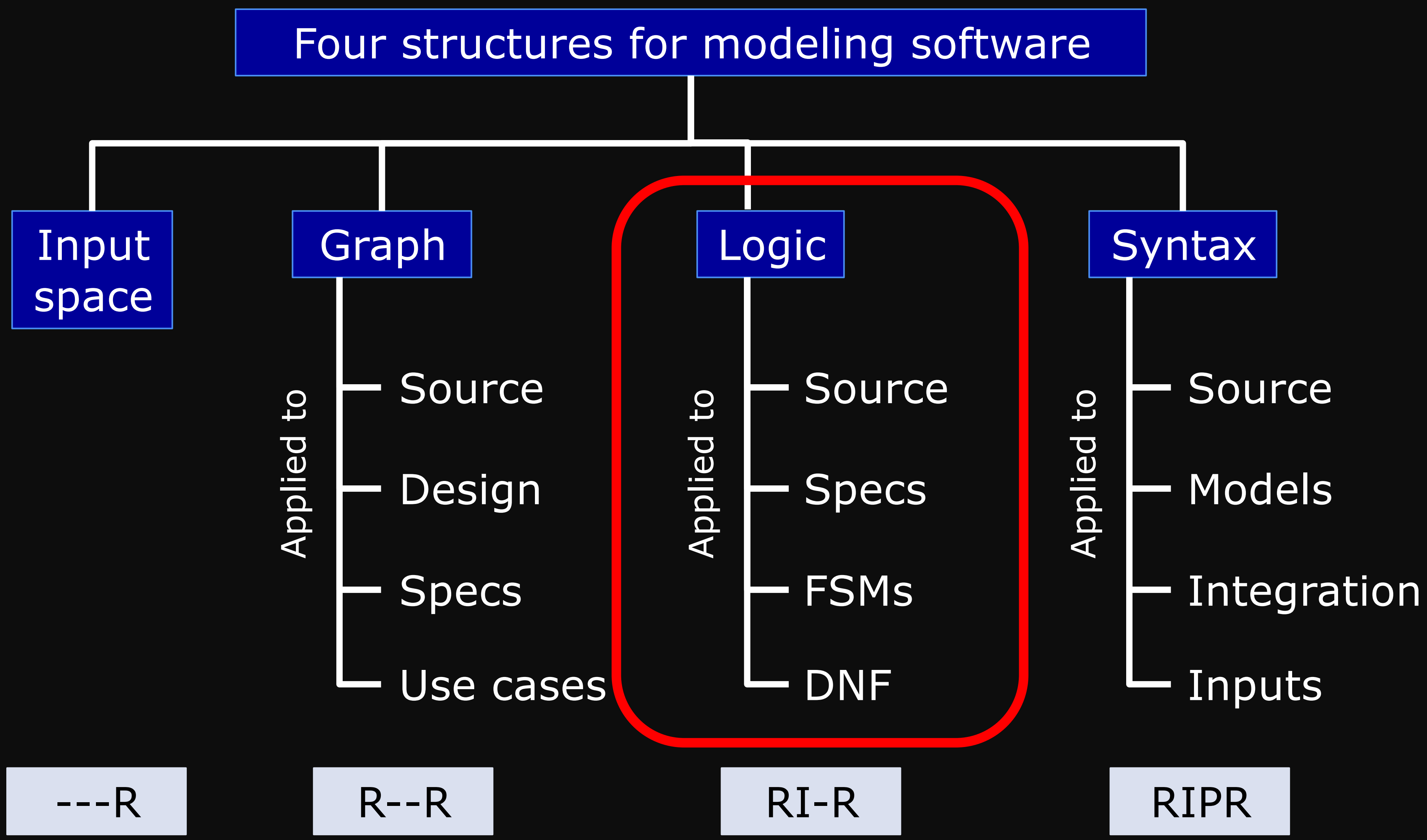
# Logic Coverage

## CS 3250
## Software Testing

[Ammann and Offutt, "Introduction to Software Testing," Ch. 8]

# Structures for Criteria-Based Testing



# Overview

- Logic coverage ensures that tests not only reach certain locations, but the internal state is infected by trying multiple combinations of truth assignments to the expressions
- Covering logic expressions is required by the US Federal Aviation Administration for safety critical avionics software
- Logical expressions can come from many sources
  - Decisions in programs
  - FSMs and statecharts
  - Requirements
  - SQL queries
- Tests are intended to choose some subset of the total number of truth assignments to the expressions

