Isolating Failure-Inducing Combinations in Combinatorial Testing using Test Augmentation and Classification

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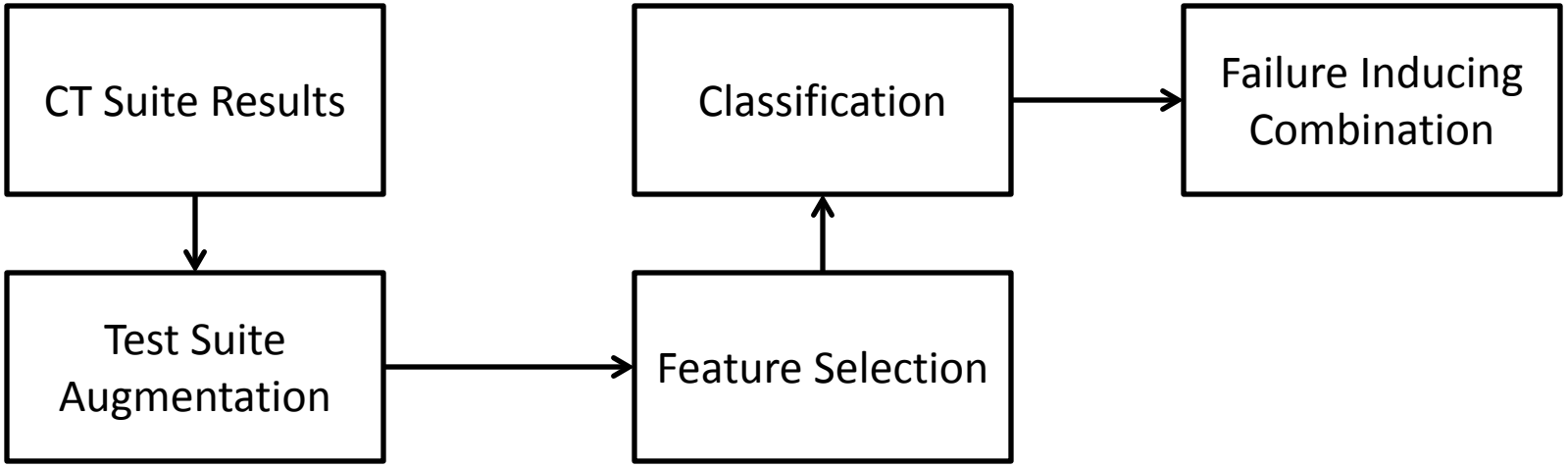
Motivation

- Software normally has faults.
- Given a System Under Test (SUT) with N input parameters, a failure is usually caused by interaction among k parameters where k << N.
- Problem:
  - Generating CT for even a small k (such as 5 or 6) is computationally expensive for SUT with large N.
  - CT results may be insufficient for diagnosis due to failures caused by interactions among 5 or more parameters (aka *faulty combinations*)

Background

Previous Approach

Our Approach



Problem

1. Often its hard to judge the size of faulty interactions.
2. Generating CT of higher strength is expensive.
3. Fault diagnosis on lower strength CT results may not be provide good results.

Agenda

1. Problem
2. Example
3. Approach
4. Proof of Concept
5. Conclusion

Example

- Consider TCAS v16
  - # of Parameters: 12
  - Total Input Space: $3 \times 2^3 \times 3 \times 2 \times 4 \times 10^2 \times 3 \times 2 \times 3 = 1036800$
- Assume we don't know in advance the nature of failures.

Example (contd..)

Parameters	Values
Cur_Vertical_Sep	299, 300, 601
High_Confidence	0, 1
Two_of_Three_Reports_Valid	0, 1
Own_Tracked_Alt	1, 2
Own_Tracked_Alt_Rate	
Other_Tracked_Alt	1, 2
Alt_Layer_Value	0,1,2,3
Up_Separation	0, 399, 400, 499, 500, …
Down_Separation	0, 399, 400, 499, 500, …
Other_RAC	0, 1, 2
Other_Capability	1, 2
Climb_Inherit	0,1

Example (continue..)

