Improving Efficiency of Passive Testing

Zhi Xu, Hasan Ural, and Zhang Fan
School of Information Technology and Engineering, University of Ottawa
Ottawa, Ontario, K1N 6N5 Canada
Email: {zxu061, ural, fzhang}@site.uottawa.ca

1 Introduction

Fault detection is a fundamental part of passive testing which determines whether a system under test (SUT) is faulty by observing the input/output behavior of the SUT without interfering its normal operations [Lee02].

The passive fault detection problem can be formulated as follows: given a specification M modeled as an FSM and a sequence Q of input/output pairs observed from an implementation N of M, where the starting state (when Q starts) of N is unknown, determine whether N is faulty. Such a decision can be based on the number of states in subset S_0 that are compatible with Q. A state s of M is *compatible with* Q if Q is a trace of M starting at s. If the number of states compatible with Q is zero then Q is sufficient to determine that N is faulty. Otherwise, Q is insufficient to determine whether N is faulty. That is there are one or more states that are compatible with Q and Q needs to be augmented by an additional I/O sequence of N to continue with the fault detection.

Lee et al developed an approach for passive fault detection problem for FSM and *Nondeterministic Finite State Machine* (NFSM) models [Lee97]. Their approach can be summarized as follows: suppose that the starting state of N is any state of M, check the observed sequence Q of input/output pairs one-by-one from the beginning, reduce the size of possible current states by eliminating impossible states until either no state is possible (N is faulty) or there is at least one state (no fault can be detected by Q) (as in Figure 1). The approach in [Lee97] is comprehensive but not efficient enough. In this approach, every state of M needs to be checked. However, the number of states compatible with Q is usually comparatively small and checking every state of M would be unnecessary. Further, this approach only determines the set of possible current states when it terminates. A post-processing will be needed to retrieve the information about possible starting state and possible trace corresponding to Q.

In this paper, we propose a new approach to *Finite State Machine-based* (FSM–based) passive fault detection which aims at improving the performance of the approach in [Lee97] and gathering more information during testing compared with the approach in [Lee97]. The results of theoretical and experimental evaluations are reported.

2 The new Approach

The new approach proposed is based on the following idea: randomly pick a state s in subset S_0 of the set of states of M and determine whether Q is the trace of M at s; if s is compatible with Q, stop and declare that Q is not sufficient to determine whether N is faulty. In this case, Q is a trace of M at s and the current state of M can be determined readily; if not, continue to check other states in S_0 (as in Figure 1). After checking all the states in S_0, if no state is found to be compatible with Q, then N is declared to be faulty.

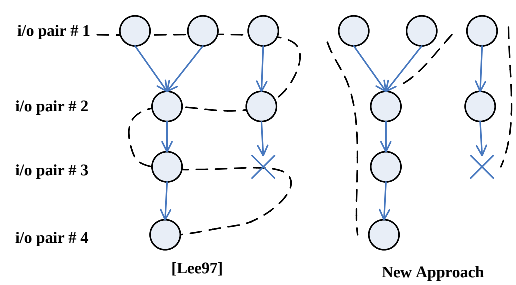

Figure 1. checking order

3 Comparison of the Approaches

In order to make the analysis and further comparisons of the approaches, we consider the *number of comparisons* between the actual output y_j and the expected output $\lambda(s, x_j)$ as the measure of computational complexity

(1) Let S_j denote the set of possible current states right after the first j input/output pairs of Q, the computational complexity of [Lee97] is $C_1 = \sum_{j=1}^{k} |S_j|$.

(2) For a given state s_i of M and an I/O sequence $Q = x_1\ldots x_k$ / $y_1\ldots y_k$, let $c_i'(Q)$ denote the largest number j ($2 \le j \le$ k) such that (I) $y_1\ldots y_{j\text{-}1} = \lambda(s_i, x_1\ldots x_{j\text{-}1})$; (II) for every l ($1 \le l \le j$-1), $\delta(s_i, x_1\ldots x_l)$ is not in the set of visited states. If the r^{th} state checked, s_r, is the first state of M such that Q is a trace of M at s, then the computational complexity of the new approach: $C_2(M, S_0, Q) = \sum_{i=1}^{r} c_i'(Q)$; if N is faulty, then $C_{2worst}(M, S_0, Q) = \sum_{i=1}^{n} c_i'(Q)$; if $r = 1$, $C_{2best}(M, S_0, Q) = c_1'(Q)$.

