Model Based Testing

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FSM based testing

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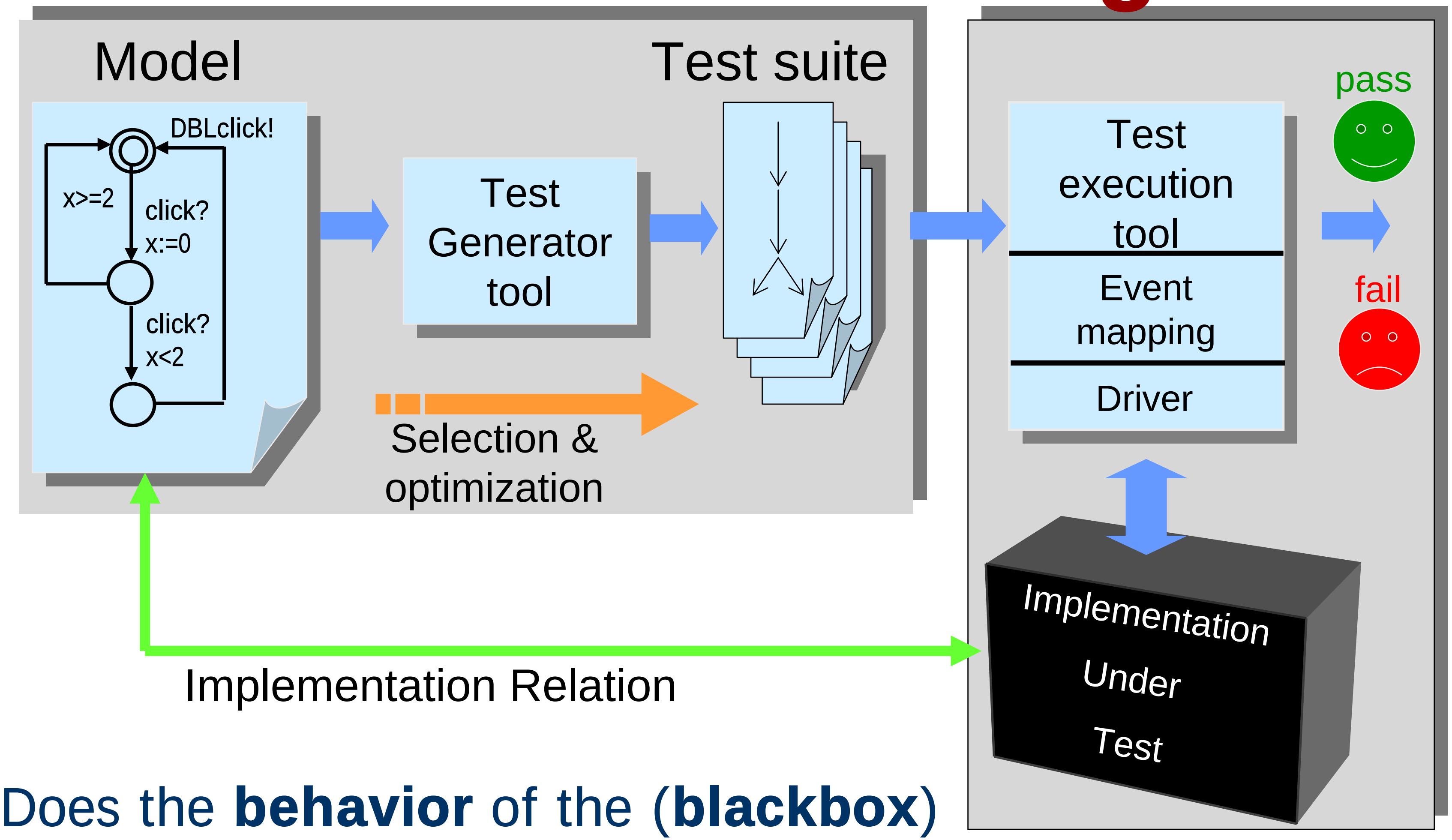
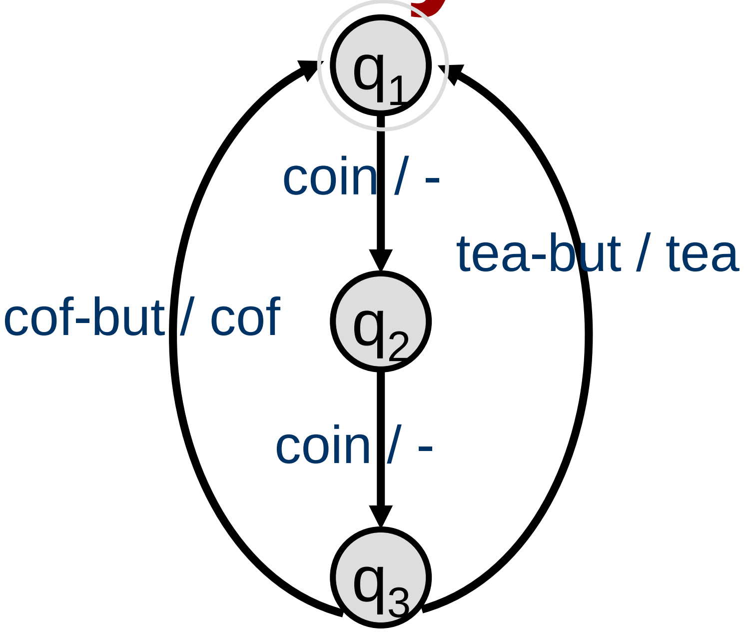
Automated Model Based Conformance Testing



