Improving the Effectiveness of the Classification-Tree Methodology in Software Testing

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Abstract

This paper reports on the experience in the applications of the classification-tree methodology to a real-life system. As a result of the study, we found the need to supplement the original method by introducing a new relation operator and a new technique for constructing classification trees. Our supplement helps to enforce the completeness of test cases and improve on the effectiveness of classification trees.

Keywords: Black-box testing, classification trees, partition testing, software testing, specification-based testing, test case selection.

1 Introduction

As a black-box testing technique, the classification-tree method [1, 2, 3] was developed by Grochtmann and Grimm as an extension of the category-partition method [4, 5] for identifying classifications and their associated classes from a specification. They define classifications as the different criteria for partitioning the input domain of the program to be tested, and classes as the disjoint subsets of values for each classification. The classifications of the specification are arranged hierarchically to form a classification tree. Test cases for the specification are determined by joining the terminal classes of the tree in a systematic manner.1

However, Grochtmann and Grimm assume that software testers can construct a classification tree from a specification according to their personal experience and expertise. No recommendation has been given on the actual process. Chen and Poon [6, 8] enhanced Grochtmann and Grimm’s approach by proposing a methodology for building classification trees systematically. They introduced the concept of a classification-hierarchy table and a tree construction algorithm to handle the problems of ad hoc examination of the relations among classifications and joining classifications for building a classification tree. They defined four operators (⊗, ∼, ⇒ and ⇔ ) for categorizing the hierarchical relation of a pair of classifications. A summary of the operators is shown in Appendix A.

The algorithm of constructing a classification tree consists of (i) the construction of sub-trees associated with ancestor relations; (ii) the integration of the sub-trees by putting them under a root node; and (iii) the restructuring of duplicated classifications to improve the effectiveness [7, 9, 10] of the classification tree. It is possible to have test cases generated by a classification tree with incorrect class combinations. Each legitimate test case is formed by a set of classifications such that each classification only contributes one and only one of its classes to the test case. If a test case involves two mutually exclusive classes within the same classification, it will be illegitimate.

Let \( N_l \) be the number of legitimate test cases determined from a classification tree and \( N_t \) be the total number of test cases from the tree. The effectiveness of a classification tree is defined as the ratio of \( N_l \) to \( N_t \). In general, \( N_l \geq N_t \), and hence the effectiveness of a classification tree is less than or equal to 1.

To differentiate classifications and classes from normal text, we shall use the following two symbols throughout this paper: \( \Delta(X) \) indicates a classification \( X \) and \( V(x) \) indicates a class \( x \).

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1By combining a terminal class originated from every top-level classification at a time, a class combination table is formed. Each row of the table is a test case.
2 Review of Original Construction Algorithm

2.1 Problem observed

We have studied the construction algorithm proposed by Chen and Poon by applying it to build a classification tree for an examination cancellation module of a healthcare information system. The system is a multi-user database application and has been put into production since 1994. The specification of the module was prepared with data-oriented techniques. It is shown in Appendix B. The classification-hierarchy table for the seven classifications identified from the specification is shown in Table 1.

The classification tree constructed according to the Chen and Poon methodology is shown in Figure 1(i). Let \( T_1 \) denote this classification tree. It generates 57 test cases, 10 of which are legitimate. If we check the completeness of the legitimate test cases, we will find that some valid class combinations are not included in the classification tree. The missing class combinations lead to eight legitimate test cases that cannot be generated from the classification tree. The classification-hierarchy relations involved with the missing class combinations are tabulated in Table 2.

Table 1: Classification-Hierarchy Table of the Specification for Examination Cancellation

<table>
<thead>
<tr>
<th>Classification Details</th>
<th>Associated classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam Status</td>
<td>RG, AI</td>
</tr>
<tr>
<td>Cancel Reason</td>
<td>specified, absent</td>
</tr>
<tr>
<td>User Reply</td>
<td>go, stop</td>
</tr>
<tr>
<td>Link Type</td>
<td>PS, PL, SU</td>
</tr>
<tr>
<td>Report Status</td>
<td>en, ed, pe, del</td>
</tr>
<tr>
<td>Capture Mode</td>
<td>pending, done</td>
</tr>
<tr>
<td>User Dialogue</td>
<td>yes, no</td>
</tr>
</tbody>
</table>

