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Test Suite Minimization using Fuzzy Clustering for Aspect-Oriented Software System

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Abstract: Now-a-days, optimization of test suite using model-based testing techniques are gaining more popularity as they are easy to implement and less costly as compare to code-based testing. Aspect-oriented programming paradigm is relatively a new field of software development. In this paper, a UML activity diagram-based test suite minimization technique has been developed for Aspect-Oriented Software System by using Fuzzy Clustering. This technique will reduce the size of the test suitewithout compromising thespecified coverage criteria.

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I. INTRODUCTION

Aspect-oriented programming (AOP) paradigm is widely used to develop large and complex software applications. It also increases the concept of modularity, cohesion and reusability due to the proper handling of *"Separation of Concern (SoC)"*. Separation of Concern (SoC) principle states that any complex problem can be divided into different concerns and solved these concerns individually in different modules. Ghani *et.al.* suggested that, *"A concern is a feature which is described requirement model for the software"* **[Ghaniet.al., 2013]**. AOP divides the complex problem into two types of concerns, e.g. Core concern or functional properties and Crosscutting concern or non-functional properties.

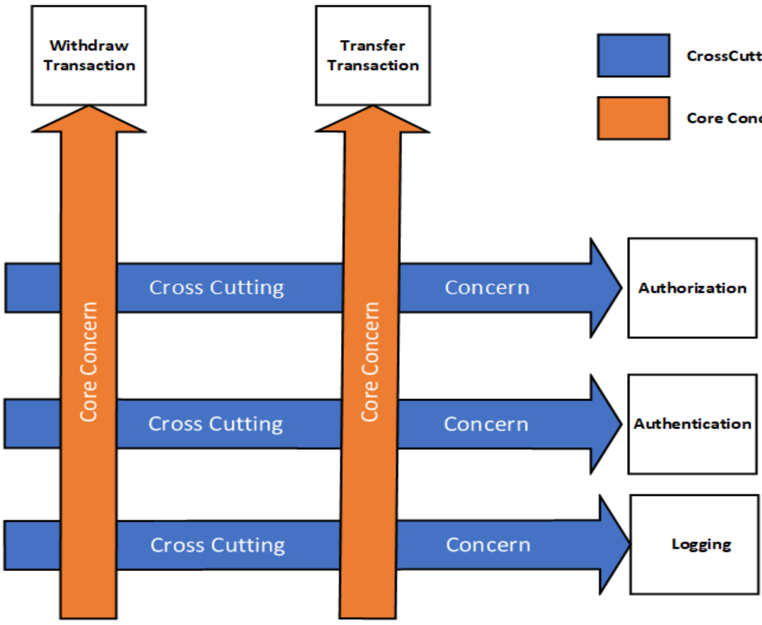

Figure 1. Concept of Aspect-Oriented Programming

Figure 1 shows the concept of core concerns and crosscutting concerns of aspect-oriented programming by illustrating the banking information system in which withdrawal transaction and transfer transaction are the primary concerns. The system's functionality is associated with these concerns. Authentication, authorization and logging are also considered as security requirements. These security requirements are considered as a crosscutting concerns or non-functional properties.

Now-a -days, Unified Modeling Language (UML) is becoming more popular in the field of software testing as models are used to represent the behavioral of the software system. Model-based testing is performed at early stage of Software Development Life Cycle (SDLC) and errors can be removed at earlier stage of the software development. UML activity diagram depicts the external behavior of the software without providing the internals details. Moreover, UML activity diagram helps to better understand the system behavior and find test information easily as compared to code - based testing **[Sabharwal *et.al*.,2011]**.

Existing software testing techniques cannot be directly applied on aspect-oriented software due to new features and constructs provided by AOP. Therefore, testing an AOP remains an essential activity in an aspect-oriented software development process**[Dalal*et.al.*, 2017]**. Aspect-Oriented Software Testing (AOST) deals with new challenges and aspect related faults.In this paper, an UML activity diagram-based approach has been proposed to minimize the size of the test suite for AOSS by using the application of Fuzzy Clustering (FC). Aspectual Branch Coverage (ABC) **[Harman*et.al*., 2009]**criteriaand Effectiveness of Test Suite Minimization (ETSM) **[Yoo*et. al.*, 2012]** parameters have been used to evaluate the performance of the proposed approach.

