Introduction to Software Testing
Chapter 9.4
Model-Based Grammars

Paul Ammann & Jeff Offutt

http://www.cs.gmu.edu/~offutt/softwaretest/

Model-based Grammars

Model-based

Languages that describe software in abstract terms

- Formal specification languages
  - Z, SMV, OCL, …
- Informal specification languages
- Design notations
  - Statecharts, FSMs, UML notations
- Model-based languages are becoming more widely used

Instantiating Grammar-Based Testing

Grammar-Based Testing

9.4

Program-based

- String mutation
  - Program mutation
  - Valid strings
  - Mutants are not tests
  - Must kill mutants
- Grammar
  - Compiler testing
  - Valid and invalid strings

Integration

- String mutation
  - Test how classes interact
  - Valid strings
  - Mutants are not tests
  - Must kill mutants
  - Includes OO

Model-Based

- String mutation
  - FSMs
  - Model checking
  - Valid strings
  - Traces are tests

Input-Based

- String mutation
  - Input validation testing
  - XML and others
  - Invalid strings
  - No ground strings
  - Mutants are tests
- Grammar
  - Input validation testing
  - XML and others
  - Valid strings

BNF Grammar Testing (9.4.1)

- Terminal symbol coverage and production coverage have only been applied to algebraic specifications
- Algebraic specifications are not widely used
- This is essentially research-only, so not covered in this book

Specification-based Mutation (9.4.2)

- A finite state machine is essentially a graph *G*
  - Nodes are states
  - Edges are transitions
- A *formalization* of an FSM is:
  - *States* are implicitly defined by declaring variables with limited range
  - The *state space* is then the Cartesian product of the ranges of the variables
  - *Initial states* are defined by limiting the ranges of some or all of the variables
  - *Transitions* are defined by rules that characterize the source and target of each transition

Example SMV Machine

```
MODULE main
#define false 0
#define true 1
VAR
        x, y : boolean;
ASSIGN
          init (x) := false;
          init (y) := false;

          next (x) := case
              !x & y : true;
              !y       : true;
              x        : false;
              true    : x;
          esac;

          next (y) := case
              x & !y : false;
              x & y  : y;
              !x & y : false;
              true    : true;
           esac;
```

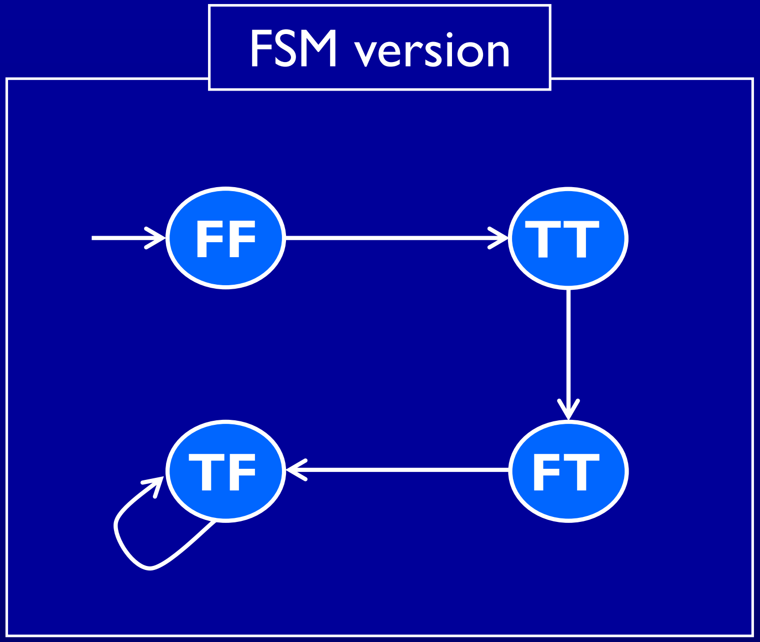
- Initial state : (F, F)
- Value for x in next state:
  - if x=F and y=T, next state has x=T
  - if y=F, next state has x=T
  - if x=T, next state has x=F
  - otherwise, next state x does not change
- Value for y in next state:
  - if (T, F), next state has y=F
  - if (T, T), next state y does not change
  - if (F,T), next state has y=F
  - otherwise, next state has y=T
- Any ambiguity in SMV is resolved by the order of the cases
- "true : x" corresponds to "default" in programming

