CS 5154: Software Testing

Coverage Criteria and Input Space Partitioning

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Fall 2021

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?

- What rule do we want to impose on the tests?

- How do we check if the rule is satisfied?

Example 2: branch coverage criterion

- What elements of software should tests exercise?

- What rule do we want to impose on the tests?

- How do we check if the rule is satisfied?

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 criteri{a,on}**
- How do we measure the degree to which the rules are met?
  - **Coverage level**

Defining these three concepts generally

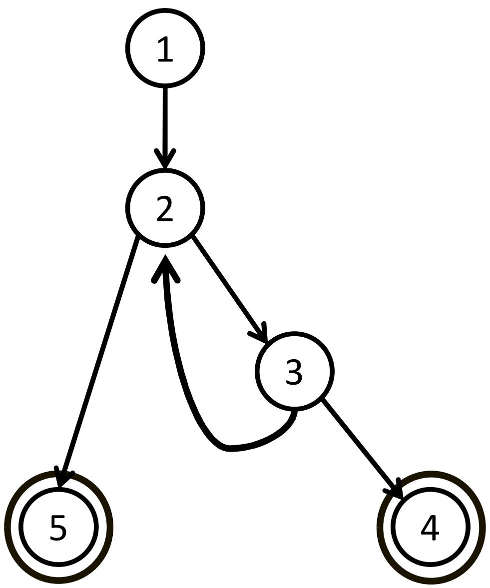
- **Test Requirement** : A software element that a test must satisfy or cover

- **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



Convention :

Edges
1 2
2 3
3 2
3 4
2 5
Initial Node: 1
Final Nodes: 4, 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]

([1, 2], [2, 3]) = [1, 2, 3]

Question for you

- 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 writing the code for our program?
  - 100% coverage is too expensive to attain?
  - we just want to get a sense of how we are doing?

- It sometimes 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

- Other 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.

coverage criteria?

Are all criteria born equal?

