# Model-Based Testing

(DIT848 / DAT260)

Spring 2013

**Lecture 6**

**Selecting your tests**

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# What have we seen so far?

- Testing in general
  - Unit, integration, system test
  - Black-box vs white-box testing
- Introduction to MBT
  - Automation of black-box testing (automatic generation of inputs with oracle to check output)

**Today**: more on MBT -> how to select test cases based on model coverage criteria

Any question?

# About coverage criteria

- Test selection criteria help to design black-box test suites
  - They do not depend on the SUT code
- Model coverage criteria and SUT code coverage are complementary
- In white-box testing, coverage criteria are used for:
  - Measuring the adequacy of test suite
  - Deciding when to stop testing
- Coverage criteria may be used prescriptively
  - "Try to cover all branches"
- Test generation tools can provide metrics on how well the coverage was, and which parts of the model where not covered

# Test selection criteria

1. Structural model coverage criteria
2. Data coverage criteria
3. Fault-model criteria
4. Requirements-based criteria
5. Explicit test case specifications
6. Statistical test generation methods

**Focus on the first 2**
**Not much about the rest**

# Structural model coverage

- Major issue: measure and maximize coverage of the **model**
  - Not of the SUT
- Different "families" of structural model coverage criteria:
  1. Control-flow-oriented coverage criteria
  2. Data-flow-oriented coverage criteria
  3. Transition-based coverage criteria
  4. UML-based coverage criteria

Focus on the first 3

# Structural model coverage Control-flow oriented

- The **control-flow oriented criteria** we will see are mostly for pre/post notations
  - E.g., Statement Coverage (SC) not relevant in FSM -> rather talk about *all-states* or *all-transitions* coverage
  - It makes more sense on modeling languages like B
- Still, some of the criteria are useful also for transition-based notations with data information (e.g. EFSMs)

**Notation:**

- **Decision** -> branch (an **if-then-else**)
- A decision contains one or more primitive **conditions** (combined by *and*, *or*, and *not* operators)

# Structural model coverage
# Control-flow oriented

Multiple Condition Coverage (MCC)

All possible combinations of condition outcomes in each decision
- Decision with *N* conditions: $2^N$ tests

↓

Modified Condition/Decision Coverage (MC/DC)

Requires condition *c* to *independently affect* the outcome of decision *d* (vary just *c* and get the rest fixed)
- Decision with *N* conditions: max *2N* tests

↓

Full Predicate Coverage (FPC)

Tests forcing each condition *c* to true (false) whenever *c* is *directly correlated* with the outcome *d* of the decision (*d equiv c* or *d equiv not(c)*)
- Decision with N conditions: max 2N tests

↓

Decision/Condition Coverage (D/CC)

When you achieve both DC and CC

Decision Coverage (DC)

Each reachable decision made true by some tests and false by others (also called **branch coverage**)

Condition Coverage (CC)

Each condition is tested with a true and a false result
-Decision with N conditions: 2 tests (1 will all conditions true, 1 with all false )

↓ (from DC)

Statement Coverage (SC)

Test suite must execute every reachable statement



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

# Structural model coverage
# Control-flow oriented

- **Often combined with transition-based and data-oriented coverage criteria**
- *Code coverage* is based on statements, decisions (branches), loops, and paths
- In some modeling notations (eg. UML/OCL, B) there are no loops!
- Path coverage (test suite must execute every satisfiable path through the control-flow graph) not possible in code-based testing
  - In pre/post notations: if all combinations of decision outcomes are tested, path coverage is obtained (?!)
  - … so, no path coverage in previous slide ☺

# Structural model coverage Data-flow oriented

- Control-flow graphs can be annotated with extra information on the **definition** and **use** of data variables
- Def-use pair $(d_v,u_v)$ – $d_v$ is a definition of $v$, $u_v$ is its use

All–def–use–paths

Test suite to test all def-use pairs $(d_v,u_v)$ and to test all paths from $d_v$ till $u_v$

↓

All–uses

Test suite to test all def-use pairs $(d_v,u_v)$ (all feasible use of all definitions)