This paper is organized into five sections. The first section of this paper describes the concept of Aspect-Oriented Programming paradigm, UML activity diagram and model-based testing in AOSS. Second section describes the basic concept of Fuzzy Clustering (FC). Third section discusses the proposed model-based testing technique, methodology and flow chart, and pseudocode of FC based testing technique for AOSS. Fourth section of this paper describes the experimental evaluation of the FC based testing technique for AOSS. Last section of this paper concluded the paper and caters the future directions in the field of AOSS.

II. OVERVIEW OF FUZZY CLUSTERING (FC)

Soft computing is not a single methodology but it is a blend of several methodologies such as evolutionary computation, fuzzy logic, Machine learning, Genetic algorithms etc.*"Clusteringis the method to segregate data elements into distinct groups or clusters in such a manner that the data elements inside a group have high similarity while they distinct from the data elements resides in a different group*" **[Bora *et.al.*, 2014]**.Generally, clustering is divided into two categories such as; 1) hard clustering and 2) soft clustering. Therefore, according to Kumar *et.al."Fuzzy clustering is a procedure to defined the membership level and then assign this membership level to each data elements of one or more clusters"* **[Kumar *et.al*, 2013]**.The mechanism is to make group is different in each of this category.Soft clustering is commonly known as fuzzy clustering. In soft clustering, data elements can belong to more than one clusters and membership level is assigned to each data element. Strength of association between data element and cluster is used to measure the membership level.

Fuzzy C- Means (FCM) is the basic algorithm used in soft clustering or fuzzy clustering. The basic steps of FCM has been describe as follows:

Step 1: - Define a number of clusters.
Step 2: - Randomly assign coefficient to each point data in the cluster.
Step 3: - Repeat until the algorithm has converged
(i) Calculate centroid for each cluster
(ii) For each number of clusters, calculate the aggregate of center of clusters and then calculate standard deviation from them.

Wherever, there is minimum standard deviation found that will be the optimum number of cluster as we require for the problem.

III. APPLICATION OF FC TECHNIQUE FOR TESTING AN ASPECT-ORIENTED SOFTWARE SYSTEM

This research paper proposes UML activity model-based test suite minimization testing technique for AOSS by using the application of FC. This approach selects the testing paths from UML activity diagram by using the maximum node coverage criteria. Maximum node coverage parameter is used to measure the percentage of covered nodes among all nodes. A fitness function is being used to evaluate individual candidate testing paths according to the specified coverage criteria. The subsequent sections of this paper present the results that yield proofs to support the claim that FC technique for AOSS is cost effective and reduces the testing effort by achieving complete or partial maximum node coverage criteria.

3.1 Methodology and Flowchart of FC based Testing Technique for Aspect-Oriented Software System

This subsection describes the methodology and flowchart for model-based test suite minimization technique using FC. The following steps have to be taken:

1. Construct an aspect-integrated or aspectual UML diagram from SUT and then transform into Control Flow Graph (CFG).
2. Testing paths are generated by using depth-first -search algorithm.
3. Calculate the fitness function of each testing path.
4. Formulate the number of clusters.
5. Assign fuzziness coefficient to each data point or testing path.
6. Select the best testing path from each cluster.
7. Evaluate the performance of each testing path.

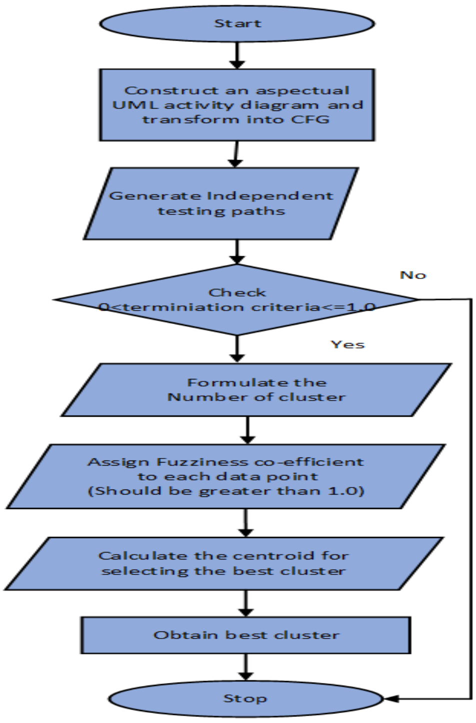

Figure 2: Detailed flow chart of FC based technique for AOSS

Figure 2 depicts the flow chart of FC based test suiteminimization technique for AOSS.