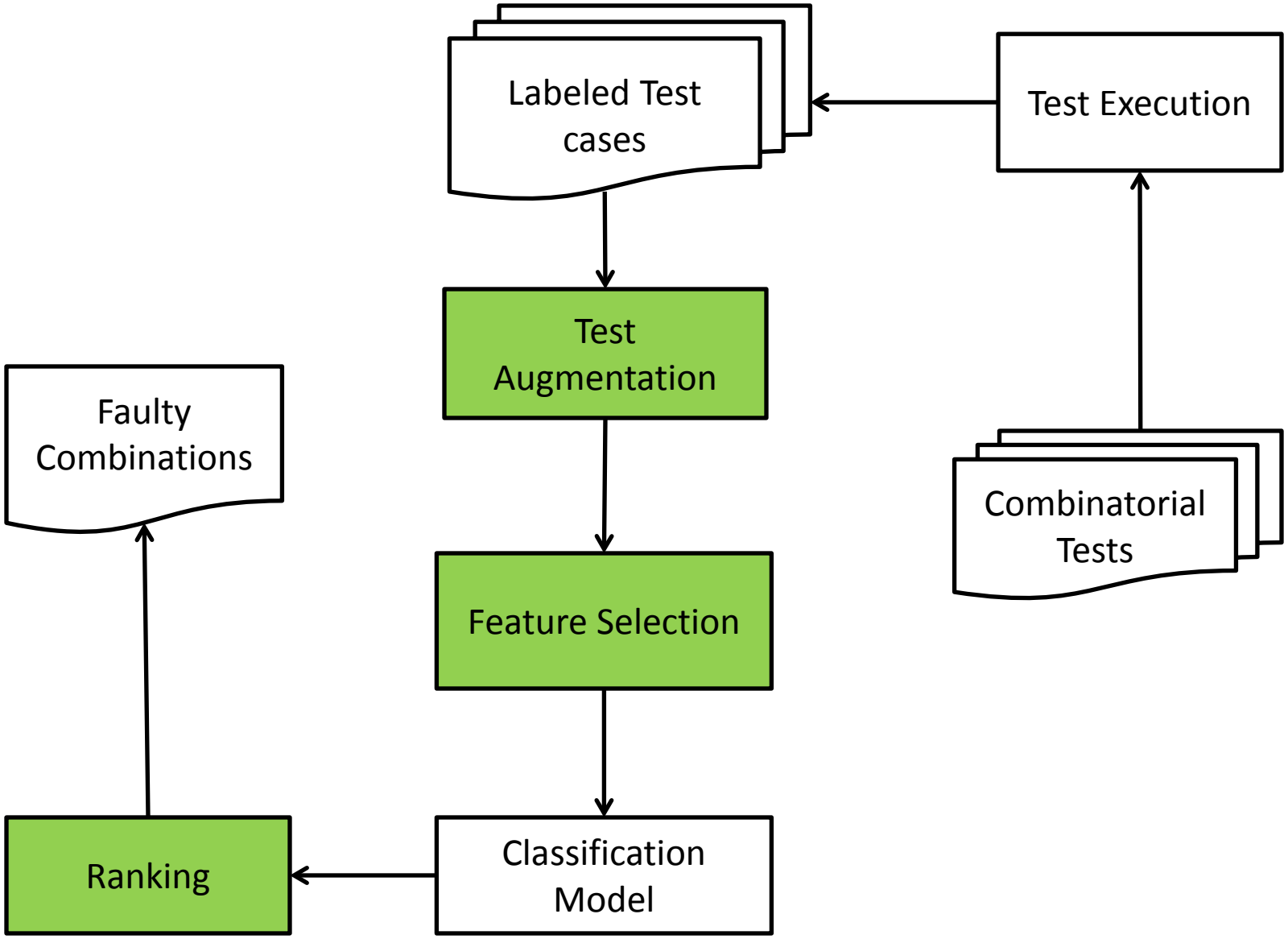
Characteristic of Failure (TCAS v16)

CT Strength	Failing/Total Number of Tests
2-way	0/156
3-way	1/461
4-way	6/1450
5-way	14/4309

Example (continue..)

- Result of Classification Tree:
  - (EMPTY)
- Reason:
  - Data Set is Highly Unbalanced.
  - Not enough Failing Tests.

Approach


Labeled Test cases
Test Execution
Test Augmentation
Faulty Combinations
Combinatorial Tests
Feature Selection
Ranking
Classification Model

Test Augmentation

- Use OFOT [1] (one factor one time) method to generate additional tests from failing tests.

Ex: Given a Failing Test:

601,1,1,1,600,2,3,740,400,0,2,1

OFOT generates

300,1,1,1,600,2,3,740,400,0,2,1

299,1,1,1,600,2,3,740,400,0,2,1

601,0,1,1,600,2,3,740,400,0,2,1

.....

1. C. Nie and H. Leung, “The minimal failure-causing schema of combinatorial testing,” 2011.

Test Augmentation (continue..)

- Maximum number of tests generated by OFOT is

$$m \times \left(\sum_{i=1}^{k} a_i - k \right)$$

where m is total no of failing tests, k is the number of parameters, and a_i is distinct input values for each parameter.