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

```
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 *C1* subsumes *C2* if and only if every set of test cases that satisfies *C1* also satisfies *C2*

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

Homework: Set relationships in subsumption

- Let C1 and C2 be two distinct coverage criteria whose sets of test requirements are TR(C1) and TR(C2), respectively. If C1 subsumes C2, which of the following is correct?

  - ❑ TR(C1) is a superset of TR(C2)
  - ❑ There is a many-to-one relation between TR(C1) and TR(C2)
  - ❑ There is a one-to-many relation between TR(C1) and TR(C2)

Questions about coverage criteria

?

So, how can criteria help us with ISP?

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

Characteristic	b_1	b_2	b_3	b_4
q_1	greater than 1	equal to 1	equal to 0	less than 0
q_2	greater than 1	equal to 1	equal to 0	less than 0
q_3	greater than 1	equal to 1	equal to 0	less than 0

- 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 test inputs is the product of the number of blocks in each characteristic :

$$\prod_{i=1}^{Q} (B_i)$$

ACoC for triang()

Characteristic	b_1	b_2	b_3	b_4
q_1	greater than 1	equal to 1	equal to 0	less than 0
q_2	greater than 1	equal to 1	equal to 0	less than 0
q_3	greater than 1	equal to 1	equal to 0	less than 0

- Owolabi relabeled the blocks using same values in corresponding blocks for each characteristic for illustration purposes only:

Characteristic	b_1	b_2	b_3	b_4
q_1	2	1	0	-1
q_2	2	1	0	-1
q_3	2	1	0	-1

ACoC test inputs for triang()

2 2 2	1 2 2	0 2 2	-1 2 2
2 2 1	1 2 1	0 2 1	-1 2 1
2 2 0	1 2 0	0 2 0	-1 2 0
2 2 -1	1 2 -1	0 2 -1	-1 2 -1
2 1 2	1 1 2	0 1 2	-1 1 2
2 1 1	1 1 1	0 1 1	-1 1 1
2 1 0	1 1 0	0 1 0	-1 1 0
2 1 -1	1 1 -1	0 1 -1	-1 1 -1
2 0 2	1 0 2	0 0 2	-1 0 2
2 0 1	1 0 1	0 0 1	-1 0 1
2 0 0	1 0 0	0 0 0	-1 0 0
2 0 -1	1 0 -1	0 0 -1	-1 0 -1
2 -1 2	1 -1 2	0 -1 2	-1 -1 2
2 -1 1	1 -1 1	0 -1 1	-1 -1 1
2 -1 0	1 -1 0	0 -1 0	-1 -1 0
2 -1 -1	1 -1 -1	0 -1 -1	-1 -1 -1

ACoC yields 4*4*4 = 64 test inputs for triang()!

This is almost certainly more than we need

Only 8 inputs have 3 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 <u>at least</u> the largest number of blocks among all characteristics :

$$\mathrm{Max}_{i=1}^{Q}(B_i)$$

ECC Example

Characteristic	b_1	b_2	b_3
q_1	A	B	
q_2	1	2	3
q_3	x	y	

- 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 combining a value with other values
  - e.g., (A, 2, y) may reveal a fault

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 <u>at least</u> the product of the size of the two largest characteristics:

$$(\mathrm{Max}_{i=1}^{Q}(B_i)) * (\mathrm{Max}_{j=1,\, j!=i}^{Q}(B_j))$$

PWC Example

Characteristic	b_1	b_2	b_3
q_1	A	B	
q_2	1	2	3
q_3	x	y	

- 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)

"–" : any value

Can still miss (A, 2, y)

Idea 4: extend pairwise to t-wise

- Problem(?): pair-wise only requires all two-combination 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?

Product of largest 't' characteristics

- What happens if *t* is equal to the number of characteristics?

ACoC

- 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

Characteristic	b_1	b_2	b_3
q_1	A	B	
q_2	1	2	3
q_3	x	y	

- Let 'A', '1', and 'x' be the base choice blocks in q_1, q_2, and q_3 respectively
- Base choice test: (A, 1, x)
- Additional tests: (B, 1, x)
  (A, 2, x)
  (A, 3, x)
  (A, 1, y)

Idea 6: choosing more than one 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

Each Choice Coverage

ECC

Pair-Wise Coverage

PWC

T-Wise Coverage

TWC

Base Choice Coverage

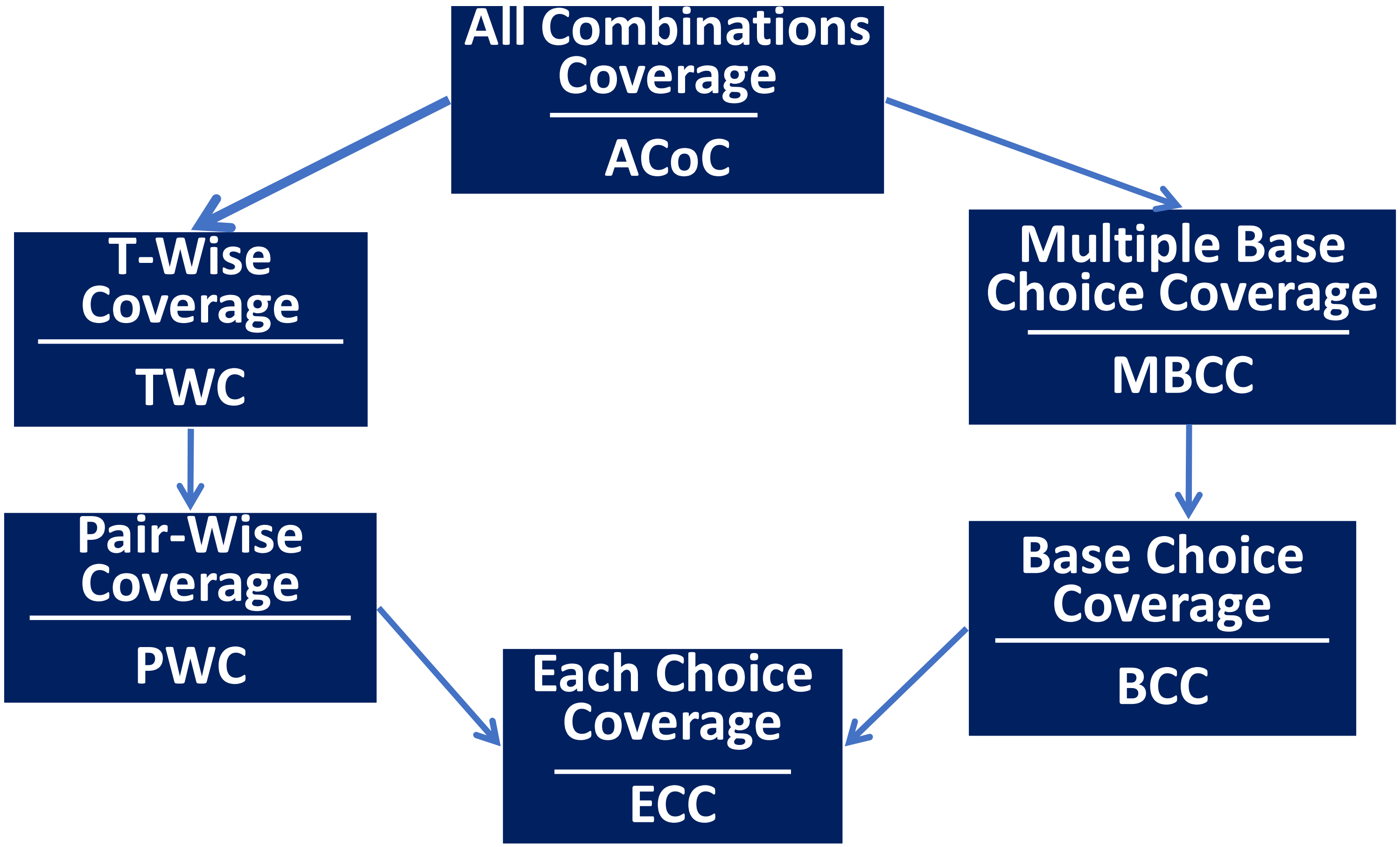
BCC

Multiple Base Choice Coverage

MBCC

Which of these criteria subsume the other(s)?

Subsumption among ISP criteria



Summary: Input Space Partitioning

- Step 1: Identify testable functions in your program
- Step 2: Find all input parameters
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Next…

- Graph-based Model-Driven Test Design