Does the **behavior** of the (**blackbox**) implementation ***comply*** to that of the specification?

Mealy FSM



condition		effect	
current state	input	output	next state
q_1	coin	-	q_2
q_2	coin	-	q_3
q_3	cof-but	cof	q_1
q_3	tea-but	tea	q_1

Inputs = {cof-but, tea-but, coin}
Outputs = {cof,tea}
States: $\{q_1,q_2,q_3\}$
Initial state = q_1
Transitions= {
$(q_1$, coin, -, $q_2)$,
$(q_2$, coin, -, $q_3)$,
$(q_3$, cof-but, cof, $q_1)$,
$(q_3$, tea-but, tea, $q_1)$
}

Sample run:

$q_1 \xrightarrow{\text{coin/ -}} q_2 \xrightarrow{\text{coin/-}} q_3 \xrightarrow{\text{cof-but / cof}} q_1 \xrightarrow{\text{coin/ -}}$

$q_2 \xrightarrow{\text{coin/ -}} q_3 \xrightarrow{\text{cof-but / cof}} q_1$

State Machine : FSM Model

FSM - Finite State Machine - or *Mealy Machine* is 5-tuple

$$M = (S, I, O, \delta, \lambda)$$

S	finite set of states
I	finite set of inputs
O	finite set of outputs
$\delta : S \times I \rightarrow S$	transfer function
$\lambda : S \times I \rightarrow O$	output function

Natural extension to sequences : $\delta : S \times I^* \rightarrow S$
$\lambda : S \times I^* \rightarrow O^*$

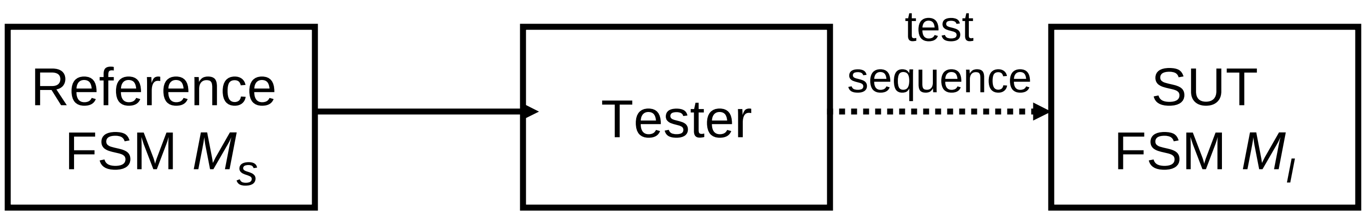
Concepts

- Two states ***s*** and ***t*** are (language) **equivalent** iff
  - *s* and *t* accepts same language
  - has same traces: $tr(s) = tr(t)$
- Two Machines M0 and M1 are equivalent iff initial states are equivalent
- A **minimized** / reduced M is one that has no equivalent states
  - for no two states *s*,*t*, *s*!=*t*, s equivalent t

