Prioritizing the Test Cases of Web Services by APFD Metric

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Abstract: ***Regression Testing is a major component of most major testing systems but has only begun to be applied to Web services. A number of different approaches have been studied to maximize the value of the accrued test suite: minimization, selection and prioritization. Test suite minimization seeks to eliminate redundant test cases in order to reduce the number of tests to run. Regression test selection optimizes the regression testing process by selecting a subset of all tests, while still maintaining some level of confidence about the system performing no worse than the unmodified system. Test case prioritization seeks to order test cases in such a way that early fault detection is maximized.***

Keywords: Regression Testing, Test case prioritization, Test case selection, APFD metric

1. Introduction

Web services have enabled business workflows to be extended beyond the boundaries of companies and organizations. Since the business world often involves very rapid change to keep up with current market conditions, the business processes inevitably need frequent adjustment, along with their supporting Web services. Every time the system is modified, we must ensure that the modification does not have an adverse affect on any unmodified areas, or regions, of code (the modification does not introduce new problems into the code).Typically, this is done by running the test cases previously used to test the system prior to modification again.

This processing of "retesting" is called regression testing and its goal is to determine whether or not the system has been made worse by the modification. Reducing the number of tests be rerun is called regression test selection. An ideal regression test selection technique for the verification of Web service systems would have the following properties: 1) safe, 2) interoperable, 3) compos able, 4) decentralized, 5) end-to-end, and 6) automated. The testing and analysis of web services have posed new foundational and practical challenges, such as the non- observability problem , the extensive presence of non-executable artifacts within and among web services, safeguards against malicious messages from external parties, ultra-late binding and cross-organizational issues. Many web services (or services for short) use the Web Services Description Language (WSDL) (W3C) to specify their functional interfaces and message parameters. They also use XML documents to represent the messages.

2. Web Services

Web services refer to self-contained web applications that are loosely coupled, distributed, capable of performing business activities, and possessing the ability to engage other web applications in order to complete higher-order business transactions, all programmatically accessible through standard internet protocols, such as HTTP (Hypertext Transfer Protocol), JMS (Java Messaging Service), SMTP (Simple Mail Transfer Protocol), etc [1]. More specifically, Web services are Web applications built using a stack of emerging standards that form service-oriented application architecture (SOA), an architectural style whose goal is to achieve loose coupling among interacting software components through the use of simple, well defined interfaces. Extensible Markup Language (XML) provides the basis for most of the standards that Web services are based on. XML is a standard that has been developed by the World Wide Web Consortium (W3C) [2]. XML is a text-based meta-language for describing data which is extensible and therefore used to define additional markup languages. SOAP is designed to be a lightweight protocol for information interchange among disparate systems in a distributed environment. The actual format consists of an envelope which define the contents of the messages and how to process those contents. Web Service Definition Language (WSDL) [3] provides a mechanism for describing Web services in a standard way. The description provides an interface for using the Web services, in terms of available operations, their names, parameters and return types. Figure 1 describes the web service architecture. The description binds a service, termed abstract endpoints in the specification, to concrete endpoints, which is a description of the service defined abstractly then bound to a concrete network protocol and message format. Universal Description, Discovery and Integration (UDDI) [4] specification provides a means to locate and use Web Services programmatically. Service providers publish high level descriptions of their Web services into a UDDI repository, with which their services can be looked up and used. This is shown in figure 1.

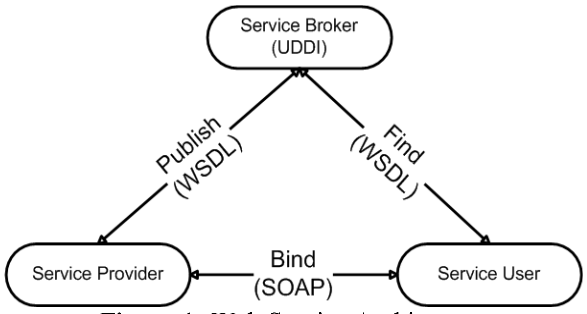


Figure 1: Web Service Architecture

3. Regression Testing

Regression testing is an important and expensive activity that is undertaken every time a program is modified to ensure that the modifications do not introduce new bugs into previously validated code. An important problem is the selection of a relevant subset of test cases from the initial test suite that would minimize both the regression testing time and effort without sacrificing the thoroughness of regression testing. Regression testing is performed between two different versions of software in order to provide confidence that the newly introduced features of the System Under Test (SUT) do not interfere with the existing features.

