CS 5154: Software Testing

Active Clause Coverage

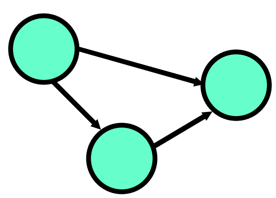
Owolabi Legunsen

Recall the four software models in this course

Input Domains

A: {0, 1, >1}
B: {600, 700, 800}
C: {cs, ece, is, sds}

Graphs



Logic Expressions

(!x | !y) & a & b

Syntax

```
if (x > y)
    z = x - y;
else
    z = 2 * x;
```

We need criteria that are not as costly as CoC

- The general idea is quite simple:

Test each clause independently from the other clauses

- But, getting the details right is hard
  - e.g., what exactly does "independently" mean ?
- The book presents this idea as "*making clauses active*" …

Active Clauses

- A weakness of Clause Coverage: values do not always make a difference

- *Values* $((5 < 10) \vee true) \wedge (1 >= 1*1)$ for $((a < b) \vee D) \wedge (m >= n*o)$
  - Only the last clause counts!

- To really test the results of a clause, the clause should be the determining factor in what the predicate evaluates to

Determination

A clause c_i in predicate p, called the *major clause*, *determines* p if and only if the values of the remaining *minor clauses* c_j are such that changing c_i changes the value of p

- Making c_i determine p is said to make the clause active
- Condition under which c_i determines p

$\forall c_j \in C_p \setminus c_i \ \exists$ assignment(c_j) s.t. $p(c_i = \text{true}) \neq p(c_i = \text{false})$

where assignment(c_j) is $c_j = \text{true}$ or $c_j = \text{false}$

Active clause criteria

The essence of testing with determination

1. Pick one clause in predicate p to be the major clause c_i

2. Find conditions under which c_i determines p

3. Find a test that makes c_i true and a test that makes c_i false

4. Repeat steps 1 to 3 for all other clauses in p

5. Eliminate redundant tests

Examples: determining predicates

$P = A \vee B$

if *B = true*, *p* is always true.

so if *B = false*, *A* determines *p*.

if *A = false*, *B* determines *p*.

$P = A \wedge B$

if *B = false*, *p* is always false.

so if *B = true*, *A* determines *p*.

if *A = true*, *B* determines *p*.

	a	b	$a \vee b$
1	T	T	T
2	T	F	T
3	F	T	T
4	F	F	F

	a	b	$a \wedge b$
1	T	T	T
2	T	F	F
3	F	T	F
4	F	F	F

More examples: determining predicates

$P = A \oplus B$

if *B = true*, *A* determines *p*.

if *B = false*, *A* determines *p*.

so, *A* determines *p for any B*.

	a	b	$a \oplus b$
1	T	T	F
2	T	F	T
3	F	T	T
4	F	F	F

$P = A \leftrightarrow B$

if *B = true*, *A* determines *p*.

if *B = false*, *A* determines *p*.

so, *A* determines *p for any B*.

	a	b	$a \leftrightarrow b$
1	T	T	T
2	T	F	F
3	F	T	F
4	F	F	T

Testing with determination ☺

- Goal : Find tests for each clause when that clause determines the value of the predicate

- This goal is formalized in a family of criteria that have subtle, but very important, differences

