Accelerated reliability testing approach for high-reliability software based on the reinforced operational profile

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Schedule

1. Introduction

2. The Definition and Constructing Approach Of the Reinforced OP

3. The Accelerated SRGT Based On the Reinforced OP

4. Conclusion
1、Introduction

Software reliability testing is very significant to assure high-reliability software.

- SRGT can improve software reliability to meet the high-reliability requirement by detecting and removing the software defects which have important influence on software reliability.
- SRDT can determine the software product should be accepted or rejected by validating whether its reliability achieves the required level.
1、Introduction

However, the application of software reliability testing for high-reliability software is not very satisfactory.

- For one important reason that it often requires enormous test cases generated by the traditional reliability testing approaches under the actual OP.
- It was not feasible that the high-reliability software could be evaluated and validated by the traditional reliability testing approaches.
1、Introduction

How to accelerate testing process and achieve the same reliability requirement within the limited time and resource consuming?

Many works devoted to the accelerated software reliability testing approach have been proposed.

- Drake introduced execution time theory into testing process by the acceleration factor.
- Musa proposed testing compression factor (TCF).
- Alam proposed an approach through the experimental design.
1、Introduction

Any other approach can be used to the accelerated software reliability testing?

This paper will take Musa’s OP as the research basis.

Musa’s OP is one of the most important approaches for constructing the OP, which has many notable advantages, such as convenient modeling and unambiguous definition.

Nowadays the researches aiming to SRDT are more than the ones to SRGT.

Thus, by improving Musa’s OP based on the failure, two methods to construct the reinforced OPs and one approach to accelerate the SRGT process is presented in this paper.
Schedule

1. Introduction
2. The Definition and Constructing Approach Of the Reinforced OP
3. The Accelerated SRGT Based On the Reinforced OP
4. Conclusion
### The Definition and Constructing Approach

#### The definition of Musa’s OP

<table>
<thead>
<tr>
<th>Operation</th>
<th>$O_1$</th>
<th>$O_2$</th>
<th>$\ldots$</th>
<th>$O_n$</th>
<th>$\ldots$</th>
<th>$O_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Domain</td>
<td>$D_1$</td>
<td>$D_2$</td>
<td>$\ldots$</td>
<td>$D_n$</td>
<td>$\ldots$</td>
<td>$D_m$</td>
</tr>
<tr>
<td>Occurrence probability of Corresponding domain $D_i$</td>
<td>$p_1$</td>
<td>$p_2$</td>
<td>$\ldots$</td>
<td>$p_n$</td>
<td>$\ldots$</td>
<td>$p_m$</td>
</tr>
</tbody>
</table>

Where $O_1, O_2, \ldots, O_m$ are the operations divided by the actual usage of user $D_1, D_2, \ldots, D_m$ are the corresponding input domains of these operations, namely the division of the input space of $S$, $p_1, p_2, \ldots, p_m$ are the occurrence probabilities of the corresponding domains, which satisfy $\sum_{i=1}^{m} p_i = 1$, $p_i > 0$, $i = 1, 2, \ldots, m$. Suppose that numbers of test cases generated from $D_1, D_2, \ldots, D_m$ are $n_1, n_2, \ldots, n_m$ and $n = \sum_{i=1}^{m} n_i$, $i = 1, 2, \ldots, m$. 
2、The Definition and Constructing Approach

The reinforced OP

<table>
<thead>
<tr>
<th>Operation</th>
<th>$O_1$</th>
<th>$O_2$</th>
<th>...</th>
<th>$O_i$</th>
<th>...</th>
<th>$O_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Domain</td>
<td>$D_1$</td>
<td>$D_2$</td>
<td>...</td>
<td>$D_i$</td>
<td>...</td>
<td>$D_m$</td>
</tr>
<tr>
<td>Occurrence probability of Corresponding domain $D_i$ in Musa’s OP</td>
<td>$p_1$</td>
<td>$p_2$</td>
<td>...</td>
<td>$p_i$</td>
<td>...</td>
<td>$p_m$</td>
</tr>
<tr>
<td>Occurrence probability of Corresponding domain $D_i$ in the reinforced OP</td>
<td>$p'_1$</td>
<td>$p'_2$</td>
<td>...</td>
<td>$p'_i$</td>
<td>...</td>
<td>$p'_m$</td>
</tr>
<tr>
<td>Acceleration factor of each operation</td>
<td>$\frac{p_1}{p'_1}$</td>
<td>$\frac{p_2}{p'_2}$</td>
<td>...</td>
<td>$\frac{p_i}{p'_i}$</td>
<td>...</td>
<td>$\frac{p_m}{p'_m}$</td>
</tr>
</tbody>
</table>
2、The Definition and Constructing Approach

The acceleration factor

- The acceleration factor of the operation is defined as the ratio of the occurrence probability in Musa’s OP and the occurrence probability in the reinforced OP.