Table 2: Relations Excluded by the Construction Algorithm

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Cancel Reason</th>
<th>User Reply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam Status</td>
<td>⊙</td>
<td>⊙</td>
</tr>
<tr>
<td>Cancel Reason</td>
<td>⊙</td>
<td>⊙</td>
</tr>
<tr>
<td>User Reply</td>
<td>⊙</td>
<td>⊙</td>
</tr>
<tr>
<td>Link Type</td>
<td>⊙</td>
<td>⊙ ⊙</td>
</tr>
<tr>
<td>Report Status</td>
<td>⊙</td>
<td>⊙ ⊙</td>
</tr>
<tr>
<td>Capture Mode</td>
<td>⊙</td>
<td>⊙ ⊙ ⊙</td>
</tr>
<tr>
<td>User Dialogue</td>
<td>⊙</td>
<td>⊙ ⊙ ⊙</td>
</tr>
</tbody>
</table>

Four of the missing legitimate test cases are formed by combining \( \nabla(RG) \) of \( \Delta(\text{Exam Status}) \) with the classes of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \). The other four missing cases are formed by combining \( \nabla(\text{pending}) \) of \( \Delta(\text{Capture Mode}) \) with the classes of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \).

We note from this table that all the problematic relations involve the \( \odot \) operator (referred to generally as “other relations” in the Chen and Poon method). On the other hand, the classification tree is derived only from relations involved with the \( \Rightarrow \) operator in the classification-hierarchy table (referred to as “ancestor relations”). The cause of the missing legitimate test cases is the exclusion of a special case of “other relations” when the classification tree is being constructed. We need to refine the “other relations” to tackle this problem.

2.2 Introduction of a coexistence operator

Intuitively, if any class of a classification can coexist with any class of another classification, we say that the two classifications are independent of each other. We formally introduce a new operator to indicate this type of relation for a pair of classifications in a classification-hierarchy table.

We define \( \Delta(X) \) to be independent of \( \Delta(Y) \), denoted by \( \Delta(X) \odot \Delta(Y) \), if and only if any class \( \nabla(x) \) in \( \Delta(X) \) can be part of some legitimate input irrespective of whether any class \( \nabla(y) \) in \( \Delta(Y) \) is part of the same input.

A characteristic of the relation is that given \( \Delta(X) \odot \Delta(Y) \), we have \( \Delta(Y) \odot \Delta(X) \).

Because of the introduction of the \( \odot \) operator, we need to modify the definition of the \( \odot \) operator as well. Thus, we define \( \Delta(A) \) to have other relations with \( \Delta(B) \), denoted by “\( \Delta(A) \odot \Delta(B) \)”, if and only if \( \Delta(A) \) is neither a loose ancestor nor a strict ancestor nor independent of \( \Delta(B) \), and is not incompatible with it.

2.3 Problem resolution

To construct a classification tree covering all the valid class combinations according to Table 1, we should not
Figure 1: Steps for Constructing a **Catch-All Sub-Tree**
only consider ancestor relations for grouping classifications into sub-trees. We must also group classifications with coexistence relations. In order that classifications described by coexistence relations will not be missed from a classification tree, we draw them as top-level classifications in the classification tree.

In this way, we have \( \Delta(\text{Exam Status}) \), \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) as the top-level classifications of the new classification tree. The coexistence relations in Table 2 suggest that we can arrange \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) as the children of every class of \( \Delta(\text{Exam Status}) \). This new arrangement leads to the classification tree of Figure 1(iii). Using the new classification tree, we have resolved the problem of missing legitimate test cases involving \( V(RG) \) of \( \Delta(\text{Exam Status}) \) and the classes of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \).

As for the classifications under \( V(AT) \) of \( \Delta(\text{Exam Status}) \), Table 2 reminds us to apply a similar arrangement to \( \Delta(\text{Capture Mode}) \). The resulting classifications are shown in Figure 1(iii).

Among the four classifications under \( V(AT) \), we have \( \"\Delta(\text{Capture Mode}) \Rightarrow \Delta(\text{User Dialogue})\" \). We have thus arranged \( \Delta(\text{User Dialogue}) \) as shown in Figure 1(iv). \( \Delta(\text{User Dialogue}) \) is an ancestor of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) from Table 1. The resulting classifications are shown in Figure 1(v). Let \( T'_1 \) denote the classification tree in Figure 1(v). The problem of missing legitimate test cases involving \( V(\text{pending}) \) of \( \Delta(\text{Capture Mode}) \) and the classes of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) have been fixed by \( T'_1 \).

Through the construction of \( T'_1 \), we have illustrated the usefulness of the coexistence relation when constructing a classification tree. The legitimate test cases associated with the relations in Table 2 can be reflected in \( T'_1 \).