- This is far less than the number of tests required to build higher strength array.
- For Example: 6-way Tests: 6,785 vs OFOT: 612

Test Augmentation (continue..)

- Run the classification tree algorithm

```
High_Confidence = 0: 0 (2248.0/12.0)
High_Confidence = 1
|   Alt_Layer_Value = 0
|   |   Own_Tracked_Alt_Rate = 600
|   |   |   Cur_Vertical_Sep = 299: 0 (149.0/12.0)
|   |   |   Cur_Vertical_Sep = 300
|   |   |   |   Two_of_Three_Reports_Valid = 0: 0
(28.0/2.0)
|   |   |   |   Two_of_Three_Reports_Valid = 1
|   |   |   |   |   Other_RAC = 0
|   |   |   |   |   |   Other_Tracked_Alt = 1
|   |   |   |   |   |   |   Other_Capability = 1: 1 (4.0)
|   |   |   |   |   |   |   Other_Capability = 2: 0 (3.0)
|   |   |   |   |   |   Other_Tracked_Alt = 2: 1 (6.0)
...(and many more nodes)
```

Test Augmentation (continue..)

Test Augmentation Result

Version	Test Aug	Effectiveness
16	302/357	73%
26	407/407	80%

Feature Selection

- Can we do more?
  - Developers typically use classification tree to manually analyze the nature of faults
  - Clearly smaller the size of tree, easier will be the debugging process
- For Example:
  - Classification tree generated for TCAS has 56 nodes
  - Can we reduce the size of classification tree?

Feature Selection (continue..)

- Objective of Feature Selection
  - Identifying and removing irrelevant and redundant information as much as possible.
- What kind of feature Selection:
  - Correlation based feature selection (H.A.Mark, Ph.D.dissertation, Univ of Waikato, 1999.)

Feature Selection (contd..)

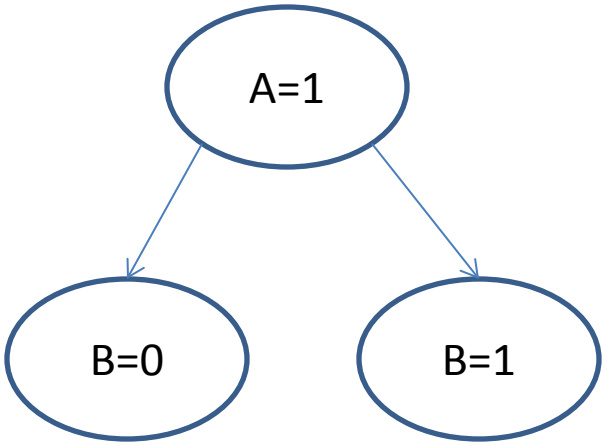
Parameters	Values
Cur_Vertical_Sep	299, 300, 601
High_Confidence	0, 1
~~Two_of_Three_Reports_Valid~~	~~0, 1~~
~~Own_Tracked_Alt~~	~~1, 2~~
Own_Tracked_Alt_Rate	
~~Other_Tracked_Alt~~	~~1, 2~~
Alt_Layer_Value	0,1,2,3
Up_Separation	0, 399, 400, 499, 500, …
Down_Separation	0, 399, 400, 499, 500, …
Other_RAC	0, 1, 2
Other_Capability	1, 2
~~Climb_Inherit~~	~~0,1~~

Feature Selection (Evaluation)

Version	Test Aug	Effectiveness	Size of Tree	Feature Subset	Size of Reduced Tree	Effectiveness
16	302/357	73%	56	8	31	65%
26	407/407	80%	85	10	28	74%

Ranking

- For each leaf node that indicates a failure, a corresponding likely faulty combination is computed by
  - Taking the conjunction of the parameter values found in the path from the root node to the leaf node
  - Calculate its score



Combination:
A =1 and B=1
10/12 = .83

Proof of Concept

- Hypothesis: The faulty should show up higher in the rank.

- Final Outcome:
  - TCAS v26, our approach did found the faulty combination.
  - TCAS v16, out of two combinations, our approach found one of them.

Proof of Concept

Real Fault

```
int  alt_sep_test() {
 ....
enabled=High_Confidence &&
 /*(Own_Tracked_Alt_Rate<=OLEV) && BUG  */
 (Cur_Vertical_Sep>MAXALTDIFF);
....
}
```

HighConfidence=1 && OwnTrackedAltRate>OLEV(=600) &&
CurVerticalSep>MAXALTDIFF(=600)

Conclusion

- Diagnosis of failure when the number of failures are low.
- Our approach:
  - Tries to balance the test generation and classification for fault diagnosis
- Proof of concept on two versions of TCAS

Thank you

Questions?