# Logic Predicates and Clauses

- Predicate: An expression that evaluates to a Boolean value
  - May contain
    - Boolean variable
    - Non-Boolean variables that contain >, <, ==, >=, <=, !=
    - Boolean function calls
  - Created by the logical operators

| | |
|---|---|
| ¬ | *negation* operator |
| ∧ | *and* operator |
| ∨ | *or* operator |
| → | *implication* operator |
| ⊕ | *exclusive or* operator |
| ↔ | *equivalence* operator |

- Clause: A predicate with no logical operators

# Example

Logically equivalent

$(a == b) \vee (C \wedge f(x))$

A predicate with logical operators

**Three clauses**

A relational expression (a == b)

A boolean variable C

A boolean-valued function p(x)

$((a == b) \vee C) \wedge ((a = b) \vee f(x))$

A predicate with logical operators

**Three clauses**

A relational expression (a == b)

A boolean variable C

A boolean-valued function p(x)

# Note on Predicates

- Most predicates have few clauses
- Sources of predicates
  - Decisions in program source code

```
public boolean isSatisfactory()
{
   if ((good && fast) || (good && cheap) || (fast && cheap))
      return true;
   else
      return false;
}
```

$(good \wedge fast) \vee (good \wedge cheap) \vee (fast \wedge cheap)$

  - Guards in finite state machines

button2 == true (when gear == park)

$(gear == park) \wedge (button2 == true)$

  - Precondition in specifications

pre: stack not full AND object reference parameter not null

$\neg stackFull() \wedge (newObj \neq null)$

# Note on Predicates

- Be careful when translating from English

"I am interested in CS6501 and CS4501"

⬇

Which one ?

| |
|---|
| (course = CS6501) AND (course = CS4501) ✗ |
| (course = CS6501) OR (course = CS4501) ✓ |

From a study of 63 open source programs (>400,000 predicates), most predicates have few clauses [Ammann and Offutt]

- 88.5% have 1 clauses
- 9.5% have 2 clauses
- 1.35% have 3 clauses
- Only .65% have 4 or more

Try to keep the predicate simple and short.
How? Refactor it.

# Short Circuit Evaluation

- Impacted by the order of operation
- Evaluate an expression or predicate until an outcome is known

$$((a == b) \vee C) \wedge f(x)$$

If f(x) is evaluated to T, we evaluate (a == b) $\vee$ C which can be T or F

If f(x) is evaluated to F, we stop. The outcome of the predicate is F

# Short Circuit Evaluation

Boolean variable

Method call – something can change

```
if (isHungry && (time == f(time)))
{

}
```

If isHungry is evaluated to T, we evaluate (time == f(time)) which can be T or F

If isHungry is evaluated to F, we stop. The outcome of the predicate is F

Stop evaluating the predicate when we know the outcome

# Logic Coverage Criteria

- We use predicates in testing as follows:
  - Developing a model of the software as one or more predicates
  - Requiring tests to satisfy some combination of clauses

- Abbreviations:
  - $P$ is the set of predicates
  - $p$ is a single predicate in $P$
  - $C$ is the set of clauses in $P$
  - $C_p$ is the set of clauses in predicate $p$
  - $c$ is a single clause in $C$

# Predicate Coverage (PC)

- For each *p* in *P*, TR contains two requirements:
  - *p* evaluates to true
  - *p* evaluates to false

"Decision coverage"

p = ((a == b) ∨ C) ∧ f(x)

Need 2 test cases to satisfy PC

| a | | b | C | f(x) | p |
|---|---|---|---|---|---|
| 3 | T | 3 | T | T | **T** |
| 4 | F | 3 | F | T | **F** |

- PC does not evaluate all the clauses, especially in the presence of short circuit evaluation

# Clause Coverage (CC)

- For each *c* in *C*, TR contains two requirements:
  - *c* evaluates to true
  - *c* evaluates to false

"Condition coverage"

$p = ((a == b) \vee C) \wedge f(x)$

(a == b) evaluates to T, F
C evaluates to T, F
f(x) evaluates to T, F

| a | | b | C | f(x) | p |
|---|---|---|---|---|---|
| 3 | T | 3 | T | F | F |
| 4 | F | 3 | F | T | F |

Need 2 test cases to satisfy CC

- CC does not always ensure PC
- The simplest solution is to test all combinations

# Combinatorial Coverage (CoC)

- Evaluate all possible combination of truth values

"Multiple Condition coverage"

$p = ((a == b) \vee C) \wedge f(x)$

| a | | b | C | f(x) | p |
|---|---|---|---|---|---|
| 3 | T | 3 | T | T | T |
| 3 | T | 3 | T | F | F |
| 3 | T | 3 | F | T | T |
| 3 | T | 3 | F | F | F |
| 4 | F | 3 | T | T | T |
| 4 | F | 3 | T | F | F |
| 4 | F | 3 | F | T | F |
| 4 | F | 3 | F | F | F |