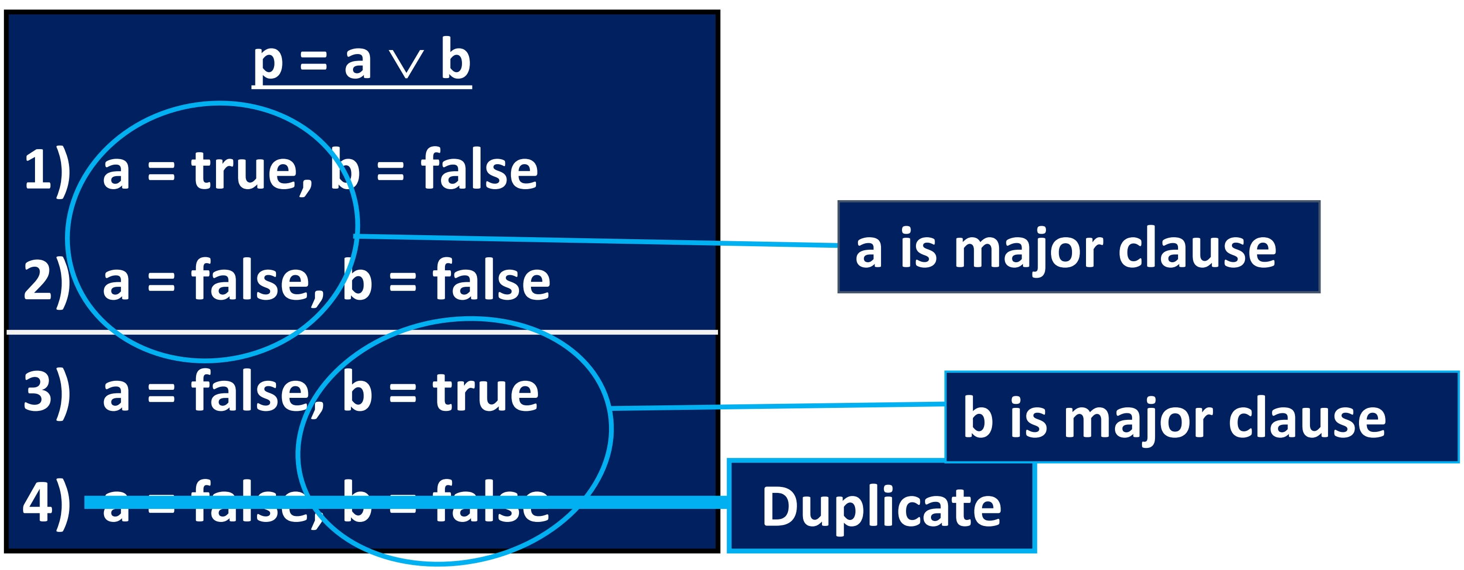
Active Clause Coverage

- Step 1: For each *p* in *P* and each major clause c_i in *Cp*, choose minor clauses $c_{j,\ j\ != i}$, so that c_i determines *p*.

<u>Active Clause Coverage (ACC)</u> : TR has two requirements for each c_i : c_i evaluates to true and c_i evaluates to false.

- ACC is a form of Multiple Condition Decision Coverage (MCDC)
- MCDC is required by the FAA for safety-critical software

Example on Active Clause Coverage



A formulaic way of determining predicates?

- Finding values for minor clauses c_j is easy for simple predicates
- How to find values for more complicated predicates?
- We need some "formula" that is easy to apply

A definitional way: when does c determine p?

- Let $p_{c=true}$ be predicate *p* with every occurrence of *c* replaced by ***true***
- Let $p_{c=false}$ be predicate *p* with every occurrence of *c* replaced by ***false***
- To find values for the minor clauses, connect $p_{c=true}$ and $p_{c=false}$ with X*OR*

$$p_c = p_{c=true} \oplus p_{c=false}$$

- After solving, p_c describes exactly the values needed for ***c*** to determine ***p***

An example using the definitional way

- Let $p = a \vee (b \wedge c)$. What values of b and c will cause a to determine p?

$$\underline{p = a \vee (b \wedge c)}$$

$$\begin{aligned} p_a &= p_{a=true} \oplus p_{a=false} \\ &= (true \vee (b \wedge c)) \oplus (false \vee (b \wedge c)) \\ &= true \oplus (b \wedge c) \\ &= !\,(b \wedge c) \\ &= !b \vee !c \end{aligned}$$

- "*!b ∨ !c*" means a determines p when either *b* or *c* is false

Exercise 1: using the definitional way

- Let $p = a \vee b$. What values of b will cause a to determine p?

<u>$p = a \vee b$</u>

$p_a = p_{a=true} \oplus p_{a=false}$

$= (true \vee b) \oplus (false \vee b)$

$= true \oplus b$

$= !b$

	a	b	$a \vee b$
1	T	T	T
2	T	F	T
3	F	T	T
4	F	F	F

- "*!b*" means a determines p when *b* is false
- We obtained the same result from reasoning about the truth table

Exercise 2: using the definitional way

- Let $p = a \leftrightarrow b$. What values of b will cause a to determine p?