Definition 1: Test Suite Minimization Problem

Given: A test suite, T, a set of test requirements $\{r_1,\ldots\ldots,rn\}$, that must be satisfied to provide the desired 'adequate' testing of the program, and subsets of T, $T_1,\ldots\ldots,T_n$, one associated with each of the r_i s such that any one of the test cases tj belonging to Ti can be used to achieve requirement r_i.

Problem: Find a representative set, T', of test cases from T that satisfies all r_i s.

Definition 2. Test Case Selection Problem

Given: The program, P, the modified version of P, P', and a test suite, T.

Problem: Find a subset of T, T', with which to test P'.

Definition 3. Test Case Prioritization Problem

Given: a test suite, T, the set of permutations of T, PT, and a function from PT to real numbers,

$f : PT \rightarrow R$.

Problem: to find $T' \in PT$ such that $(T'')(T'' \in PT)(T'' \neq T')[f(T') \geq f(T'')]$.

These three techniques will be collectively referred to as 'regression testing techniques'.

4. Regression Test Selection: Problem

Let P denote Version X that has been tested using test set T against specification S. Let P' be generated by modifying P. The behavior of P' must conform to specification S'. Specifications S and S' could be the same and P' is the result of modifying P to remove faults. S' could also be different from S in that S' contains all features in S and a few more, or that one of the features in S has been redefined in S'. The regression testing problem is to find a test set T_r on which P' is to be tested to ensure that code that implements functionality carried over from P works correctly.

Most safe RTS techniques rely on information about the program's source code. The technique which has been adopted by the approach presented in this paper involves generating control-flow graphs from the involved code [5]. They are graphs in which each node represents a code entity and each edge represents the flow of control from one node to another. An additional structure needed by this particular algorithm is a mapping of the test cases to the control-flow graphs. The techniques involving control-flow graphs follow three basic steps, which will be covered in more detail: 1) It constructs a control-flow graph for P'; 2) Identifies dangerous edges by comparing the control-flow graph of P with the control-flow graph of P'; 3) Based on coverage information and the set of dangerous edges it selects from the test suite those tests that need to be rerun. A control-flow graph is a graph in which each node represents a code entity and each edge represents the flow of control from one node to another. For example, suppose there is a method with psuedocode presented in Figure 2, the control-flow graph for this method would look like the one in figure 3.

```
1 order(item) -
2 if (item exists) -
3 if (item is in stock) -
4 order item;
5 return successful;
} else
6 return error("ERROR: 104: item not in stock");
}
} else
7 return error("ERROR: 109: item does not exist");
} }
```

Figure 2: Psuedocode for an ordering service

The process of identifying dangerous edges by comparing the control-flow graphs of P and P' is one of the important parts of the process. Dangerous edges correspond to program entities that may behave differently under a single test case due to differences between P and P'. The regression test selection algorithm compares the two control-flow graphs by traversing the two control-flow graphs simultaneously looking for differences between them. If the two nodes are different in terms of their children or their values, the algorithm adds the node to the dangerous edge list. The algorithm is recursive and stops either when it finds a difference in the control-flow graph, when it reaches a node it has already compared, or when it reaches an exit node without finding a difference.