↓

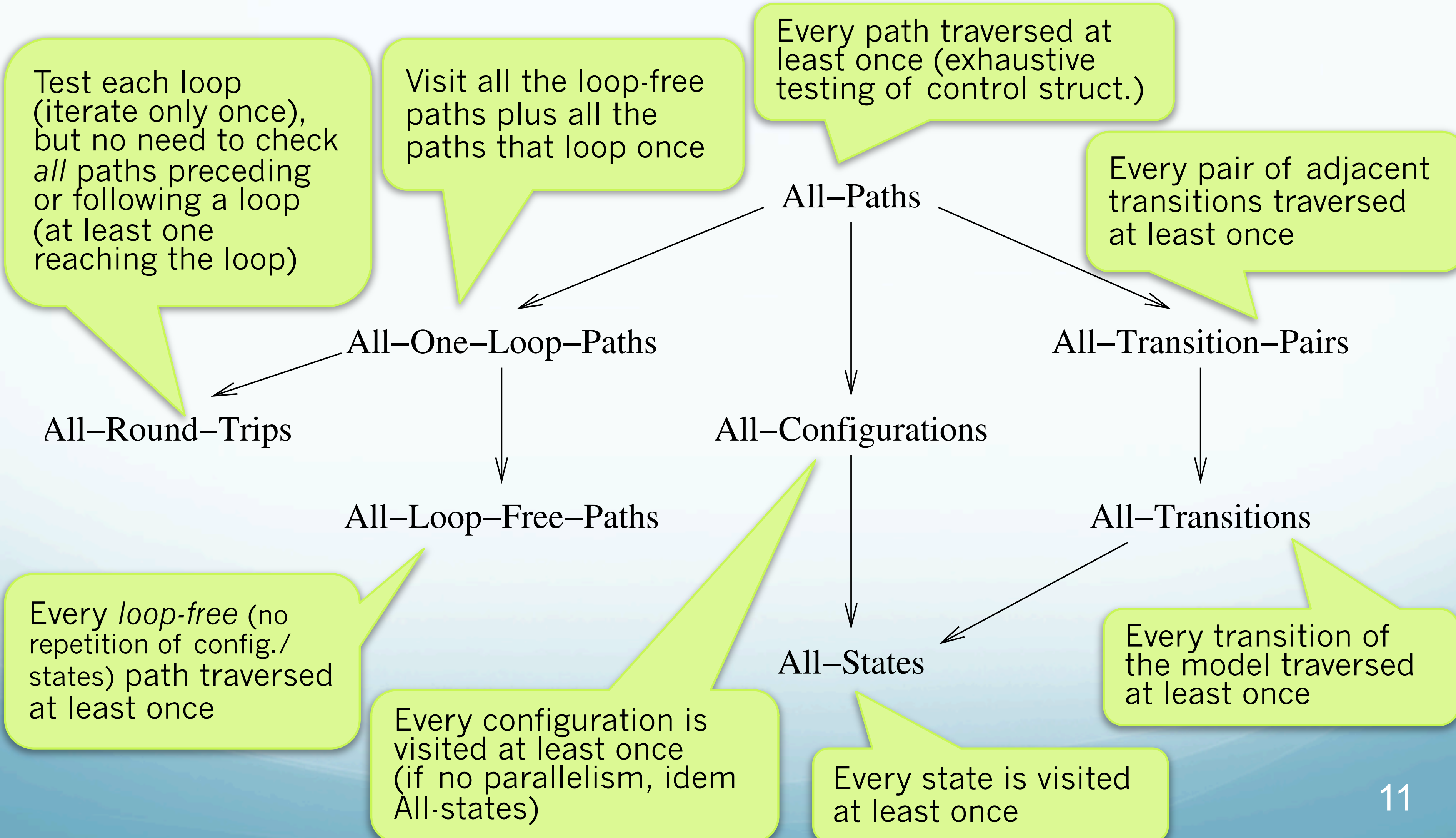
All–definitions

Test suite to test at least one def-use pair $(d_v,u_v)$ for each def. $d_v$

# Structural model coverage Transition-based

- Transitions systems made up of states and transitions
- Depending on notation, transitions labeled with inputs, outputs, events, guards, and/or actions
- Usually models parallel systems
- A configuration is roughly a snapshot of the active states (of each parallel process)
- In this coverage criteria we restrict to **reachable** paths