Example SMV Machine

```
MODULE main
#define false 0
#define true 1
VAR
        x, y : boolean;
ASSIGN
        init (x) := false;
        init (y) := false;

        next (x) := case
            !x & y : true;
            !y     : true;
            x      : false;
            true   : x;
        esac;

        next (y) := case
            x & !y : false;
            x & y  : y;
            !x & y : false;
            true   : true;
        esac;
```



- Converting from SMV to FSM is mechanical and easy to automate
- SMV notation is smaller than graphs for large finite state machines

Using SMV Descriptions

- Finite state descriptions can capture system behavior at a very high level – suitable for communicating with end users
- The verification community has built powerful analysis tools for finite state machines expressed in SMV
- These tools produce explicit evidence for properties that are not true
- This "*evidence*" is presented as sequences of states, called "counterexamples"
- Counterexamples are *paths* through the FSM that can be used as test cases

Mutations and Test Cases

- Mutating FSMs requires mutation operators (like mutating programming source)
- Most FSM mutation operators are similar to program language operators

Constant Replacement operator:

- changes a constant to each other constant
- in the *next(y)* case: *!x & y : false* is mutated to *!x & y : true*
- To kill this mutant, we need a sequence of states (a path) that the original machine allows but the mutated machine does not
- This is what model checkers do
  - Model checkers find counterexamples – paths in the machine that violate some property
  - Properties are written in "temporal logic" – logical statements that are true for some period of time
  - *!x & y: false* has different result from *!x & y: true*

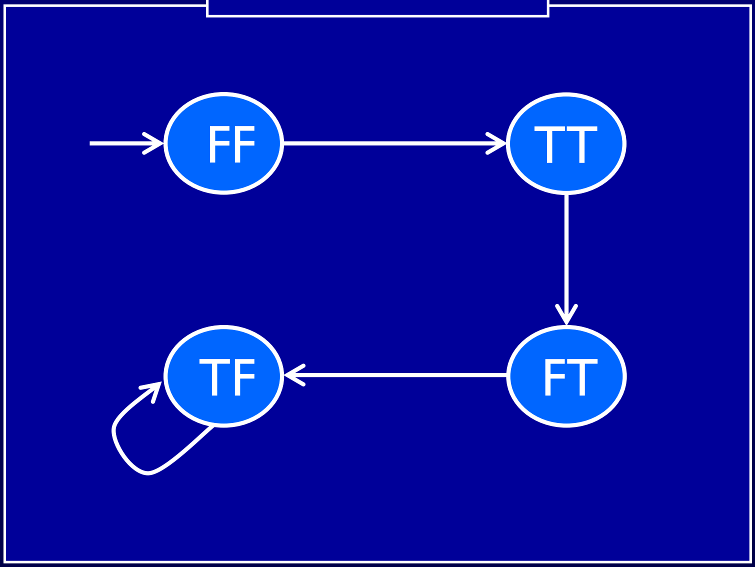
Counter-Example for FSM

```
next (y) := case
              x & !y : false;
              x & y  : y;
              !x & y : false;
Δ 1           !x & y : true;
              true   : true;
           esac;
```