Fundamental Results

- Every FSM may be determinized accepting the same language (potential explosion in size).
- For each FSM there exist a language-equivalent *minimal* deterministic FSM.
- FSM's are closed under $\cap$ and $\cup$
- FSM's may be described as regular expressions (and vise versa)

Conformance Testing



Given a specification FSM M_S

a (black box) implementation FSM M_I

determine whether M_I conforms to $M_{S.}$

i.e., M_I behaves in accordance with M_S

i.e., whether outputs of M_I are the same as of M_S

i.e., whether the reduced M_I is equivalent to M_S

Today:

- Deterministic Specifications
- SUT is an (unknown) deterministic FSM (testing hypothesis)

Restrictions

FSM restrictions:

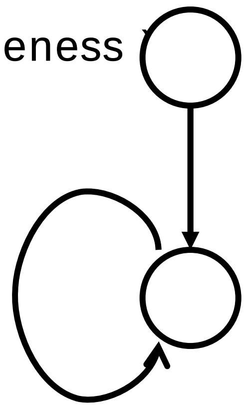
- ***deterministic***

  δ : S x I $\rightarrow$ S and λ : S x I $\rightarrow$ O are *functions*

- *completely specified*

  δ : S x I $\rightarrow$ S and λ : S x I $\rightarrow$ O are *complete* functions

  (empty output is allowed; sometimes implicit completeness)