Furthermore, for this example, we need not apply the restructuring algorithm [7, 9, 10] to improve the effectiveness of \( T'_1 \) because the sub-tree \( S_{\Delta(\text{User Dialogue})} \) appears only once in \( T'_1 \). As we illustrate below, restructuring is by no means a trivial process.

Referring to Figure 1(i), the arrangement of \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) under \( \Delta(\text{User Dialogue}) \) is the structure of \( S_{\Delta(\text{User Dialogue})} \). Before applying the restructuring algorithm to \( T_1 \), the sub-tree \( S_{\Delta(\text{User Dialogue})} \) appeared under \( V(\text{pe}) \) or \( V(\text{del}) \) of \( \Delta(\text{Report Status}) \), \( V(PS) \) of \( \Delta(\text{Link Type}) \), and \( V(\text{done}) \) of \( \Delta(\text{Capture Mode}) \). Based on the criterion of returning the minimum number of test cases after restructuring, \( S_{\Delta(\text{User Dialogue})} \) under \( V(PS) \) is retained.

For the manipulation of the classifications under \( V(AT) \), the only way to retain this sub-tree while maintaining the classes \( \Delta(\text{Cancel Reason}) \) and \( \Delta(\text{User Reply}) \) with \( V(\text{pending}) \) of \( \Delta(\text{Capture Mode}) \) in \( T'_1 \) is to make use of the ancestor relation between \( \Delta(\text{Capture Mode}) \) and \( \Delta(\text{User Dialogue}) \) for establishing the hierarchy of these classifications.

### 3 Effectiveness Improvement with Catch-All Sub-Trees

In the previous section, we have demonstrated the use of both the coexistence relations and ancestor relations to construct a classification tree in a situation where the problems have already been identified. In general, we need to establish a systematic way for constructing a classification tree from a classification-hierarchy table based on the new concept. With this idea in mind, we recommend the following revised procedure:

#### (a) Construction of Catch-All Sub-Trees

Referring to Table 1 again, we note that top-level classifications cannot be descendants of other classifications. Furthermore, top-level classifications cannot be incompatible with other classifications either. However, any other classifications may be top-level classifications.

Based on these observations, we select the following as potential top-level classifications: classifications that can coexist with other classifications but are not descendents of any other classifications. We construct a sub-tree under each potential top-level classification.

In our earlier example, we have selected \( \Delta(\text{Exam Status}) \) as the only top-level classification of \( T'_1 \). In general, we recommend determining it in a systematic manner from the classification-hierarchy table. We consider every row of the classification table. If the classification corresponding to some row is a potential top-level classification, then construct a sub-tree with this classification as the root. In this case, construct other elements in the sub-tree based on every entry in the same row. We will refer to such a sub-tree as a catch-all sub-tree, since it captures all types of relations under a potential top-level classification, with the exception of “incompatible” relations. For example, \( T'_1 \) is the catch-all sub-tree of the row in Table 1 corresponding to the potential top-level classification \( \Delta(\text{Exam Status}) \).

#### (b) Streamlining the Hierarchy of Catch-All Sub-Trees

Because of the coexistence relations among potential top-level classifications, we can establish a hierarchical relationship among the potential top-level classifications. This hierarchical relationship can be streamlined in a step-by-step fashion, as illustrated
below. The streamlining steps enable us to ultimately select one of the potential top-level classifications as the only top-level classification of the final tree.

With Figure 1(v) as the starting point in determining the hierarchy of classifications under $V(AT)$, we put $\Delta(\text{Link Type})$ as a child of every class of $\Delta(\text{Capture Mode})$. This is illustrated in Figure 1(vi). According to Table 1, $\Delta(\text{Link Type})$ is an ancestor of $\Delta(\text{User Dialogue})$, $\Delta(\text{Cancel Reason})$ and $\Delta(\text{User Reply})$. This explains why we have the hierarchy in Figure 1(vi) after the arrangement.

Following the same principle, we put $\Delta(\text{Report Status})$ as a child of every class of $\Delta(\text{Capture Mode})$, as shown in Figure 1(vii). Since

- there is a coexistence relation between $\Delta(\text{Link Type})$ and $\Delta(\text{Report Status})$, and
- $\Delta(\text{Report Status})$ is an ancestor of $\Delta(\text{User Dialogue})$, $\Delta(\text{Cancel Reason})$ and $\Delta(\text{User Reply})$ according to Table 1,

we further put $\Delta(\text{Link Type})$ as a child of every class of $\Delta(\text{Report Status})$, as shown in Figure 1(viii). Let $T''_1$ denote the classification tree in Figure 1(viii). The effectiveness of $T_1$, $T'_1$ and $T''_1$ is compared in Table 3. It shows that $T''_1$ not only generates as many as valid class combinations according to Table 1, but also offers the highest effectiveness of test case generation.