Need $2^N$ test cases to satisfy CoC, where N = number of clauses

# Note on CoC

- Coc is simple and comprehensive
- But quite expensive
- $2^N$ tests, where N is the number of clauses
  - Impractical for predicates with more than 3 or 4 clauses
- The literature has lots of suggestions – some confusing
- The general idea is simple:

> Test each clause that makes a big difference … "active clause"

# Revisit CoC Example

Which clause makes a big difference

$p = ((a == b) \vee C) \wedge f(x)$

| a | | b | C | f(x) | p |
|---|---|---|---|---|---|
| 3 | T | 3 | T | T | T |
| 3 | T | 3 | T | F | F |
| 3 | T | 3 | F | T | T |
| 3 | T | 3 | F | F | F |
| 4 | F | 3 | T | T | T |
| 4 | F | 3 | T | F | F |
| 4 | F | 3 | F | T | F |
| 4 | F | 3 | F | F | F |

# Active Clauses

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

- Determination
  - A clause $c_i$ in predicate $p$, called the major clause, determines $p$ if an only if the values of the remaining minor clauses $c_j$ are such that changing $c_i$ changes the value $p$
  - That is:
    - Major clause – the clause (being considered) that determine the predicate
    - Minor clause – all other clauses in the predicate

- This is considered to make the clause active

# Determination

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

- Determination: the conditions under which a clause solely determines the outcome of a predicate

  - Given a major clause $c_i$ in a predicate $p$, $c_i$ determines $p$ if the minor clauses $c_j \neq c_i$ $(j \neq i)$

  - Major clause – "active clause" – controls the behavior

- Consider `p = a ∨ b`

  - If b = true, the value of a does not matter

  - If b = false, the value of a is the determining factor in the value of the predicate

# Revisit Coc Example (again)

Which clause determines the predicate

$p = ((a == b) \vee C) \wedge f(x)$

| a | | b | C | f(x) | p |
|---|---|---|---|---|---|
| 3 | T | 3 | T | T | T |
| 3 | T | 3 | T | F | F |
| 3 | T | 3 | F | T | T |
| 3 | T | 3 | F | F | F |
| 4 | F | 3 | T | T | T |
| 4 | F | 3 | T | F | F |
| 4 | F | 3 | F | T | F |
| 4 | F | 3 | F | F | F |

f(x) determines the predicate – but when ??

# Deriving Determination Predicates, Using Mathematical Approach

# Deriving (Mathematical Approach) Determination Predicates

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

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

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

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

# Deriving (Mathematical Approach) Determination Predicates

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

**Major clause: a**

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

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | | |
| 3 | T | | T | T | T | | |
| 4 | T | | | | | | |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

(Fill in a table to make it easy to read)

Blank indicates F

# Deriving (Mathematical Approach) Determination Predicates

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

**Major clause: b**

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

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | T | |
| 3 | T | | T | T | T | | |
| 4 | T | | | | | T | |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

(Fill in a table to make it easy to read)

Blank indicates F

# Deriving (Mathematical Approach) Determination Predicates

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

**Major clause: c**

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

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | T | |
| 3 | T | | T | T | T | | T |
| 4 | T | | | | | T | T |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

(Fill in a table to make it easy to read)

Blank indicates F

# Deriving Determination Predicates, Using Tabular Approach

# Identifying Determination Using Truth Table

$p = a \wedge (b \vee c)$ **Major clause: a**

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | | |
| 3 | T | | T | T | T | | |
| 4 | T | | | | | | |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

Blank indicates F

# Identifying Determination Using Truth Table

$p = a \wedge (b \vee c)$ **Major clause: b**

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | T | |
| 3 | T | | T | T | T | | |
| 4 | T | | | | | T | |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

Blank indicates F

# Identifying Determination Using Truth Table

$p = a \wedge (b \vee c)$ **Major clause: c**

| row | a | b | c | p | $p_a$ | $p_b$ | $p_c$ |
|---|---|---|---|---|---|---|---|
| 1 | T | T | T | T | T | | |
| 2 | T | T | | T | T | T | |
| 3 | T | | T | T | T | | T |
| 4 | T | | | | | T | T |
| 5 | | T | T | | T | | |
| 6 | | T | | | T | | |
| 7 | | | T | | T | | |
| 8 | | | | | | | |

Blank indicates F

# What’s next?

- Use determination
- Apply logic coverage criteria to derive test requirements and design test cases
  - Active Clause Coverage (ACC)
  - General Active Clause Coverage (GACC)
  - Correlated Active Clause Coverage (CACC)
  - Restricted Active Clause Coverage (RACC)