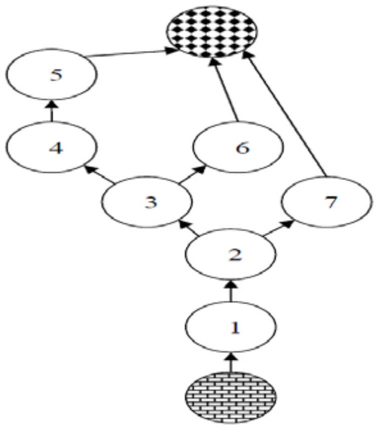


Figure 3: Control Flow Graph for pseudocode in Figure 2

For example, suppose that service A is represented by the psuedocode and the control-flow graph presented above which was presented in Figure 2 and 3 respectively. Suppose after some time, the developers of service A modify the psuedocode to what is shown in figure 4. The differences are shown in italics.

```
1 order(item) -
2 if (item exists) -
3 if (item is in stock) -
4 if (customer has money) -
5 order item;
6 return successful;
} else
7 return ERROR: 103: customer lacks funds
}
} else -
8 return error("ERROR: 104: item not in stock");
}
} else
9 return error("ERROR: 110: item does not exist");
} }
```

Figure 4: Altered psuedocode for ordering service from Fig 2.

The regression test selection approach must build the control-flow graph for this new version of the order service and that is shown with the original one in Figure 5.

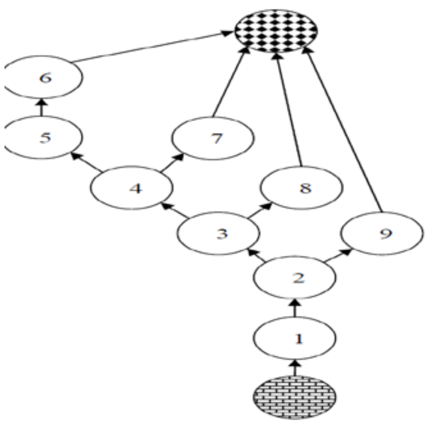


Figure 5: Control Flow Graph for pseudocode in Figure 4

The algorithm which determines the set of dangerous edges compares the two control-flow graphs by performing a dual-traversal as described. The result of the dual traversal marks the following edges dangerous: 1-2, 2-3, 2-7, and, 3-4. It selects these edges because the node corresponding to four is structurally different than the original and because the node corresponding to seven is textually different. The coverage information can easily be thought of as a table and the process is simply a table lookup using that coverage information. The technique guarantees that any test case which does not cover a dangerous edge, or entity, will behave exactly the same in both P and P', and thus can never expose a new fault in P'. Since it is guaranteed to only remove those tests which can never expose new faults in P', this technique is safe because it minimizes the number of test cases while maintaining the same level of confidence provided by selecting all test cases. For example, suppose that the original service A was augmented with test cases and coverage information which are both shown in figure 6. Note that since the code shown is psuedocode, the test cases will follow suit.

Test Cases
Inputs corresponding to three test cases
1. Order item which does not exist
2. Order item which does exist but is not in stock
3. Order item which does exist and is in stock

Expected outputs corresponding to the three test cases
1. return error
2. return error
3. return successful

Coverage Information
1. 1-2-7
2. 1-2-3-6
3. 1-2-3-4-5

Figure 6: Three test cases and their coverage information for service A

The coverage table is used as lookup table and tests numbered one and three are selected for retesting. These tests are selected because the dangerous edge list prefixes these two tests completely. Control-flow graphs are ideal for use in Web service environments for a number of reasons. Firstly, control-flow graphs can be generated from programs written in any language, or extracted from designs at any granularity. Secondly, since control-flow graphs are special cases of finite state machines, they can be composed into global finite state machines [6]. These two characteristics of control-flow graphs are essential for supporting both the interoperability and composition of web services.

5. Testing Web Services

Testing web services is more challenging compared to traditional systems for two primary reasons; the complex nature of web services and the limitations that occur due to the nature of SOA. It has been argued [7] that the distributed nature of web services based on multiple protocols such as UDDI and SOAP, together with the limited system information provided with WSDL specifications, makes web service testing challenging.

6. Test Case Prioritization

The purpose of test case prioritization is to increase the likelihood that if the test cases are used for regression testing in the given order, they will more closely meet some objective than they would if they were executed in some other order. Test cases can be prioritized in terms of the number of statements, basic blocks, or methods they executed on a previous version of the software. A second way in which prioritization techniques can be distinguished involves the use of "feedback". A third way in which prioritization techniques can be distinguished involves their use of information about code modifications. Most prioritization techniques proposed to date focus on increasing the rate of fault detection of a prioritized test suite. To measure rate of fault detection we use a metric, APFD (Average Percentage Faults Detected), introduced for this purpose in [8], which measures the weighted average of the percentage of faults detected over the life of a test suite. APFD values range from 0 to 100; higher numbers imply faster (better) fault detection rates. More formally, let T be a test suite containing n test cases, and let F be a set of m faults revealed by T. Let TF_i be the first test case in ordering T' of T that reveals fault i.