- Such as the acceleration factor of the operation $i$ in Table I and Table II can be expressed as $\Lambda_i = \frac{p_i}{p_i'}$. 

2、The Definition and Constructing Approach

The acceleration factor (Continued)

So the acceleration factor of the profile can be shown as follows.

\[
\Lambda = \frac{n'}{n} = \frac{1}{n} \left( \frac{p_1'^2}{p_1} + \frac{p_2'^2}{p_2} + \ldots + \frac{p_i'^2}{p_i} + \ldots + \frac{p_m'^2}{p_m} \right) = \frac{1}{\sum_{i=1}^{m} \frac{p_i'^2}{p_i}}
\]
2、The Definition and Constructing Approach

Constructing the reinforced OP.

The following two approaches are recommended to construct the reinforced OP.

⭐ Approach 1: Let the occurrence probabilities of the regular operations be zero and the sum of the occurrence probabilities of the critical operations be the acceleration factor.

⭐ Approach 2: Reversing the occurrence probabilities of all operations with the maximum occurrence probability.
2、The Definition and Constructing Approach

Approach 1:

- The reinforced OP only contains the critical operations, namely the undetected defects are mainly in the critical operations.
- Thus we can neglect the regular operations, reallocate the occurrence probabilities of the critical operations by improving their probabilities according to the same proportion and normalize these probabilities. Then we have

\[
p_{ci}^\prime = \frac{pc_i}{pc_1 + pc_2 + \cdots + pc_k} \quad (2)
\]

\[
\sum_{i=1}^{n} p_{ci}^\prime = 1 \quad (3)
\]
2、The Definition and Constructing Approach

It can be found that the acceleration factor of each operation is identical and satisfies the following equation.

\[ \Lambda_i = \frac{pc_i}{pc_i'} = pc_1 + pc_2 + \cdots + pc_k \quad (4) \]

The acceleration factor of the profile can be given as follows.

\[ \Lambda = \frac{1}{\sum_{i=1}^{m} \Lambda_i} = \Lambda_i = pc_1 + pc_2 + \cdots + pc_k \quad (5) \]

The acceleration factor of each operation is as the same as the acceleration factor of the profile.
2. The Definition and Constructing Approach

The problems of approach 1

- The application of Approach 1 requires abundant experience or special prior information and high confidence that undetected defects which have significant influence on reliability exist only in the critical operations with small occurrence probabilities.
- Obviously, Approach 1 has some risks when there is no prior information.

So we recommend another approach, namely Approach 2.
2、The Definition and Constructing Approach

Approach 2:

★ The reinforced OP constructed by Approach 2 not only contains the general operations, but also contains the critical operations.

★ Thus Approach 2 doesn’t have the subjectivity of Approach 1 to define the critical operations and makes all operations tested more adequately. Then we have

\[
p_i' = \frac{p_{\max} - p_i}{\sum_{i=1}^{n}(p_{\max} - p_i)}
\]

the maximum occurrence probability of all operations in Musa’s OP

★ From (1), the acceleration factor of the profile can be given as follows

\[
\Lambda = \frac{1}{\sum_{i=1}^{m} \frac{p_i^2}{p_i}}
\]

(7)
Schedule

1、Introduction

2、The Definition and Constructing Approach OF the Reinforced OP

3、The Accelerated SRGT Based On the Reinforced OP

4、Conclusion
The principle of the accelerated SRGT based on the reinforced OP

Suppose $\alpha$ is a defect of the operation $O_i$ which will cause a failure, defects $\beta, \gamma, \ldots, \theta$ are also the defects like $\alpha$ and shown in Fig.1.

The input domain which will trigger the defect $\alpha$ is expressed as $S_\alpha$.
3. The Accelerated SRGT Based On the Reinforced OP

The module of \( S_\alpha \) is denote by \( |S_\alpha| \) which means the number of the input points in \( S_\alpha \).

\( S_{\text{Oie}} \) means the set of the inputs which can cause failures in the input domain \( D_i \) of the operation \( O_i \), namely the defect domain of the input domain \( D_i \).

\( |S_{D_i}| \) means the number of the input points contained in \( D_i \).
Because one failure is caused only by one defect and is removed once it is detected in SRGT process, the failure caused by this defect can only occur once and is independent with the other failures.