<u>$p = a \leftrightarrow b$</u>

$$
\begin{aligned}
p_a &= p_{a=true} \oplus p_{a=false} \\
&= (true \leftrightarrow b) \oplus (false \leftrightarrow b) \\
&= b \oplus !b \\
&= true
\end{aligned}
$$

	a	b	a ↔ b
1	T	T	T
2	T	F	F
3	F	T	F
4	F	F	T

- "*true*" means that a always determines p
- We obtained the same result from reasoning about the truth table

Is there a problem with Active Clause Coverage?

- Step 1: For each *p* in *P* and each major clause c_i in *Cp*, choose minor clauses c_j, j != i, so that c_i determines *p*.

Active Clause Coverage (ACC) : TR has two requirements for each c_i : c_i evaluates to true and c_i evaluates to false.

- Ambiguity : Must minor clauses have the same values when the major clause is true and when the major clause is false?

Illustrating the ambiguity in ACC

- Recall: a determines p when "*!b* $\vee$ *!c*", i.e., when either *b* or *c* is false

$p = a \vee (b \wedge c)$

Major clause : a

a = true, b = false, c = true

a = false, b = false, c = false

Is this allowed ?

Three options for resolving ACC ambiguity

- Minor clauses do not need to be the same
- Minor clauses must be the same
- Minor clauses allow the predicate to become both true and false

Option 1: minor clauses don't need to be the same

- Step 1: For each *p* in *P* and each major clause c_i in C_p, choose minor clauses c_j, *j != i*, so that c_i determines *p*.

- Step 2 (ACC): TR has two requirements for each c_i : c_i evaluates to true and c_i evaluates to false.

General Active Clause Coverage (GACC) : The values chosen for the minor clauses c_j do not need to be the same when c_i is true as when c_i is false, that is, $c_j(c_i = true) = c_j(c_i = false)$ for all c_j OR $c_j(c_i = true) \mathrel{!=} c_j(c_i = false)$ *for all* c_j.

Problem: GACC doesn't subsume Predicate Coverage

Major clause : a

	a	b	$a \leftrightarrow b$
1	T	T	T
2	T	F	F
3	F	T	F
4	F	F	T

Option 2: minor clauses do need to be the same

- Step 1: For each *p* in *P* and each major clause c_i in C_p, choose minor clauses c_j, *j != i*, so that c_i determines *p*.

- Step 2 (ACC): TR has two requirements for each c_i : c_i evaluates to true and c_i evaluates to false.

Restricted Active Clause Coverage (RACC) : The values chosen for the minor clauses c_j must be the same when c_i is true as when c_i is false, that is, it is required that $c_j(c_i = true) = c_j(c_i = false)$ for all c_j.

Exercise 3: using the definitional way

- Let $p = a \wedge (b \vee c)$. What values of b and c will cause a to determine p?

$$\underline{p = a \wedge (b \vee c)}$$

$$\begin{aligned} p_a &= p_{a=true} \oplus p_{a=false} \\ &= (true \wedge (b \vee c)) \oplus (false \wedge (b \vee c)) \\ &= (b \vee c) \oplus false \\ &= (b \vee c) \\ &= b \vee c \end{aligned}$$

- "$b \vee c$" means a determines p when either b or c is true

Example on Restricted Active Clause Coverage

Major clause : a, P_a= **b** ∨ **c**

	a	b	c	a ∧ (b ∨ c)
1	T	T	T	T
2	T	T	F	T
3	T	F	T	T
4	T	F	F	F
5	F	T	T	F
6	F	T	F	F
7	F	F	T	F
8	F	F	F	F

RACC (c_i = a) can only be satisfied by row pairs (1, 5), (2, 6), or (3, 7)

Only three pairs can be used

Notes on RACC

- Does RACC subsume predicate and clause coverage?