7. Average Percentage Faults Detected (APFD) Metric

To quantify the goal of increasing a subset of the test suite's rate of fault detection, i use a metric called APFD developed by Elbaum et al. [9,10] that measures the average rate of fault detection per percentage of test suite execution. The APFD is calculated by taking the weighted average of the number of faults detected during the run of the test suite. APFD can be calculated using a notation:

Let T → The test suite under evaluation
m → the number of faults contained in the program under test P
n →The total number of test cases
TFi → The position of the first test in T that exposes fault i.

$$APFD = 1 - \frac{TF_1 + TF_2 + \dots\dots + TF_m}{nm} + \frac{1}{2n}$$

So as the formula for APFD shows that calculating APFD is only possible when prior knowledge of faults is available. The APFD metric relies on two assumptions: (1) all faults have equal costs. (2) all test cases have equal costs. These assumptions are manifested in the fact that the metric plots the percentage of faults detected against the percentage of the test suite run. In practice, however, there are cases in which these assumptions do not hold: cases in which faults vary in severity and test cases vary in cost. In such cases, the APFD metric can provide unsatisfactory results, necessitating a new approach to test case prioritization that is "cognizant" of these varying test costs and fault severities.

8. Limitations of the APFD Metric

Consider the following four scenarios of cases in which the assumptions of equal test costs and fault severities are not met.

Table 1: Example Test Suite and Faults Exposed

Test	*Fault*									
	1	2	3	4	5	6	7	8	9	10
A	X				X					
B						X	X			
C	X	X	X	X	X	X	X			
D					X					
E								X	X	X

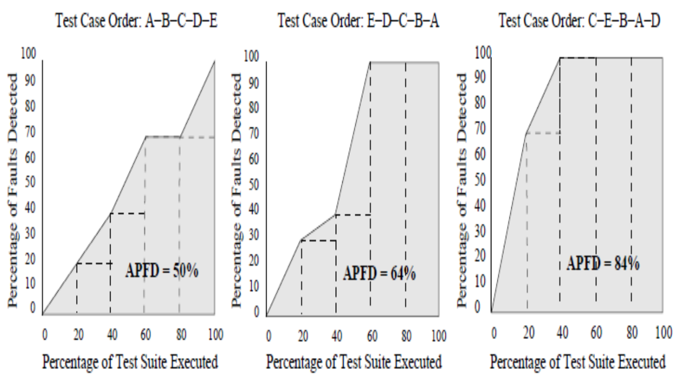
Example 1. Under the APFD metric, when all ten faults are equally severe and all five test cases are equally costly, orders A-B-C-D-E and B-A-C-D-E are equivalent in terms of rate of fault detection; swapping A and B alters the rate at which particular faults are detected, but not the overall rates of fault detection. This equivalence would be rejected in equivalent APFD graphs (as in Figure 7A) and equivalent APFD values (50%). Suppose, however, that B is twice as costly as A, requiring two hours to execute where A requires one.3 In terms of faults-detected-per-hour, test case order A-B-C-D-E is preferable to order B-A-C-D-E, resulting in faster detection of faults. The APFD metric, however, does not distinguish between the two orders.

Example 2. Suppose that all five test cases have equivalent costs, and suppose that faults 2-10 have severity k, while fault 1 has severity 2k. In this case, test case A detects this more severe fault along with one less severe fault, whereas test case B detects only two less severe faults. In terms of fault-severity detected, test case order A-B-C-D-E is preferable to order B-A-C-D-E. Again, the APFD graphs and values would not distinguish between these two orders.