Thus, in Musa’s OP, if one failure occurs when \( n \) test cases are executed, the failure probability caused by defect \( \alpha \) is denoted as follows.

\[
P_{f\alpha} = p_i \frac{|S_\alpha|}{|S_{D_i}|} \quad (8)
\]
Although the occurrence probabilities of the same operation $O_i$ in Musa’s OP and reinforced OP are different, the input domain of this operation does not change, namely $|S_{D_i}| = |S_{D'_i}|$. We have

$$\frac{p_i}{p'_i} = \frac{n'}{n}$$  \hspace{1cm} (12)

Then (12) can be rewritten as

$$n = n' \frac{p'_i}{p_i} = \frac{n'}{\Lambda_i}$$  \hspace{1cm} (13)

In other words, if one failure is detected by $n'$ test cases according to the reinforced OP, it means that one failure is detected by $\frac{n'}{\Lambda_i}$ test cases according to Musa’s OP.
3、The Accelerated SRGT Based On the Reinforced OP

Fig.2 The process of the accelerated SRGT
3. The Accelerated SRGT Based On the Reinforced OP

Case study

1) The design of case study

- A software system for selling and managing the commodities (COMS for short) is selected as the studied case.
- 27 defects are injected into COMS prior to the case study. Firstly we improve the reliability of COMS up to a high level by SRGT according to Musa’s OP.
3、The Accelerated SRGT Based On the Reinforced OP

Case study

1) The design of case study

Then we construct Musa’s OP and generate reliability test cases according to this profile.

Next we collect failure data shown in Table IV by executing these test cases and select Duane SRGM to obtain the estimate failure rate of COMS.

<table>
<thead>
<tr>
<th>No. of failure</th>
<th>MTBF(s)</th>
<th>No. of failure</th>
<th>MTBF(s)</th>
<th>No. of failure</th>
<th>MTBF(s)</th>
<th>No. of failure</th>
<th>MTBF(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>111.6</td>
<td>6</td>
<td>5 950.8</td>
<td>11</td>
<td>3 229.2</td>
<td>16</td>
<td>676.8</td>
</tr>
<tr>
<td>2</td>
<td>457.2</td>
<td>7</td>
<td>871.2</td>
<td>12</td>
<td>3 798</td>
<td>17</td>
<td>6 321.6</td>
</tr>
<tr>
<td>3</td>
<td>280.8</td>
<td>8</td>
<td>6 073.2</td>
<td>13</td>
<td>1 936.8</td>
<td>18</td>
<td>2 696.4</td>
</tr>
<tr>
<td>4</td>
<td>774</td>
<td>9</td>
<td>5 763.6</td>
<td>14</td>
<td>13 575.6</td>
<td>19</td>
<td>3 1824</td>
</tr>
<tr>
<td>5</td>
<td>115.2</td>
<td>10</td>
<td>849.6</td>
<td>15</td>
<td>17 676</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Then we construct two reinforced OPs shown in Table III according to Approach 1 and Approach 2.

