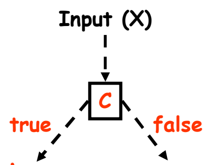
Predicate-based Testing

- Predicates are conditions
  - Divides the input domain into partitions
  - Define the paths of the program
- Program P
  - Input X; Predicate *C*
  - If outcome of *C* is incorrect,
    - Either *C* is incorrect,
    - Or statement(s) executed before *C*
  - Most likely, P's output is incorrect
    - Low probability of "coincidental correctness"
- Predicate-based testing
  - Require certain types of tests for each predicate in the program



Importance of Predicate-based Testing

- Thorough testing of *C* used to
  - Detect faults in *C*,
  - Statements executed before *C*
  - Statements executed after *C*

Terms Defined

- Predicate
  - Simple or compound predicate
- Simple predicate
  - Boolean variable, or
  - Relational expression,
  - May have one or more NOT (¬) operators
- Relational expression
  - E1 <rop> E2
    - E1 and E2 are arithmetic expressions
    - <rop> ∈ {<, <=, >, >=, /=, =}

Terms Defined (2)

- Compound predicate
  - At least one "binary Boolean operator"
  - Two or more operands
  - Maybe NOT operators
  - Maybe parenthesis
- Binary Boolean operators
  - OR (|) and AND (&)
- Simple operand
  - Operand without binary Boolean operators
- Compound operand
  - Operand with at least one binary Boolean operator

Terms Defined (3)

- Boolean expression
  - Predicate with no relational expressions
- Bi = Boolean expression
- Ei = Arithmetic expression
- <rop> or $<rop_i>$ = relational operator
- <bop> or $<bop_i>$ = binary Boolean operator

Assumptions

- Predicate has no syntactic faults

Types of Faults

- An "incorrect" predicate may have one or more of the following faults
  - Boolean operator fault
    - Incorrect AND/OR or missing/extra NOT
  - Boolean variable fault
    - Incorrect Boolean variable
  - Parenthesis fault
    - Incorrect location
  - Relational operator fault
    - Incorrect relational operator
  - Arithmetic expression fault
    - Various types

Yet More Terms

- Existence of one/more faults is "detected by a test" T if an execution of C with T produces an incorrect outcome of C
- Test set T for C "guarantees the detection" of certain type of faults F in C if the existence of F in C can be detected by at least one element in T, provided C doesn't contain faults of other types

Yet More Terms (2)

- Assume that C* has the same set of variables as C and is not equivalent to C. Test set T “distinguishes” C from C* if C and C* produce different outcomes for T
- Assume that C contains faults and C” is the correct version of C. Test set T is “insensitive” to the faults in C if this test cannot distinguish C from C”

Testing Simple Predicates

- Branch testing
  - TRUE and FALSE branches be executed at least once
- Relational Operator Testing
  - Given E1 <rop> E2
  - Need 3 tests
  - E1 > E2; E1 < E2; E1 = E2
  - If only <rop> is incorrect and E1 and E2 are correct, then detection is guaranteed

Testing Compound Predicates

- Complete branch testing
  - All TRUE and FALSE branches of each simple/compound operand in compound predicate C be executed at least once
- Exhaustive branch testing
  - All combinations of TRUE and FALSE branches of simple operands in C be executed at least once
  - C has N Boolean Operators, then N+1 simple operands. Requires 2^(n+1) test cases

Testing Compound Predicates (2)

- Complete relational operator testing
  - Relational operator testing for each relational expression in C
  - Let C# be (E1 = E2) & (E3 /= E4)
  - Assume T1 contains 3 tests
    - T11 makes E1 = E2 and E3 = E4
    - T12 makes E1 > E2 and E3 > E4
    - T13 makes E1 < E2 and E3 < E4
  - T1 satisfies relational operator testing for each simple operand of C#
- If E1, E2, E3, and E4 are correct, what can we say about the correctness of operators?

Complete Relational Operator Testing

- Can the test cases T11, T12, and T13 distinguish between C# and
  - (E1 = E2) & (E3 < E4)
  - (E1 /= E2) & (E3 = E4)

BR-constraints

- Given a predicate
  - $(\langle opd_1\rangle \langle bop_1\rangle \langle opd_2\rangle \langle bop_2\rangle \ldots \langle opd_n\rangle \langle bop_n\rangle$
  - $\langle opd_i\rangle$ is the ith simple operand
- BR-constraint
  - (D1, D2, …, Dn)
    - Each Di is a symbol specifying a constraint on the Boolean variable or relational expression in $\langle opd_i\rangle$

BR-constraints (2)

- Constraints for a Boolean variable B
  - The value of B is TRUE
  - The value of B is FALSE
  - No constraint
- Symbols
  - t
  - f
  - *

BR-constraints (2)

- Constraints for a relational expression (E1 <rop> E2)
  - Value is TRUE t
  - Value is FALSE f
  - (E1 – E2) > 0 >
  - (E1 – E2) = 0 =
  - (E1 – E2) < 0 <
  - No constraint *