Example 3. Examples 1 and 2 provide scenarios in which the APFD metric proclaims two test case orders equivalent when intuition says they are not. It is also possible, when test costs or fault severities differ, for the APFD metric to assign a higher value to a test case order that would be considered less valuable. Suppose that all ten faults are equally severe, and that test cases A, B, D, and E each require one hour executing, but test case C requires ten hours. Consider test case order C-E-B-A-D. Under the APFD metric, this order is assigned an APFD value of 84% (see Figure 7C). Consider alternative test case order E-C-B-A-D. The APFD for this order is 76% lower than the APFD for test case order C-E-B-A-D. However, in terms of faults-detected-per-hour, the second order (E-C-B-A- D) is preferable: it detects 3 faults in the first hour, and remains better in terms of faults-detected-per-hour than the first order up through the end of execution of the second test case. An analogous example can be created by varying fault severities while holding test costs uniform.

Example 4. Finally, consider an example in which both fault severities and test costs vary. Suppose that test case B is twice as costly as test case A, requiring two hours to execute where A requires one. In this case, in Example 1, assuming that all ten faults were equally severe, test case order A-B-C-D-E was preferable. However, if the faults detected by B are more costly than the faults detected by A, order B-A-C-D-E may be preferable. For example, suppose test case A has cost "1", and test case B has cost "2". If faults 1 and 5 (the faults detected by A) are assigned severity "1", and faults 6 and 7 (the faults detected by B) are assigned severities greater than "2", then order B-A-C-D-E achieves greater \"units-of fault- severity-detected-per-unit-test-cost" than does order A-B-C-D-E. Again, the APFD metric would not make this distinction. Consider an example program with 10 faults and a suite of five test cases, A through E, with fault detecting abilities as shown in Table 3. Suppose the test cases are placed in order A-B-C-D-E to form a prioritized test suite T1. Figure 7A shows the percentage of detected faults versus the fraction of T1 used. After running test case A, two of the 10 faults are detected; thus 20% of the faults have been detected after 20% of T1 has been used. After running test case B, two more faults are detected and thus 40% of the faults have been detected after 40% of the test suite has been used. In Figure 7A, the area inside the inscribed rectangles (dashed boxes) represents the weighted percentage of faults detected over the corresponding percentage of the test suite. The solid lines connecting the corners of the rectangles delimit the area representing the gain in percentage of detected faults. The area under the curve represents the weighted average of the percentage of faults detected over the life of the test suite. This area is the prioritized test suite's average percentage faults detected metric (APFD); the APFD is 50% in this example.

The notion that a tradeoff exists between the costs of testing and the costs of leaving undetected faults in software is fundamental in practice and testers face and make decisions about this tradeoff frequently. It is thus appropriate that this tradeoff be considered when prioritizing test cases, and so a metric for evaluating test case orders should accommodate the factors underlying this tradeoff. There is such a metric by adapting the APFD metric; the new "cost-cognizant" metric is named $APFD_C$. In terms of the graphs used in Figure 7 the creation of this new metric entails two modifications. First, instead of letting the horizontal axis denotes "Percentage of Test Suite Executed", the horizontal axis denotes "Percentage Total Test Case Cost Incurred".



A. APFD for prioritized suite T1 B. APFD for prioritized suite T2 C. APFD for prioritized suite T3

Figure 7: Example test case orderings illustrating the APFD metric

Now, each test case in the test suite is represented by an interval along the horizontal axis, with length proportional to the percentage of total test suite cost accounted for by that test case. Second, instead of letting the vertical axis in such a graph denotes "Percentage of Faults Detected", the vertical axis denotes "Percentage Total Fault Severity Detected". Now, each fault detected by the test suite is represented by an interval along the vertical axis, with height proportional to the percentage of total fault severity for which that fault accounts.

9. Conclusion

Assuring the quality of Web services has become increasingly more important. Organizations which depend on Web services to fulfill their business process needs must verify that those needs are being met even as the business processes evolve especially for mission critical systems such as those which directly involve customers. Therefore, regression test selection techniques will become increasingly important to any enterprise seeking to ensure that their services remain of the highest quality. A framework was developed to perform regression test selection and regression testing for the verification of Web services based on the proposed approach which is safe, distributed, automated, end-to-end, and handles the composability and interoperability aspects of Web services.

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