3.2 Pseudocode of FC based Technique for Aspect-Oriented Software System

1. Construct an aspect-integrated UML activity diagram for SUT and transforms into CFG.
2. Display the number of independent paths by using the application of Depth-First-Search algorithm.
3. Calculate the cost of each independent path until CFG has not traversed
   (i) Calculate IF=fan-in * fan-out for each node
   (ii) Calculate weight of each node based on its type
   If node type = Normal Node
   Weight = 1
   If node type = Decision Node
   Weight = 2
   If node type = Concurrent Node
   Weight = 3
   If node type = Aspect Node
   Weight = 4
4. While (0.0 <termination criteria<=1.0)

(a) Formulate the number of clusters.
(b) Assign fuzziness coefficient to each data point or testing path (should be >1.0)

5. Repeat until the algorithms has converged:
(i) Compute the centroid for each cluster to select best testing paths by using given below formula:

$$X_i = \sum_{i,j=1}^{n} \min|a_i - a_j|$$

Where n=number of data points in clusters 1< = i< =n, 1 < = j< =n

6. Min=X_i is the best cluster.

IV. EXPERIMENTAL EVALUATION OF FC BASED TESTING TECHNIQUE FOR AOSS

Fuzzy Clustering algorithm has been applied on UML activity diagram-based test suite minimization technique for well- known aspect-oriented problem of Automatic Teller Machine **[Kaur *et.al.*,2011]**.