Consider the average complexity. In [Lee97], once the set (M, S_0, Q) is fixed, the number of comparisons needed is determined and does not change during its application. On the other hand, the performance of our approach is affected by the number of states in S_0 which are compatible with Q. Suppose there are m ($0 \le m \le n$) states in S_0 which are compatible with Q. Let $P_r(m)$ denote the probability that the r^{th} state is the first state which is compatible with Q. The average complexity of the our approach is

$$\begin{aligned} A_2 &= \sum_{r=1}^{n-m+1} P_r(m) C_2(M, S_0, Q) \\ &= \sum_{r=1}^{n-m+1} \left(P_r(m) \sum_{i=1}^{r} c_i'(Q)\right). \end{aligned}$$

$$P_r(m) = \begin{cases} \dfrac{m}{n} & (r=1); \\ \dfrac{m(n-m)(n-m+1)\ldots(n-m-r+2)}{n(n-1)\ldots(n-r+1)} & (2 \le r \le n-m+1). \end{cases}$$

If there is no state in S_0 which is compatible with Q, both approaches need to check the entire trace from every state in S_0 and thus these two approaches perform equally. That is $\sum_{i=1}^{n} c_i'(Q) = \sum_{j=1}^{k} |S_j|$.

If there is only one state s in S_0 which is compatible with Q, then the total number of comparisons made by [Lee97] is $\sum_{j=1}^{k} |S_j|$ whereas the total number of comparisons made by the our approach is $\sum_{i=1}^{r} c_i'(Q)$ ($r \le n$). Clearly, $\sum_{i=1}^{r} c_i'(Q) \le \sum_{i=1}^{n} c_i'(Q) = \sum_{j=1}^{k} |S_j|$, ($r \le n$) where the r^{th} state checked is the state compatible with Q.

Thus, our approach always performs at least as well as [Lee97]. The equality in their computational complexity occurs when $r = n$.

4 Experimental Evaluation

In the experiment, we use a set of FSMs randomly generated by CSG team [TSG94]. This set consists of FSMs with different number of states ($|S_0|$), finite set of inputs ($|X|$) and outputs ($|Y|$). We select 5 configurations in the form of ($|S_0|$, $|X|$, $|Y|$), such as (5, 3, 3), (10, 4, 4), (15, 4, 4), (20, 5, 5), (30, 10, 10). For each configuration, we generate 5 FSMs correspondingly. For each FSM M in F, two cases are considered in the experiment.

In Case I, called *correct implementation*, there is exactly only one state in S_0 that is compatible with Q ($m = 1$). In Case II, called *faulty implementation*, there is no state in S_0 that is compatible with Q ($m = 0$) and "faulty" is expected to be reported. For every state s of M, we generate three random I/O sequences of length ($|Q|$) $|S_0|*|X|*2$, $|S_0|*|X|*4$, $|S_0|*|X|*10$ respectively, starting from s. When generating the I/O sequence, we randomly select a transition of the current state of M and repeat this at the next state.

Table 1 shows the number of comparisons (between the actual output y_j and the expected output $\lambda(s, x_j)$) for each of the two approachess in the best case, worst case, and average case.

Table 1

			Case I : m = 1			Case II : m = 0		
[Lee97]	$\|Q\|$	$\|S_0\|$	best	worst	average	best	worst	average
	60	5	64	74	65.5	6	58	17.8
	160	10	169	175	171.3	11	162	31.7
	240	15	254	262	258.0	16	252	42.8
	400	20	419	429	423.0	21	399	44.7
	1200	30	1229	1236	1231.9	31	1122	73.0
New Approach	|Q|	|S0|	Best	worst	average	best	worst	average
	60	5	60	65	61.9	6	58	17.8
	160	10	160	171	164.3	11	162	31.7
	240	15	240	262	247.9	16	252	42.8
	400	20	400	427	409.6	21	399	44.7
	1200	30	1200	1234	1215.3	31	1122	73.0

The experimental results confirm the assertions we present in previous complexity analysis.

5 Conclusion

In this paper, we proposed a new approach to *Finite State Machine-based* (FSM–based) passive fault detection. Compared with the former approach in [Lee97], the proposed approach has better performance and provides more information during testing. The results of both theoretical and experimental evaluations confirm the improvement over the approach of [Lee97].

6 Reference

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