime concentration.
Rule 4: An agent is killed if it finds antibiotic substance.
Rule 5: Search an activity edge represents one normal work load for an agent at a particular time. An agent can only take one workload at a time.
Rule 6: An agent can clone itself if it is requested to carry out a higher workload. The cloned agents inherit the complete information of the fathering agent and exhibit the same behavior of the fathering agent.

When using the proposed agents to search an activity diagram, special attentions need to be paid to two types of nodes in an activity diagram:

- The final nodes are considered as spots which contain antibiotic substance. An agent is killed if it arrives at a final node.
- The branch nodes are considered as the spots which contain rich nutrients. If a branch node has m outgoings, then the requested workload for an agent which arrives at the branch node is m times higher than its normal workload. Therefore, the agent has to reproduce m-1 clones at the branch node; each agent will carry on a search in a different outgoing.

The overall behavior of the adaptive agents in our approach is governed by an activity diagram illustrated in Figure 6. Note that for simplicity, it is assumed in this paper that each cyclic loop is executed at most two times. This assumption is the same as the one in [16].

3.2 Algorithm

We define a scenario tree as an interim storing structure. The initial node of an activity diagram is regarded as the root of the tree. Each tree node denotes the elements of the activity diagram such as the action states, the forks, the joins, the branches, the merges, the guard conditions, and the final states. Test scenarios can then be derived from the scenario tree by traversing the tree.

First of all, we represent the guard conditions in
forms which are slightly different from the originals. A guard condition which consists of an attribute type and a value are denoted as <Type: value>. In general, there are three kinds of guard conditions in an activity diagram, namely text which is a string description, counter which is an integer mostly used to represent the loop times, and Boolean or Boolean expression which represents a conditional decision. For example, a condition can be denoted as <Boolean: True>.

The pseudo codes of the algorithm, which implement the behavior model shown in Figure 6, are illustrated as follows:

```plaintext
/* Initialization */
for every edge (i,j) do
    P_{ij} = 0; /*Set 0 slime level to every edge*/
endfor;

Call an agent to traverse the activity diagram from its initial state.

While (true) do
    Evaluate status at node i;
    /*Report initial node to the scenario tree as the root*/
    if (is initial node) do
        Create tree root;
    endif;
    if (found antibiotics) do
        break;
    else
        kill agent;
    endif;

    /* Data Reporting */
    if (access Data) do
        Report data access to the scenario tree;
    endif;

    /* Clone agent */
    If the outgoing edges of the traversed node are m, clone m-1 agents to traverse the different edges

    /* If arrives at a fork node */
    if (found fork-join pair) do
        if (the node is a SFJ) do
            Call SFJ algorithm;
        else
            Decompose SNFJ or BNFJ into SFJ;
            Call SFJ algorithm for each SFJ;
            Merge the generated test scenarios;
        endif;
        Merge fork-join test scenarios into the scenario tree;
    endif;
```

Figure 6 The behavior model of the adaptive agents
Agent moves to an outgoing edge;
/*Condition reporting*/
if (found Condition) do
  Report guard condition node to the
  scenario tree;
endif;
/*Increased Pij by one when an agent
arrives at an edge*/
Pij ++;
/*loops are only permitted to execute
two times due to the coverage
criterion adopted in this paper */
if (Pij >= 3) do
  Cut redundant tree branch;
  if (is last alive agent) do
    Break;
  else
    Turn the agent into a spore;
  endif;
endif;
Agent moves to next node;
endwhile;
/* Generate a test scenario*/
Generate sequence of action states and
transitions formed from the root to a
leaf of the scenario tree.

The pseudo codes are straightforward to be followed.

4. Tool support

We have developed a prototype tool called TSGAD
(Test Scenarios Generator for Activity Diagrams) using
the proposed algorithm to automatically generate test
scenarios for given activity diagrams. An activity
diagram can be developed using many standard UML
tools and exported into a XMI file. TSGAD can
directly read a XMI file which includes all UML
diagrams, extract the contained activity diagram, and
automatically generate test scenarios afterwards.

Due to space limitation, we can not describe
TSGAD in details here. However, we use an example
to demonstrate the tool. The example shown in Figure
7 is an activity diagram which simulates a test scenario
generator. The generator in Figure 7 takes an activity
diagram generated using Rational Rose, Poseidon or
Visio, and converts the imported diagram into a generic
XML format. Afterwards, the generator parses the
XML file to derive all test scenarios.

The activity diagram shown in Figure 7 was drawn
using Poseidon UML and a XMI file was exported. As
shown in Figure 8, the generated XMI file was
imported into TSGAD, namely, the intermediate
scenario tree was displayed in the left panel; the
corresponding activity diagram was displayed in the
central panel; while the XML representation for the
activity diagram was shown in the right panel. TSGAD
automatically generated all test scenarios for the
imported activity diagram, as shown in the bottom
panel in Figure 8. The details of all generated test
scenarios have to be deleted due to space limitation.

5. Related work

In [16], the concept of basic paths (BPs) for the
activity diagrams is defined. From BPs, the test
scenarios are derived by depth first search. However, a
detailed walkthrough of the proposed algorithm shows
that some test scenarios are not generated, especially
when the test scenarios are derived from the fork-join
parts of the activity diagrams. For example, only 6
execution paths are generated for the fork-join structure
shown in Figure 2 using the algorithm proposed in
[16]. Furthermore, it has been assumed in [16] that the
activity diagrams have pairs of branches and merges,
and pairs of forks and joins; a fork in an activity
diagram can only have two outgoings. Obviously,
these assumptions limit the applicable scope of the
algorithm proposed in [16]. The algorithm proposed in
this paper removes most of the constraints imposed in
[16], and the proposed algorithm is more efficient due
to the use of the adaptive agents.

An algorithm using anti-ant-like agents is given in
[13] to generate thin threads from the activity diagrams.
While the algorithm proposed in [13] doesn’t rely on
the assumptions used in [16], the efficiency of the test
thread generation is not optimal. For example, a group
of ants is used to explore an activity diagram; each ant
starts from the initial state of the activity diagram such
that some parts of the activity diagram are explored
many times. In contrast, the algorithm proposed in this
paper uses one agent to start the initial exploration.

More agents are adaptively reproduced if and only if
it is necessary. Therefore, redundant exploration of the
activity diagrams is avoided.

Similar to [16], the algorithm proposed in [13] can
not generate complete test scenarios for fork-join pairs
in general. In comparison, the algorithm proposed in
this paper can generate all test scenarios for these fork-
join structures described in Section 2.

6. Conclusion

This paper presented an automated approach to
generated test scenarios from the UML activity
diagrams. Using the developed algorithm, an adaptive
agent can effectively explore the UML activity diagrams and automatically generate test scenarios.

Our approach has the following advantages: 1) the UML activity diagrams exported by UML tools are directly used to generate test scenarios, and the whole generation process is fully automated; 2) redundant exploration of the activity diagrams is highly avoided due to the use of adaptive agents, resulting in improved efficiency in the generation of the test scenarios.

References