Constraint Satisfaction

- Definition
  - Constraint D on predicate C is covered (or satisfied) by a test if during the execution of C with this test, the value of each Boolean variable or relational expression in C satisfies the corresponding constraint in D
- E.g.,
  - (=, <)
  - for ((E1 >= E2) | ¬(E3 > E4))
- Coverage requires that (E1 = E2) and (E3 < E4)

Constraint Satisfaction (2)

- Definition
  - Set S of BR-constraints on predicate C is covered (or satisfied) by a test set T if each constraint in S is covered for C by at least one test in T

Terms Redefined

- In terms of BR-constraints
  - Branch testing (E1 <rop> E2)
    - {(t), (f)}
  - Relational operator testing (E1 <rop> E2)
    - {(>), (=), (<)}
  - Complete branch testing ((E1 <rop1> E2) <bop> (E3 <rop2> E4))
    - {(t, *), (f, *), (*, t), (*, f)}
  - Complete relational operator testing ((E1 <rop1> E2) <bop> (E3 <rop2> E4))
    - {(>, *), (=, *), (<, *), (*, >), (*, =), (*, <)}

Terms Defined

- Concatenation
  - Let u = $(u_1, u_2, \ldots, u_m)$ and v = $(v_1, v_2, \ldots, v_n)$ be two sequences
  - (u,v) = $(u_1, u_2, \ldots, u_m, v_1, v_2, \ldots, v_n)$
- Other terms
  - Let A and B be two sets
  - A$B denotes the **union** of A and B
  - A*B is the **product** of A and B
  - |A| is the **size** of A
  - A%B is called the **onto** from A to B
    - Minimal set of (u,v) such that u ∈ A and every element in A appears in u at least once; v ∈ B and every element in B appears in v at least once

Terms Defined

- Observations
  - |A%B| = max(|A|, |B|)
  - A%B may have several possible values
    - If C = {(a), (b)} and D = {(c), (d)}
    - Then what is C%D
      - ((a,c),(b,d))
      - ((a,d),(b,c))
    - How about if E = {(a), (b)} and F = {(c), (d), (e)}

Expected Outcome

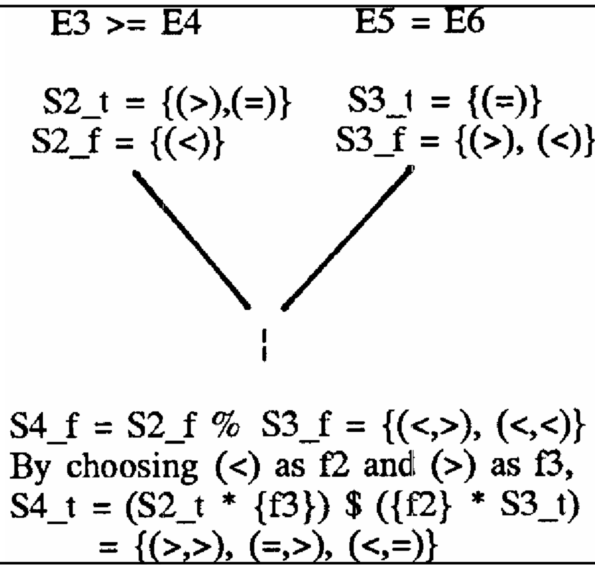
- Let X be a constraint that contains "t", "f", ">", "<", and "=" for a predicate C
- Value produced by C on any input covering X; C(X)
- X covers the TRUE branch of C if C(X)=TRUE, and
- X covers the FALSE branch of C if C(X)=FALSE
- Let S be a set of constraints for C
- Partition S into S_t and S_f
  - S_t(C) = {X in S | C(X) = t}
  - S_f(C) = {X in S | C(X) = f}

Lets Try Them Out

- E1 < E2
  - S1 = {(<), (>), (=)}
  - S1_t = {(<)}
  - S1_f = {(>), (=)}
- E3 >= E4
  - S2 = {(>), (=), (<)}
  - S2_t = {(>), (=)}
  - S2_f = {(<)}
- E5 = E6
  - S3 = {(=), (<), (>)}
  - S3_t = {(=)}
  - S3_f = {(<), (>)}

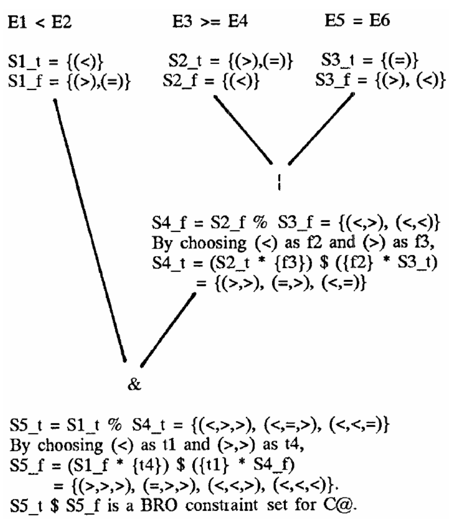
|&

- More complex predicates
  - (E3 >= E4) | (E5 = E6)
    - S4_f = {(<, <), (<, >)}
  - (E3 >= E4) & (E5 = E6)
    - S9_t = {(>, =), (=, =)}
- How about S4_t and S9_f?



Surprise Quiz

- How About S9_f?



What Next?

- Once all the constraints have been obtained, test cases may be generated