CS 5154: Software Testing

Coverage Criteria and Input Space Partitioning

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The next step in ISP require coverage criteria

• Step 1: Identify testable functions in your program
• Step 2: Find all input parameters
• Step 3: Model the input domain
• Step 4: Use a criterion to choose combination of values
• Step 5: Refine combinations of blocks into test inputs
But what is a coverage criterion?
Example 1: statement coverage criterion

• What elements of software should tests exercise?
  \[ \text{loc} \]

• What rule do we want to impose on the tests?
  \[ \text{Cover all lines} \]

• How do we check if the rule is satisfied?
  \[ \text{did you cover them all?} \]
Example 2: branch coverage criterion

- What elements of software should tests exercise?
  - Control branches (if, while)

- What rule do we want to impose on the tests?
  - Each branch must eval to T & F

- How do we check if the rule is satisfied?
  - How many branches satisfy the rule?
These questions point to general concepts

• What elements of software do should tests exercise?
  • Test requirements

• What rule(s) do we want to impose on the tests?
  • Coverage criteria

• How do we measure the degree to which the rules are met?
  • Coverage
Defining these three concepts generally

- **Test Requirement**: A software element that a test must satisfy or cover

- **Coverage Criterion**: A rule or collection of rules that impose test requirements on a set of tests

- **Coverage**: Given a set of test requirements $TR$ for coverage criterion $C$, a test set $T$ satisfies $C$ coverage if and only if for every test requirement $tr$ in $TR$, there is at least one test $t$ in $T$ such that $t$ satisfies $tr$
We saw these concepts in CS5154 (indexOf)

Graph: abstract version

Initial Node: 1
Final Nodes: 4, 5

Edges
1 2
2 3
3 2
3 4
2 5

6 requirements for Edge-Pair Coverage
1. [1, 2, 3]
2. [1, 2, 5]
3. [2, 3, 4]
4. [2, 3, 2]
5. [3, 2, 3]
6. [3, 2, 5]

Test Paths
[1, 2, 5]
[1, 2, 3, 2, 5]
[1, 2, 3, 2, 3, 4]

Convention:

\[
([1, 2], [2, 3]) = [1, 2, 3]
\]
Question after last class

• Program P has six if statements. How many test requirements does the branch coverage criteria impose on tests for P?

☐ 2 * 6

☐ 2 ^ 6

Do we need 2^6 tests to satisfy branch coverage?
Question for you

Why do we need these general and fairly abstract definitions?
Do we always want 100% coverage?

• **Coverage Level**: The ratio of the number of test requirements satisfied by \( T \) to the size of \( TR \)

• What if
  • we just started programming?
  • 100% coverage is too expensive?
  • we just want to get a sense of how we are doing?

• It makes sense to measure the degree of coverage
Is 100% coverage **always** possible?

- **Coverage**: Given a set of test requirements \( TR \) for coverage criterion \( C \), a test set \( T \) satisfies \( C \) coverage if and only if for every test requirement \( tr \) in \( TR \), there is at least one test \( t \) in \( T \) such that \( t \) satisfies \( tr \)

- What if some \( tr \) is impossible to satisfy?
  - Example: dead code

- An **infeasible** test requirement is one that cannot be satisfied
How to handle infeasible test requirements?

• Drop infeasible $tr$ from TR

• Replace infeasible $tr$ with less stringent TR

• Thoughts?
Quiz: Who said it?

Four score and seven years ago our fathers brought forth on this continent, a new nation, conceived in Liberty, and dedicated to the proposition that all men are created equal.
Are all criteria born equal?

• These tests satisfy 100% statement coverage but miss a fault

```java
int stringFactor(String i, int n) {
    if (i != null || n != 0)
        return i.length() / n;
    else
        return -1;
}
```

// Tests: ("happy", 2), (null, 0)

• Trick question: Will tests that satisfy 100% branch coverage find the fault?

• Teaser: “stronger” criteria can help, e.g., Multiple Condition Decision Coverage
Subsumption: comparing criteria “strength”

- **Criteria Subsumption**: Test criterion $C_1$ subsumes $C_2$ if and only if every set of test cases that satisfies $C_1$ also satisfies $C_2$

- Examples that we have seen in CS 5154:
  - Branch coverage subsumes statement coverage
  - Edge-Pair coverage subsumes edge coverage

- Jing
Homework: Set relationships in subsumption

- Let $C_1$ and $C_2$ be two distinct coverage criteria whose sets of test requirements are $TR(C_1)$ and $TR(C_2)$, respectively. If $C_1$ subsumes $C_2$, which of the following is correct?

  - $TR(C_1)$ is a superset of $TR(C_2)$
  - There is a many-to-one relation between $TR(C_1)$ and $TR(C_2)$
  - There is a one-to-many relation between $TR(C_1)$ and $TR(C_2)$
Questions about coverage criteria
So, how can criteria help us with ISP?

• triang() characteristic: relation of each side to 0

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$b_1$</th>
<th>$b_2$</th>
<th>$b_3$</th>
<th>$b_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_1$</td>
<td>greater than 1</td>
<td>equal to 1</td>
<td>equal to 0</td>
<td>less than 0</td>
</tr>
<tr>
<td>$q_2$</td>
<td>greater than 1</td>
<td>equal to 1</td>
<td>equal to 0</td>
<td>less than 0</td>
</tr>
<tr>
<td>$q_3$</td>
<td>greater than 1</td>
<td>equal to 1</td>
<td>equal to 0</td>
<td>less than 0</td>
</tr>
</tbody>
</table>

• How should we consider multiple partitions at the same time?
• What combination of blocks should we choose values from?
Idea 1: choose all combinations

- **All Combinations Coverage (ACoC) Criterion**: All combinations of blocks from all characteristics must be used.