- RACC was a common interpretation by developers for FAA

- Problem: RACC often leads to infeasible test requirements

Option 3: minor clauses allow predicate to be true and false

- Step 1: For each *p* in *P* and each major clause c_i in *Cp*, choose minor clauses c_j, $j \mathrel{!}= i$, so that c_i determines *p*.

- Step 2 (ACC): TR has two requirements for each c_i : c_i evaluates to true and c_i evaluates to false.

Correlated Active Clause Coverage (CACC) : The values chosen for the minor clauses c_j must cause *p* to be true for one value of the major clause c_i and false for the other, that is, it is required that $p(c_i = true) \mathrel{!}= p(c_i = false)$.

Example on CACC

	a	b	c	$a \wedge (b \vee c)$
1	T	T	T	T
2	T	T	F	T
3	T	F	T	T
4	T	F	F	F
5	F	T	T	F
6	F	T	F	F
7	F	F	T	F
8	F	F	F	F

a determines P when (b=true or c = true)

CACC (c_i = a) can be satisfied by choosing any of rows 1, 2, 3 AND any of rows 5, 6, 7 – a total of nine pairs

Notes on CACC

- CACC implicitly allows minor clauses to have different values
- CACC explicitly subsumes predicate coverage
- Does CACC subsume clause coverage?

Does CACC subsume clause coverage?

	a	b	c	$a \wedge (b \vee c)$
1	T	T	T	T
2	T	T	F	T
3	T	F	T	T
4	T	F	F	F
5	F	T	T	F
6	F	T	F	F
7	F	F	T	F
8	F	F	F	F

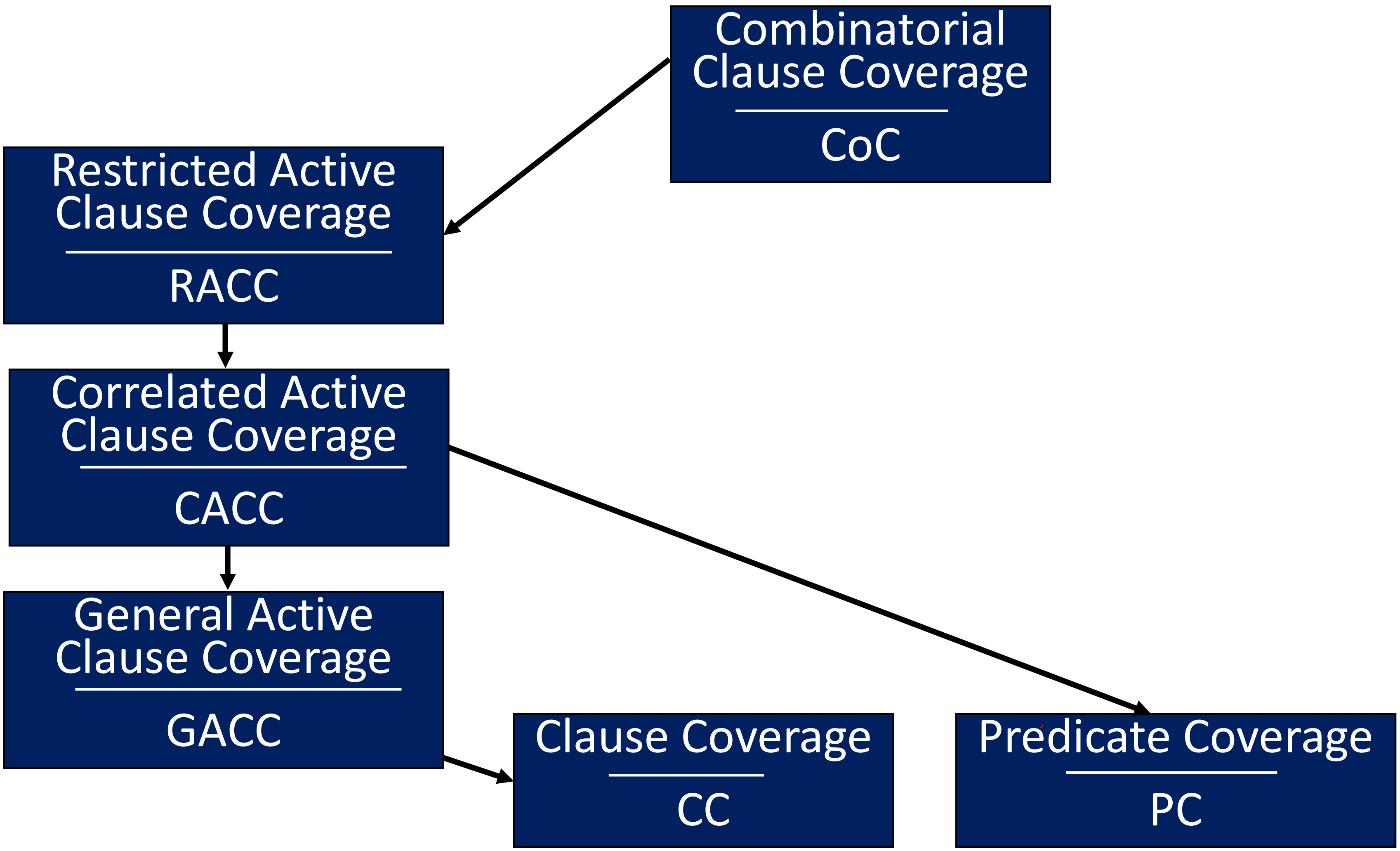
a determines P when (b=true or c = true)