# Structural model coverage
# Transition-based

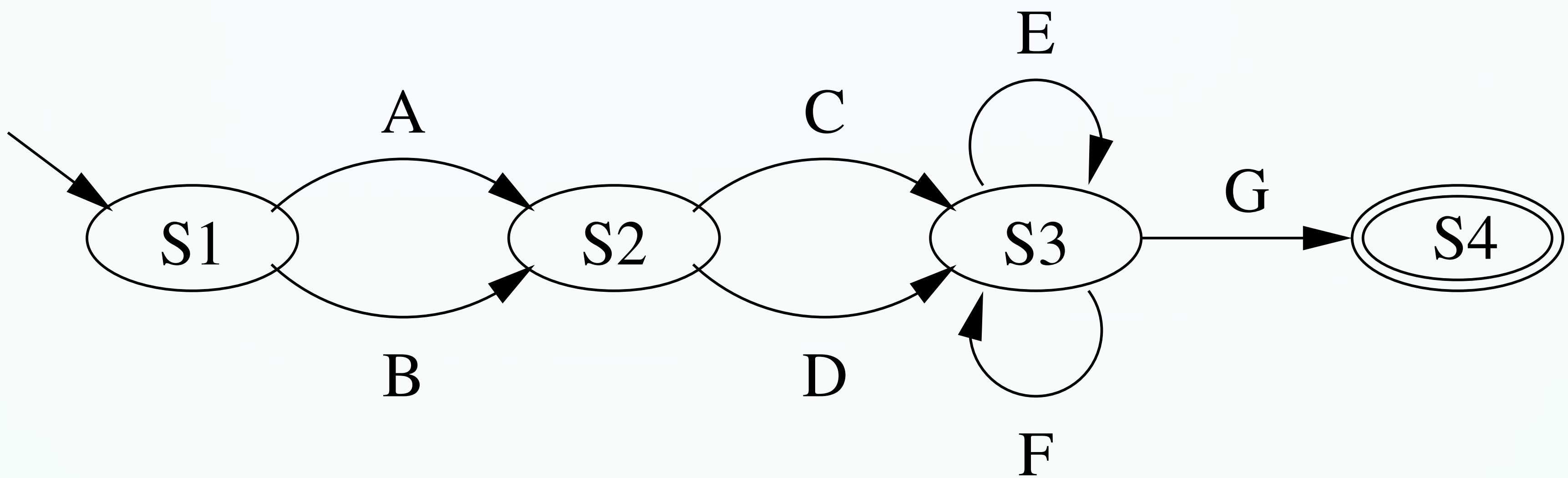


# Structural model coverage Transition-based

**REMARK**

- According to Utting & Legeard's book (p.119) All-Round-Trips should require an All-Transitions coverage too (and thus an arrow from the former to the latter should be present in the picture in previous slide). However, in this course we will take the less strict definition (consistent with the picture) that this is not the case.
- That is: **All-Round-Trips coverage does not require full coverage of all transitions, but only that all loops are part of the test suite** (finishing in the final state)