<table>
<thead>
<tr>
<th>Classification Tree</th>
<th>$E_T$</th>
<th>$N_i$</th>
<th>$N_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>0.1754</td>
<td>57</td>
<td>10</td>
</tr>
<tr>
<td>$T'_1$</td>
<td>0.1964</td>
<td>112</td>
<td>22</td>
</tr>
<tr>
<td>$T''_1$</td>
<td>1</td>
<td>42</td>
<td>42</td>
</tr>
</tbody>
</table>

Table 3: Effectiveness Comparison of the Classification Trees

4 Conclusion

In this paper, the construction of a classification tree based on the concept of catch-all sub-trees has been illustrated by a real-life example. A new operator $\odot$ has been introduced in classification-hierarchy tables to highlight coexistence relations that are an important concept in the construction of classification trees.

Using the catch-all sub-tree construction approach, we have resolved the problem of missing valid class combinations caused by solely considering ancestor relations in the original construction algorithm. By applying the new approach to the same real-life example, we have also demonstrated a marked improvement in effectiveness of the resulting classification tree.

References


Appendixes

A Original Definitions Chen and Poon’s Hierarchical Operators

(1) We define $X$ to be a loose ancestor of $Y$, denoted by $X \leftrightarrow Y$, if and only if the following conditions are satisfied:

(a) There exist some $x \in X$ and $y \in Y$ such that $\text{class}(X) = x$ and $\text{class}(Y) = y$ are part of a legitimate input.

(b) There exists some $x' \in X$ such that, for any $y' \in Y$, we cannot have $\text{class}(X) = x'$ and $\text{class}(Y) = y'$ in any legitimate input.

(c) There exists some $y'' \in Y$ such that, for any $x'' \in X$, we cannot have $\text{class}(X) = x''$ and $\text{class}(Y) = y''$ in any legitimate input.

(2) We define $X$ to be a strict ancestor (or simply an ancestor) of $Y$, denoted by $X \Rightarrow Y$, if and only if the following conditions are satisfied:

(a) There exist some $x \in X$ and $y \in Y$ such that $\text{class}(X) = x$ and $\text{class}(Y) = y$ are part of a legitimate input.

(b) There exists some $x' \in X$ such that, for any $y' \in Y$, we cannot have $\text{class}(X) = x'$ and $\text{class}(Y) = y'$ in any legitimate input.

(c) There does not exist any $y'' \in Y$ such that, for any $x'' \in X$, we cannot have $\text{class}(X) = x''$ and $\text{class}(Y) = y''$ in any legitimate input.

(3) We define $X$ to be incompatible with $Y$, denoted by $X \sim Y$, if and only if for any $x \in X$ and $y \in Y$, we cannot have $\text{class}(X) = x$ and $\text{class}(Y) = y$ in any legitimate input.

(4) We define $X$ to have other relations with $Y$, denoted by $X \otimes Y$, if and only if $X$ is neither a loose ancestor nor a strict ancestor of $Y$, and is not incompatible with it.

B Specification of Examination Cancellation

An active examination is classified into the types $RG$ and $AT$. The cancellation reason for an active examination is captured in a pop-up window. The cancellation action is committed by clicking the “OK” button of the window. The “Cancel” button of the window aborts the action. The cancellation reason is mandatory for committing the action.

(a) Examinations of $RG$ Type

The captioned pop-up window is shown as above.

(b) Examinations of $AT$ Type

Before the captioned pop-up window is shown, the following steps of checking are went through:

(b₁) If the link type of an $AT$ examination is $PL$ or $SU$, the examination cannot be cancelled. The possible link types for an $AT$ examination are $PS$, $PL$, or $SU$.

(b₂) If the report status of an $AT$ examination is $pe$ or $del$, the examination can be cancelled. The possible report status for an $AT$ examination is $ed$ (Edited), $en$ (Endorsed), $pe$ (Pending) and $del$ (Deleted).

(b₃) Whether or not the data-capture work of an $AT$ examination is completed, the examination can be cancelled. For $AT$ examinations with completed data-capture work, a dialogue window is prompted to remind the status. Two options provided by the reminder are “Go” and “Stop”. The cancellation action is halted after clicking the “Stop” button.

After going through the series of checking and satisfying the criteria as mentioned above, the cancellation reason window is shown.