CACC (c_i = a) can be satisfied by choosing any of rows 1, 2, 3 AND any of rows 5, 6, 7 – a total of nine pairs

Infeasibility

- Consider the predicate: $(a > b \wedge b > c) \vee c > a$
- *Infeasible:* $(a > b) = true$, $(b > c) = true$, $(c > a) = true$ is infeasible
- As with other criteria, infeasible test requirements must be recognized and dealt with
- Recognizing infeasible test requirements is hard, and in general, undecidable

Subsumption among Logic coverage criteria



An end-to-end example with RACC

b & *c* … diffe… determine the v…

Ag… ca…

Fin… cau…

For … caus…

Likewise, for clause *c*, only one pair, TFT and TFF, cause *c* to determine the value of *p*

	a	b	c	$a \wedge (b \vee c)$	p_a	p_b	p_c
1	T	T	T	T	✸		
2	T	T	F	T	✸	✸	
3	T	F	T	T	✸		✸
4	T	F	F	F		✸	✸
5	F	T	T	F	✸		
6	F	T	F	F	✸		
7	F	F	T	F	✸		
8	F	F	F	F			

In sum, three separate pairs of rows can cause *a* to determine the value of *p*, and only one pair each for *b* and *c*

How many tests does RACC yield, compared to Combinatorial Clause Coverage?

A more subtle exercise on determination

$$\underline{p = (a \wedge b) \vee (a \wedge !b)}$$

$$\begin{aligned} p_a &= p_{a=true} \oplus p_{a=false} \\ &= ((true \wedge b) \vee (true \wedge !b)) \oplus ((false \wedge b) \vee (false \wedge !b)) \\ &= (b \vee !b) \oplus false \\ &= true \oplus false \\ &= true \end{aligned}$$

$$\underline{p = (a \wedge b) \vee (a \wedge \neg b)}$$

$$\begin{aligned} p_b &= p_{b=true} \oplus p_{b=false} \\ &= ((a \wedge true) \vee (a \wedge \neg true)) \oplus ((a \wedge false) \vee (a \wedge \neg false)) \\ &= (a \vee false) \oplus (false \vee a) \\ &= a \oplus a \\ &= false \end{aligned}$$

A more subtle exercise on determination (2)

$p = (a \wedge b) \vee (a \wedge !b)$

- *a* always determines the value of this predicate

- *b* never determines the value – *b* is irrelevant !

- So, why would anyone write a predicate like this?

Logic Coverage Summary

- Predicates are often very simple—in practice, most have <3 clauses
  - In fact, most predicates only have one clause !
- Only clause? PC is enough
- 2 or 3 clauses? CoC is practical
- Advantages of ACC criteria can be significant for large (no. of) predicates
  - CoC is impractical for predicates with many clauses

Next

- Applying Logic Coverage to source code