# Structural model coverage Transition-based



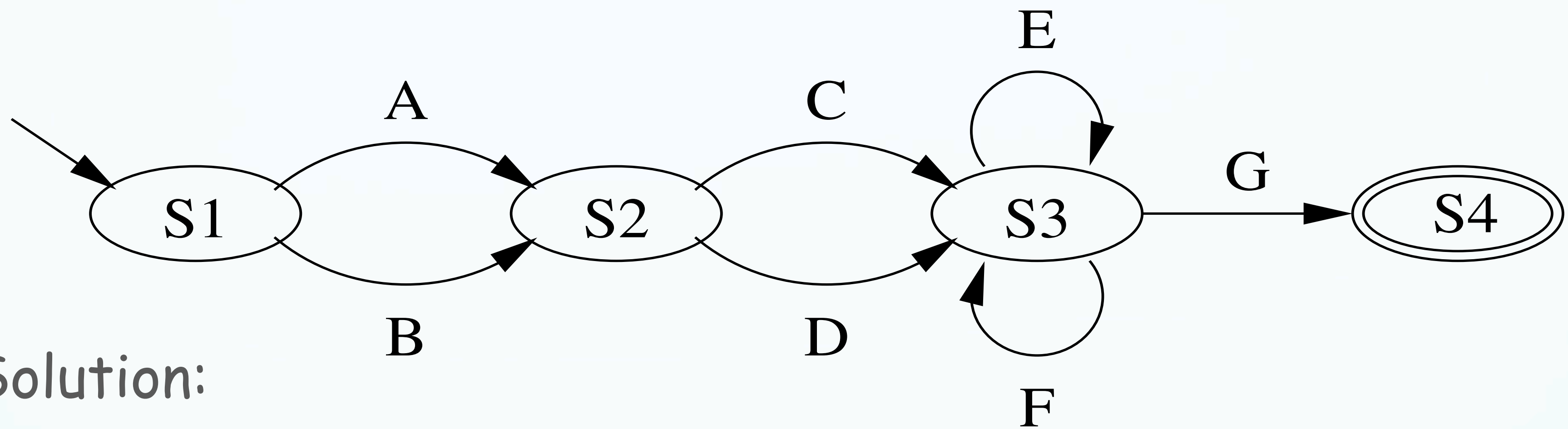

- Write down examples of each transition-based coverage criteria for the above FSM
  - All-states
  - All-configurations
  - All-transitions
  - All-transition-pairs
  - All-loop-free-paths
  - All-one-loop-paths
  - All-round-trips
  - All-paths



Groups 2-5 persons: 15-20 min

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

# Structural model coverage Transition-based




Solution:

- All-states
  - A;C;G
- All-configurations
  - Equal to All-states
- All-transitions
  - A;C;E;F;G and B;D;G
- All-transition-pairs
  - Eg..at state S2: A;C, A;D, B;C, B;D (do the same for each state)
- All-loop-free-paths
  - A;C;G, A;D;G, B;C;G, B;D;G
- All-one-loop-paths
  - 4 paths of all-loop-free-paths + combination of each of these with a single loop around either E or F transition (4+2*4=12 tests)
- All-round-trips
  - A;C;E;G, A;C;F;G (even simpler: A;C;E;F;G)
- All-paths
  - 4 paths of all-loop-free-paths but extended with any number of E and F transitions



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

# Data coverage criteria

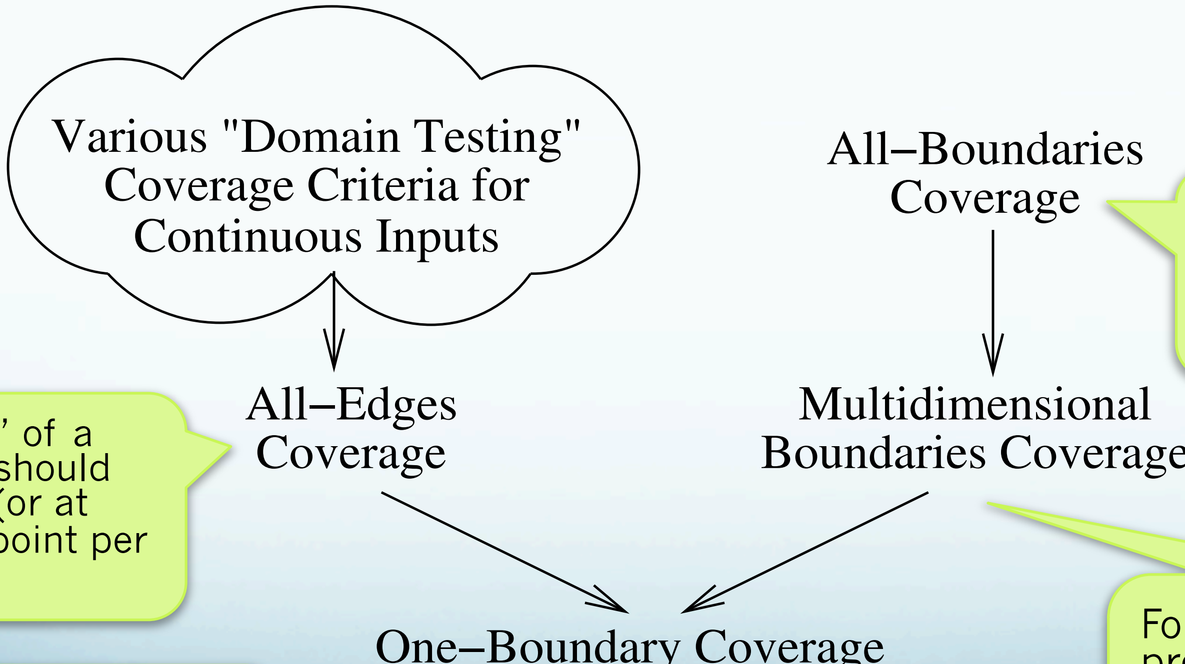
- Useful for choosing good data value representatives as test inputs
- Over a domain *D*, two extreme data coverage criteria
  - **One-value**: at least one value from *D* (in combination with other test criteria might be useful)
  - **All-values**: every value in *D*. Not practical in general
- More realistic:

1. Boundary values
2. Statistical data coverage
3. Pairwise testing

# Data coverage criteria
# Boundary value testing

Choosing values at the boundaries of input domains

- Usually constraints on values are predicates representing some regions: 1<=x<=5 and 2<=y<=7




For each predicate a test case for every boundary point satisfying the predicate

All “edges” of a predicate should be tested (or at least one point per edge)

For each variable on a predicate assign the minimum value in at least one test case (similarly for the maximum value)

For each predicate at least one boundary point of the predicated should be tested

# Data coverage criteria
# Statistical data coverage

- Choosing random tests is as good as finding faults as partition testing
  - Could then be more cost-effective
- Criterion: Random-value coverage (with distribution D)
  - Values of a given data variable in the test suit to follow the statistical distribution D

Example:

car_speed >50 and rain_level >5 (with car_speed: 0..300 and rain_level: 0..10)

- Boundary testing: 4 tests (51 and 300 for car, 6 and 10 for rain)
- If we want 50 tests: generate them randomly with some distribution

# Data coverage criteria
# Boundary value testing

1. Write a geometrical representation of the following predicate, and consider what could be the boundary values for such predicate (integer)

$$(x^2+y^2<=25) \ \& \ (0<=y) \ \& \ (x+y<=5)$$

2. Write boundary-oriented coverage for the case above so you achieve
   - All-boundaries coverage
   - Multidimensional-boundaries coverage
   - All-edges coverage

Groups 2-5 persons: 10 min

# Data coverage criteria
# Boundary value testing

Solution:

- All-boundaries coverage
  - The 22 boundary points depicted in the picture
- Multidimensional-boundaries coverage
  - Tests: (5,0), (-5,0), (0,5), and (x,0), for any -5<=X<=5
- All-edges coverage
  - Eg. (5,0) and (0,5)

Utting & Legeard book: Fig. 4.7, pp.125!



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

# Fault-based criteria

- A software testing technique using test data designed to demonstrate the absence of a set of **pre-specified faults** (known or recurrent faults)
- Mutation testing: program mutants are created by syntactic transformation of the SUT
  - Using **mutation operators**
- Executing a test suite on all mutants allows to measure the percentage of mutants **killed** by the test suite (exposing a fault in the mutant)
- Mutation of operators also guide the design of tests
  - Tests helping to distinguish a program from its mutant

# Requirements-based criteria

- Each requirement (*a testable statement of some functionality that the product must have*) should be tested
- Requirements can be used both to measure a level of coverage for the generated test case and to drive the test generation itself
- All-requirements coverage
  - Record the requirements inside the behavioral model (as annotations)
  - Formalize each requirement and use it as a test selection criterion

# Explicit test case specifications

- Besides the model, the tester writes test case specifications in some formal notation
- Used to determine which tests to generate
- Notation could be the same as the modeling language, but not necessarily
- FSMs, regular expressions, temporal logic, Markov chains, etc.
- Give precise control over generated tests

# Statistical test generation methods

- In MBT statistical test generation is usually used to generate test sequences from environmental models
- Usually using Markov chains (roughly, a FSM with probabilities)
- Test cases with greater probability to be generated first (and more often if organized in different classes)

# Combining test selection criteria

- Criteria seen have different scopes and purposes: good to combine them
- See some interesting examples in Utting & Legeard, section 4.7 (pp.134-135)

# References

- M. Utting and B. Legeard, *Practical Model-Based Testing*. Elsevier - Morgan Kaufmann Publishers, 2007
  - Chapter 4

# Remember!

- Next lecture (**Monday Apr 22**) we have two lectures!

Lecture 7: “Graph Theory Techniques in MBT”

Lecture 8: “EFSMs and ModelJUnit”

- Lectures will **start at 8:15** instead of 9:00