Table III. Musa and the reinforced OPs of COMS

<table>
<thead>
<tr>
<th>Operation</th>
<th>Musa's profile</th>
<th>Reinforced OP 1</th>
<th>Acceleration factor of operation</th>
<th>Reinforced OP 2</th>
<th>Acceleration factor of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit</td>
<td>0.041542</td>
<td>0</td>
<td>———</td>
<td>0.049651</td>
<td>0.83688</td>
</tr>
<tr>
<td>Modify password</td>
<td>0.009989</td>
<td>0.027021</td>
<td>0.036601</td>
<td>0.063253</td>
<td>0.015636</td>
</tr>
<tr>
<td>Input supplier information</td>
<td>0.059347</td>
<td>0</td>
<td>———</td>
<td>0.043693</td>
<td>1.358272</td>
</tr>
<tr>
<td>Modify supplier information</td>
<td>0.004945</td>
<td>0.135106</td>
<td>0.036601</td>
<td>0.061898</td>
<td>0.079889</td>
</tr>
<tr>
<td>Search supplier information</td>
<td>0.061325</td>
<td>0</td>
<td>———</td>
<td>0.043031</td>
<td>1.425135</td>
</tr>
<tr>
<td>Delete supplier information</td>
<td>0.006924</td>
<td>0</td>
<td>———</td>
<td>0.061236</td>
<td>0.113071</td>
</tr>
<tr>
<td>Input customer information</td>
<td>0.108803</td>
<td>0</td>
<td>———</td>
<td>0.027143</td>
<td>4.00851</td>
</tr>
<tr>
<td>Modify customer information</td>
<td>0.004945</td>
<td>0.135106</td>
<td>0.036601</td>
<td>0.061898</td>
<td>0.079889</td>
</tr>
<tr>
<td>Search customer information</td>
<td>0.066271</td>
<td>0</td>
<td>———</td>
<td>0.041376</td>
<td>1.601677</td>
</tr>
<tr>
<td>Delete customer information</td>
<td>0.006923</td>
<td>0</td>
<td>———</td>
<td>0.061236</td>
<td>0.113054</td>
</tr>
<tr>
<td>Input goods information</td>
<td>0.189911</td>
<td>0</td>
<td>———</td>
<td>0</td>
<td>———</td>
</tr>
<tr>
<td>Modify marketing information</td>
<td>0.004945</td>
<td>0.135106</td>
<td>0.036601</td>
<td>0.061898</td>
<td>0.079889</td>
</tr>
<tr>
<td>Delete marketing information</td>
<td>0.011869</td>
<td>0</td>
<td>———</td>
<td>0.059581</td>
<td>0.199208</td>
</tr>
<tr>
<td>Input supply information</td>
<td>0.118694</td>
<td>0</td>
<td>———</td>
<td>0.023833</td>
<td>4.98024</td>
</tr>
<tr>
<td>Change supply information</td>
<td>0.005934</td>
<td>0.162127</td>
<td>0.036601</td>
<td>0.061567</td>
<td>0.096383</td>
</tr>
<tr>
<td>Search supply information</td>
<td>0.093966</td>
<td>0</td>
<td>———</td>
<td>0.032108</td>
<td>2.92656</td>
</tr>
<tr>
<td>Delete supply information</td>
<td>0.003956</td>
<td>0.108084</td>
<td>0.036601</td>
<td>0.062229</td>
<td>0.063572</td>
</tr>
<tr>
<td>Input marketing information</td>
<td>0.089023</td>
<td>0</td>
<td>———</td>
<td>0.033763</td>
<td>2.636644</td>
</tr>
<tr>
<td>Change goods information</td>
<td>0.005934</td>
<td>0.162127</td>
<td>0.036601</td>
<td>0.061567</td>
<td>0.096383</td>
</tr>
<tr>
<td>Search marketing information</td>
<td>0.108803</td>
<td>0</td>
<td>———</td>
<td>0.027143</td>
<td>4.00851</td>
</tr>
<tr>
<td>Delete goods information</td>
<td>0.004953</td>
<td>0.135324</td>
<td>0.036601</td>
<td>0.061896</td>
<td>0.080021</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>1</td>
<td>———</td>
<td>1</td>
<td>———</td>
</tr>
</tbody>
</table>

Acceleration factor of the profile

Total acceleration factor of the profile: 0.091144
3、The Accelerated SRGT Based On the Reinforced OP

After 19 defects of COMS are detected and removed, we perform SRGT on COMS based on Musa’s OP, Profile 1 and Profile 2 separately.

The failure data collected in these three testing processes are shown in Table VI, Table VII and Table VIII respectively, and the final results are shown in Table IX.
### 3. The Accelerated SRGT Based On the Reinforced OP

Table IX. Comparision of the estimate reliability results based on these three profiles

<table>
<thead>
<tr>
<th>SRGM name</th>
<th>Traditional OP</th>
<th>Reinforced OP 1</th>
<th>Reinforced OP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated model parameters</td>
<td>$N = 0.5817$</td>
<td>$N = 0.0517$</td>
<td>$N = 0.2126$</td>
</tr>
<tr>
<td>$r = 0.2102$</td>
<td>$r = 0.3884$</td>
<td>$r = 0.2739$</td>
<td></td>
</tr>
<tr>
<td>MSE</td>
<td>0.2337</td>
<td>0.5045</td>
<td>1.1387</td>
</tr>
<tr>
<td>Estimated failure rate</td>
<td>3.02E-6</td>
<td>4.27E-6</td>
<td>1.79E-6</td>
</tr>
<tr>
<td>Number of failure detected</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Total testing time(h)</td>
<td>189.01</td>
<td>10.12</td>
<td>39.62</td>
</tr>
</tbody>
</table>
Schedule

1. Introduction

2. The Definition and Constructing Approach of the Reinforced OP

3. The Accelerated SRGT Based On the Reinforced OP

4. Conclusion
4. Conclusion

Based on Musa’s OP, changing the occurrence probabilities of the operations to construct the reinforced OPs.

The principles of accelerated SRGT, and an implementing framework.

Finally, a case study on a real software system (i.e. COMS) to validate the efficiency and the feasibility of the approach respectively.
4、 Conclusion

The experimental results show that: compared with SRGT approach based on Musa’s OP, the accelerated approach can not only significantly decrease the required testing time and test cases, but also obtain the same testing conclusions and the estimation results.

Moreover, the less the acceleration factor is, the better the acceleration efficiency is.

Furthermore, improving the probabilities of the critical operations has much more influence on accelerated testing than improving the probabilities of the general ones.
Thanks

Q & A ?

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