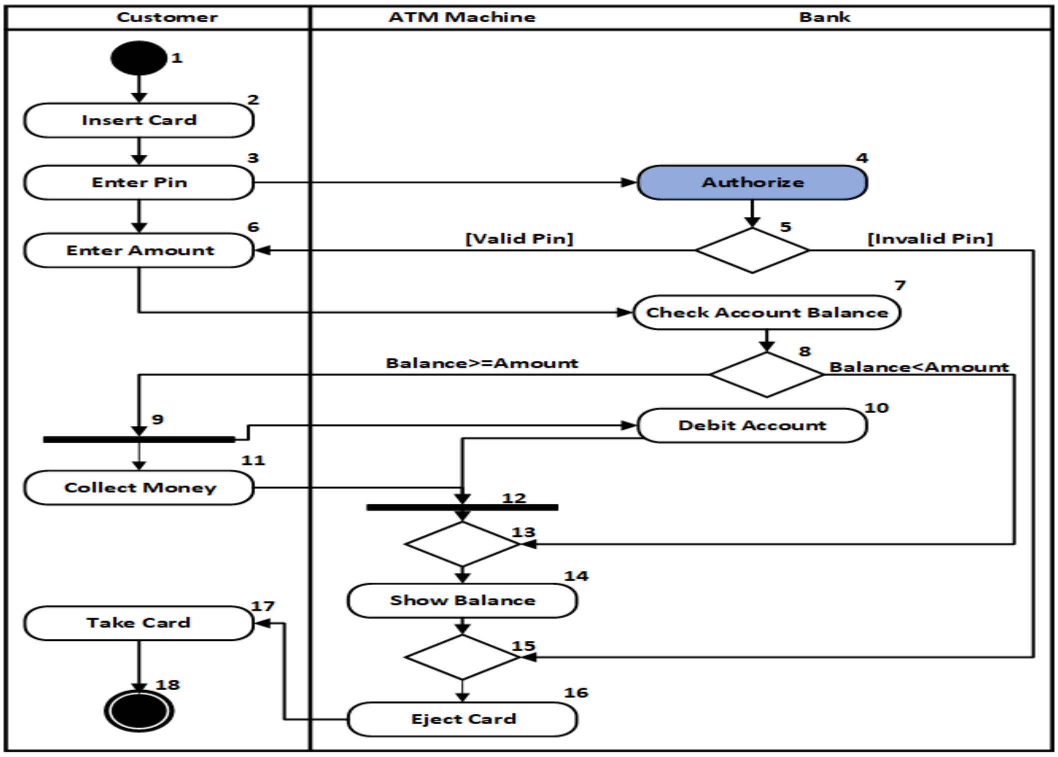

Figure 3: Aspect-weaving UML activity diagram for ATM

Step-1: Construct an Aspect weaving UML activity diagram for ATM in which three base classes; Customer, Bank and ATM machine are represented by rounded rectangle and one aspect node (node no.4); authorization is represented by dark blue rounded rectangle to distinguish with other nodes such as, decision, concurrent and normal nodes. Authorization, as an aspect is added to check whether the user is authorized or not. Figure 3 depicts the aspectual UML activity diagram and figure 4 depicts CFG for ATM.

Step-2: Seven independent testing paths are generated from the CFG for ATM by using the application of DFS (Depth-First-Search) algorithm. Generated testing paths are listed below:

T1: {1->2->3->4->5->15->16->17->18}
T2: {1->2->3->4->5->6->7->8->13->14->15->16->17->18}
T3: {1->2->3->4->5->6->7->8->9->10->12->13->14->15->16->17->18}
T4: {1->2->3->4->5->6->7->8->9->11->12->13->14->15->16->17->18

T5: {1->2->3->6->7->8->13->14->15->16->17->18}
T6: {1->2->3->6->7->8->9->10->12->13->14->15->16->17->18}
T7: {1->2->3->6->7->8->9->11->12->13->14->15->16->17->18}

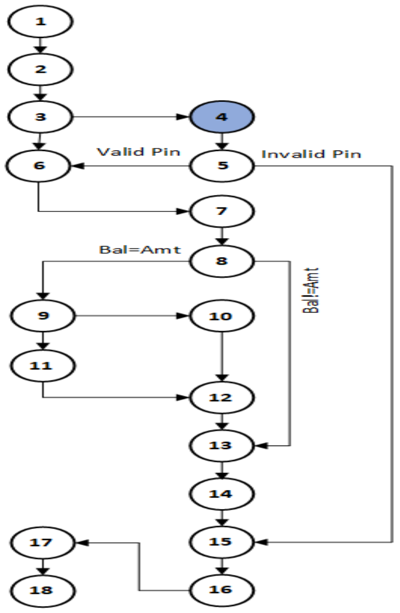

Figure 4: CFG for ATM

Step-3: Calculate the cost of each independent testing path until CFG has not traversed.

Table 1: Cost of each independent testing paths for ATM

Test Case Id	Testing Paths	$PFVi=IF_i+W_i$
T1	{1->2->3->4->5->15->16->17->18}	25
T2	{1->2->3->4->5->6->7->8->13->14->15->16->17->18}	39
T3	{1->2->3->4->5->6->7->8->9->10->12->13->14->15->16->17->18}	49
T4	{1->2->3->4->5->6->7->8->9->11->12->13->14->15->16->17->18	49
T5	{1->2->3->6->7->8->13->14->15->16->17->18}	30
T6	{1->2->3->6->7->8->9->10->12->13->14->15->16->17->18}	40
T7	{1->2->3->6->7->8->9->11->12->13->14->15->16->17->18}	40

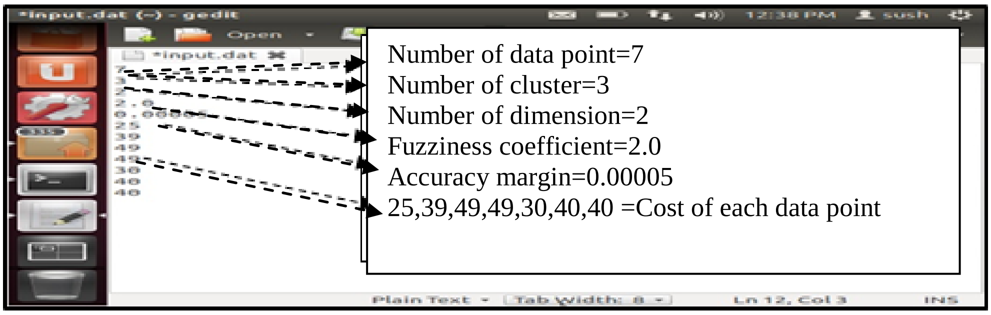

Figure 5: Input File of FC Program for ATM

Step- 4: Figure 5 depicts the input file for ATM in which, input file requires several types of input such as number of data point, clusters, dimensions, fuzziness coefficient and termination criteria.

```
# data point for cluster 0
40.000000  0.000000
# data point for cluster 1
49.000000  49.000000
# data point for cluster 2
25.000000      39.000000
30.000000      40.000000
```

Figure 6: Input File of FC program for ATM

Figure 6 depicts various cluster formations which are formed automatically during the execution of the program FC.