- The number of resulting tests is the product of the number of blocks in each characteristic:
  \[ \prod_{i=1}^{Q} (B_i) \]
ACoC for triang()

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>b₁</th>
<th>b₂</th>
<th>b₃</th>
<th>b₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>q₁</td>
<td>greater than 1</td>
<td>equal to 1</td>
<td>equal to 0</td>
<td>less than 0</td>
</tr>
<tr>
<td>q₂</td>
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<td>equal to 1</td>
<td>equal to 0</td>
<td>less than 0</td>
</tr>
<tr>
<td>q₃</td>
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- Owolabi relabeled the blocks using same values in corresponding blocks for each characteristic for illustration purposes only:
ACoC tests for triang()

ACoC yields 4*4*4 = 64 tests for triang()!

This is almost certainly more than we need

Only 8 tests have all sides greater than zero
Idea 2: use at least one value from each block

• **Each Choice Coverage (ECC) Criterion**: One value from each block for each characteristic must be used in at least one test case.

• The number of resulting tests is at least the largest number of blocks among all characteristics:

\[
\text{Max}_{i=1}^{Q} (B_i)
\]
ECC Example

- These three tests satisfy ECC: (A, 1, x), (B, 2, y), (A, 3, x)
- There are many ways to pick tests that satisfy ECC
- Do you see a weakness of ECC?
  - ECC doesn’t require using a value with other values
    - e.g., (A, 2, y) may reveal a fault

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<tbody>
<tr>
<td>q_1</td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>q_2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>q_3</td>
<td>x</td>
<td>y</td>
<td></td>
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Idea 3: require pair-wise combinations

• **Pair-Wise Coverage (PWC) Criterion**: A value from each block for each characteristic must be combined with a value from every block for all other characteristics.

• The resulting number of tests is at least the product of the size of the two largest characteristics:

\[
(\text{Max}_{i=1}^{Q}(B_i)) \times (\text{Max}_{j=1, j\neq i}^{Q}(B_j))
\]
PWC Example

• 5 combinations with A: (A, 1), (A, 2), (A, 3), (A, x), (A, y)
• 5 combinations with B: (B, 1), (B, 2), (B, 3), (B, x), (B, y)
• 6 combinations with q2 and q3 values: (1, x), (1, y), (2, x), (2, y), (3, x), (3, y)
• These 16 combinations can be combined in several ways:
  (A, 1, x) (A, 2, x) (A, 3, x) (A, -, y)
  (B, 1, y) (B, 2, y) (B, 3, y) (B, -, x)

Can still miss (A, 2, y)
Idea 4: extend pairwise to t-wise

• Problem(?): pair-wise only requires all two-combinations values
  • e.g., we may not choose (A, 2, y) on the previous slide

• The fault may be revealed by checking t-combinations

• **t-Wise Coverage (TWC) Criterion**: A value from each block for each group of t characteristics must be combined
Some questions about t-wise coverage

• What is the least number of resulting tests?

• What happens if $t$ is equal to the number of characteristics?

• Does t-wise coverage help much more than pair-wise coverage?

We don't know
A note on the ISP criteria that we saw so far

They are mindless!
Idea 5: use domain knowledge

- **Base Choice Coverage (BCC) Criterion:**
  1. A base choice block is chosen for each characteristic, and a base test is formed by using the base choice for each characteristic.
  2. Subsequent tests are chosen by holding all but one base choice constant and using each non-base choice in each other characteristic.

- The resulting number of tests: one base test + one test for each other block
  
  \[ 1 + \sum_{i=1}^{Q} (B_i - 1) \]

- BCC allows using domain knowledge to select the base choice blocks
BCC Example

• Let ‘A’, ‘1’, and ‘x’ be the base choice blocks in $q_1$, $q_2$, and $q_3$ respectively

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</tr>
<tr>
<td>$q_2$</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>$q_3$</td>
<td>x</td>
<td></td>
<td>y</td>
</tr>
</tbody>
</table>

• Base choice test: (A, 1, x)

• Additional tests: (B, 1, x)
  (A, 2, x)
  (A, 3, x)
  (A, 1, y)
Idea 6: what if I cannot choose 1 base choice?

- **Multiple Base Choice Coverage (MBCC) Criterion:**
  - At least one, and possibly more, base choice blocks are chosen for each characteristic, and base tests are formed by using each base choice for each characteristic at least once.
  - Subsequent tests are chosen by holding all but one base choice constant for each base test and using each non-base choice in each other characteristic.

- See textbook for the formula of upper bound of resulting tests
Recap on ISP coverage criteria

All Combinations Coverage
ACoC

T-Wise Coverage
TWC

Each Choice Coverage
ECC

Base Choice Coverage
BCC

Pair-Wise Coverage
PWC

Multiple Base Choice Coverage
MBCC

Which of these criteria subsume the other(s)?
Subsumption among ISP criteria

- T-Wise Coverage (TWC)
- Pair-Wise Coverage (PWC)
- Each Choice Coverage (ECC)
- All Combinations Coverage (ACoC)
- Multiple Base Choice Coverage (MBCC)
- Base Choice Coverage (BCC)
Summary: Input Space Partitioning

• Step 1: Identify testable functions in your program
• Step 2: Find all input parameters
• Step 3: Model the input domain
• Step 4: Use a criterion to choose combination of values
• Step 5: Refine combinations of blocks into test inputs
Next...

• Graph-based Model-Driven Test Design