written in SMV as →

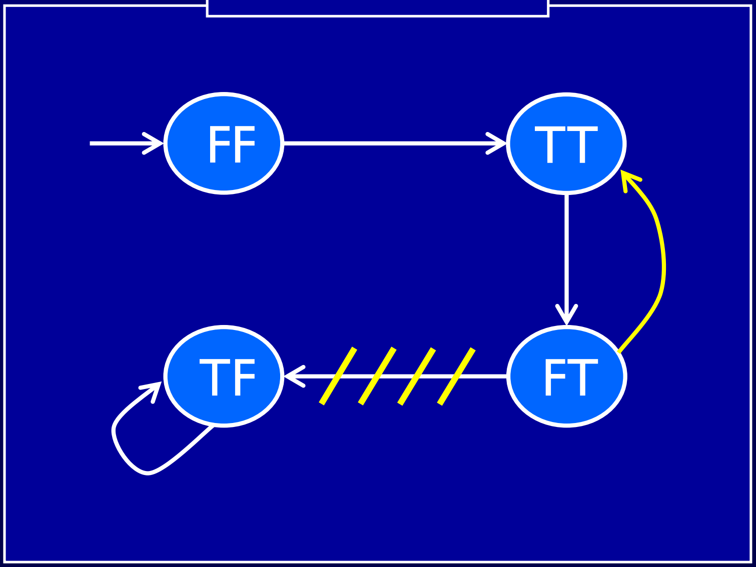
```
next (y) := case
              x & !y : false;
              x & y  : y;
              !x & y : false;
              true   : true;
           esac;
SPEC AG (!x & y) → AX (y=true)
```

FSM version



mutated FSM →

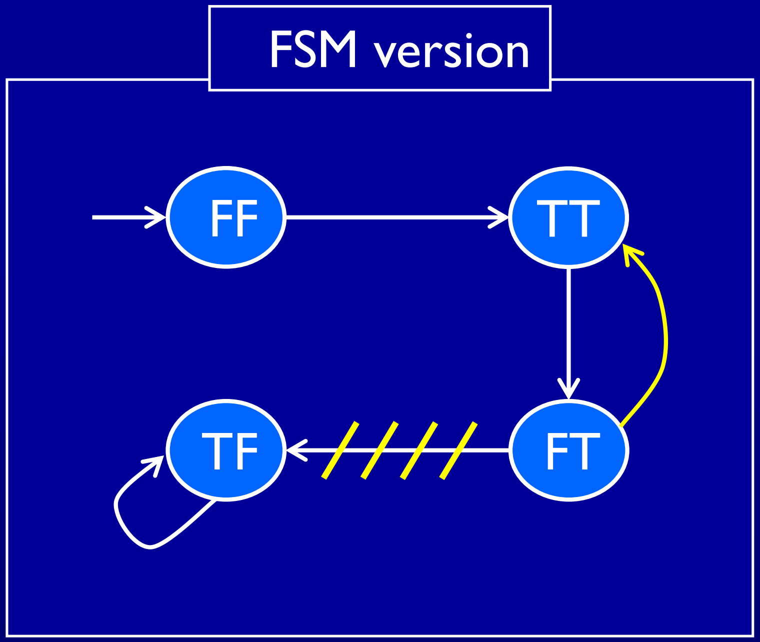
FSM version



Counter-Example for FSM

- If we add the property: SPEC AG (!x & y) →AX (y=true) to the mutated FSM, the model checker should produce :

/* state 1 */ { x = 0, y = 0 }
/* state 2 */ { x = 1, y = 1 }
/* state 3 */ { x = 0, y = 1 }
/* state 4 */ { x = 1, y = 0 }



- This state sequence represents a test case that goes from nodes FF to TT to FT to TF in the original FSM
  - The last step in the mutated FSM will be to TT, but not TF in the original, thus killing the mutant
- If no sequence is produced, the mutant is equivalent
  - *Equivalence is undecidable for programs, but decidable for FSMs*

Model-Based Grammars Summary

- Model-checking is slowly growing in use
- Finite state machines can be encoded into model checkers
- Properties can be defined on FSMs and model checking used to find paths that violate the properties
- No equivalent mutants
- Everything is finite (model checker has a finite domain to work in, and hence the equivalent mutant problem is decidable, unlike with program code)