Step- 5: Compute the centroid for each cluster to select best testing paths by using given below formula:

$$X_i = \sum_{i,j=1}^{n} \min(|a_i - a_j|)$$

Where n=number of data points in clusters 1< = i< =n, 1 < = j< =n

Best testing path or data point selection from cluster 0: 40 (as it has only one data point)

Best testing path or data point selection from cluster 1: 49 (it has two data points of same cost, can be chosen any one)

Best testing path or data point selection from cluster 2:

25= |25-39|+|25-30|+|25-40| = 34
39= |39-25|+|39-30|+|39-40| = 24
40= |40-25|+|40-30|+|40-39| = 26
30 = |30-25|+|30-39|+|30-40| = 24
Min {34,24,26,24}
Min=24, Best test case selection from data cluster 2 is T5=30

Step- 6: Obtain best testing path or data point from each cluster as shown in Table 2.

Table 2: Selected Testing paths for ATM using FC

Test Case Id	**Testing Paths**	**PFVi=IF$_i$+ W$_i$**
T2	{1->2->3->4->5->6->7->8->9->10->12->13->14->15->16->17->18}	49
T5	{1->2->3->6->7->8->13->14->15->16->17->18}	30
T7	{1->2->3->6->7->8->9->10->12->13->14->15->16->17->18}	40

4.1 Evaluate the effectiveness of FC Based Technique for AOSS

Two parameters have been considered to evaluate the performance of test suite minimization technique for AOSS using the application of Fuzzy Clustering (FC):

1. Aspectual Branch Coverage (ABC)
2. Effectiveness of Test Suite Minimization (ETSM)

Aspectual Branch Coverage (ABC): Aspectual Branch Coverage parameter is used to measure the percentage of covered aspectual branches among all aspectual branches **[Harman *et. al*., 2009]**.

Notion for calculating effectiveness of FC in terms of Aspectual Branch Coverage (ABC):

$$ABC = \left(\frac{Numberoftestingpathswhichcoversaspectualbranches}{Totalnumberoftestingpathsinoriginaltestsuite}\right) * 100$$

$ABC = \left(\frac{1}{3}\right) * 100$ = 33.33%

Effectiveness of Test Suite Minimization (ETSM): Effectiveness of Test Suite Minimizationparameter is used to measure the effectiveness of the test suite minimization **[Yoo*et.al*., 2012]**.

Notion for calculating effectiveness of FC in terms of Effectiveness of Test Suite Minimization (ETSM): -

$$ETSM = 1 - \frac{Numberoftestcasescenariosinaminimzedtestsuite}{Totalnumberoforiginaltestsuite} * 100$$

$ETSM = \left(1 - \frac{3}{7}\right) * 100$ = 57.14 %

The same procedure has been applied on other two case studies namely, Online Banking and Transfer Scenario of Banking System. Detail description aboutOnline Banking is available in **[Cui *et. al*., 2009]** and Transfer Scenario of Banking System is available in **[Dalal and Hooda, 2017]**.

Table 3: Comparative ABC and ETSM values for all three case studies using FC

Case Studies	ABC in (%)	ETSM in (%)
ATM	33.33%	57.14%
Online Banking	60%	88.37%
Transfer Scenario of Banking System	66.66%	40%

Table 3 depicts the obtained results by executing FC program for all three cases studies.

V. CONCLUSION

An aspect integrated UML activity diagram and application of FC have been used to minimize the size of the test suite. This approach can be used to minimize the testing cost and effort by executing selected testing paths. The proposed approach has been focused on Aspectual Branch Coverage and applied on small AO Problem. In future work, try to apply the proposed approach on comparatively large AO problems, plan to extend the approach for achieving other types of coverage in AOP systems and to make more efficient by using other metaheuristic techniques.

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