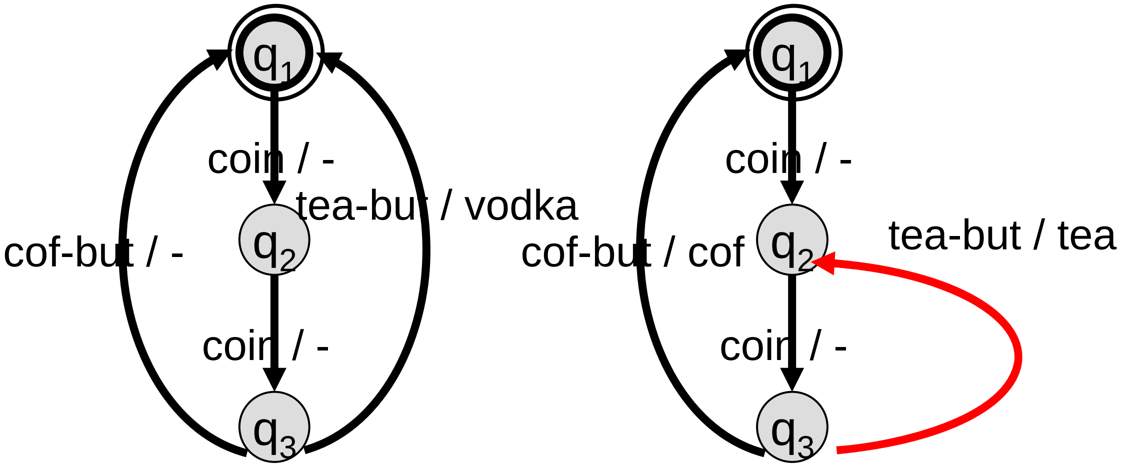
- *strongly connected*

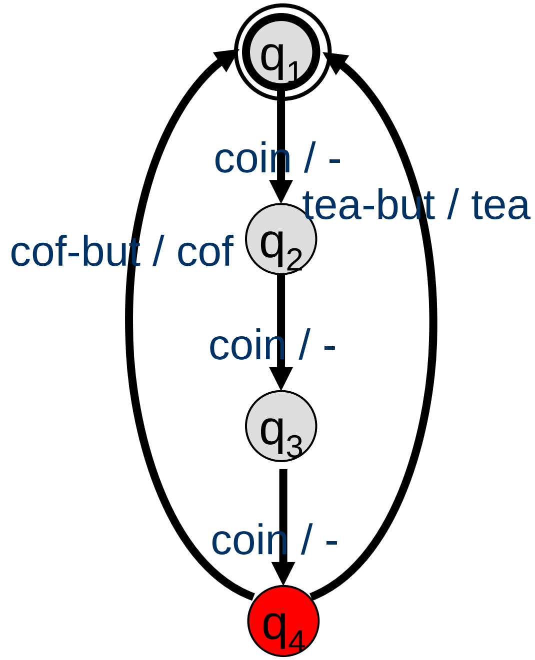
  from any state any other state can be reached

- *reduced*

  there are no equivalent states

Possible Errors

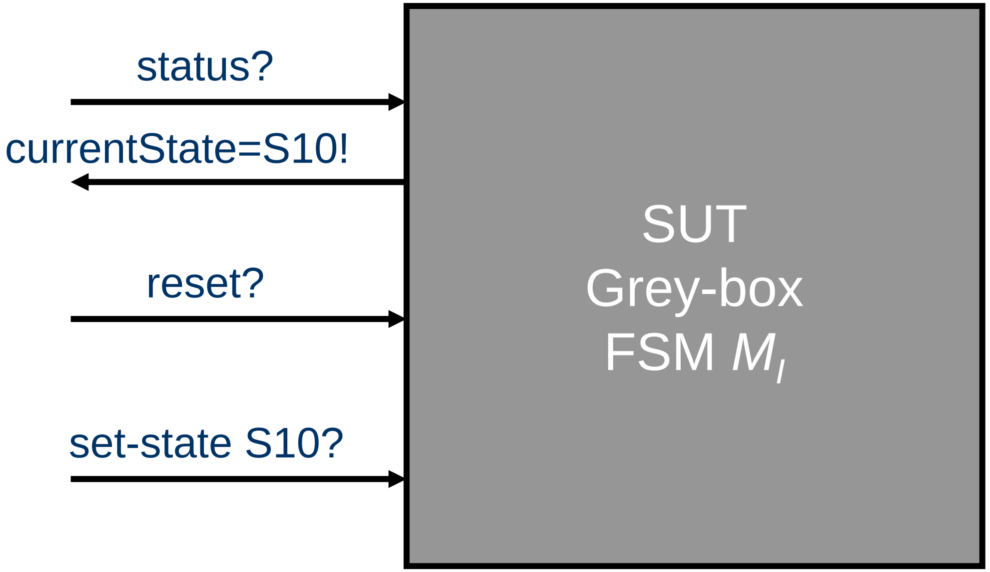




- output fault (wrong or missing)
- extra or missing states
- transition fault
  - to other state
  - to new state

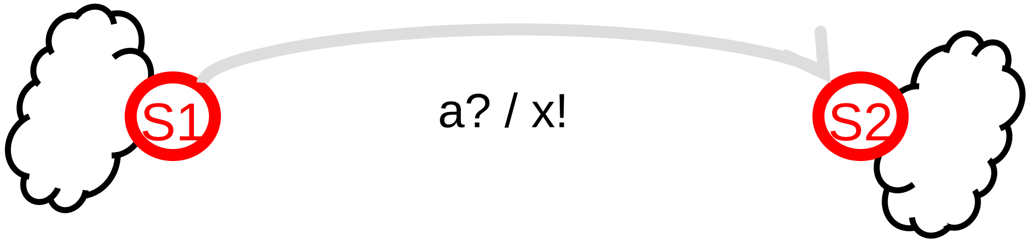
Desired Properties

- Nice, but rare / problematic
  - status messages: Assume that tester can ask implementation for its current state (reliably!!) without changing state
  - reset: reliably bring SUT to initial state
  - set-state: reliably bring SUT to any given state



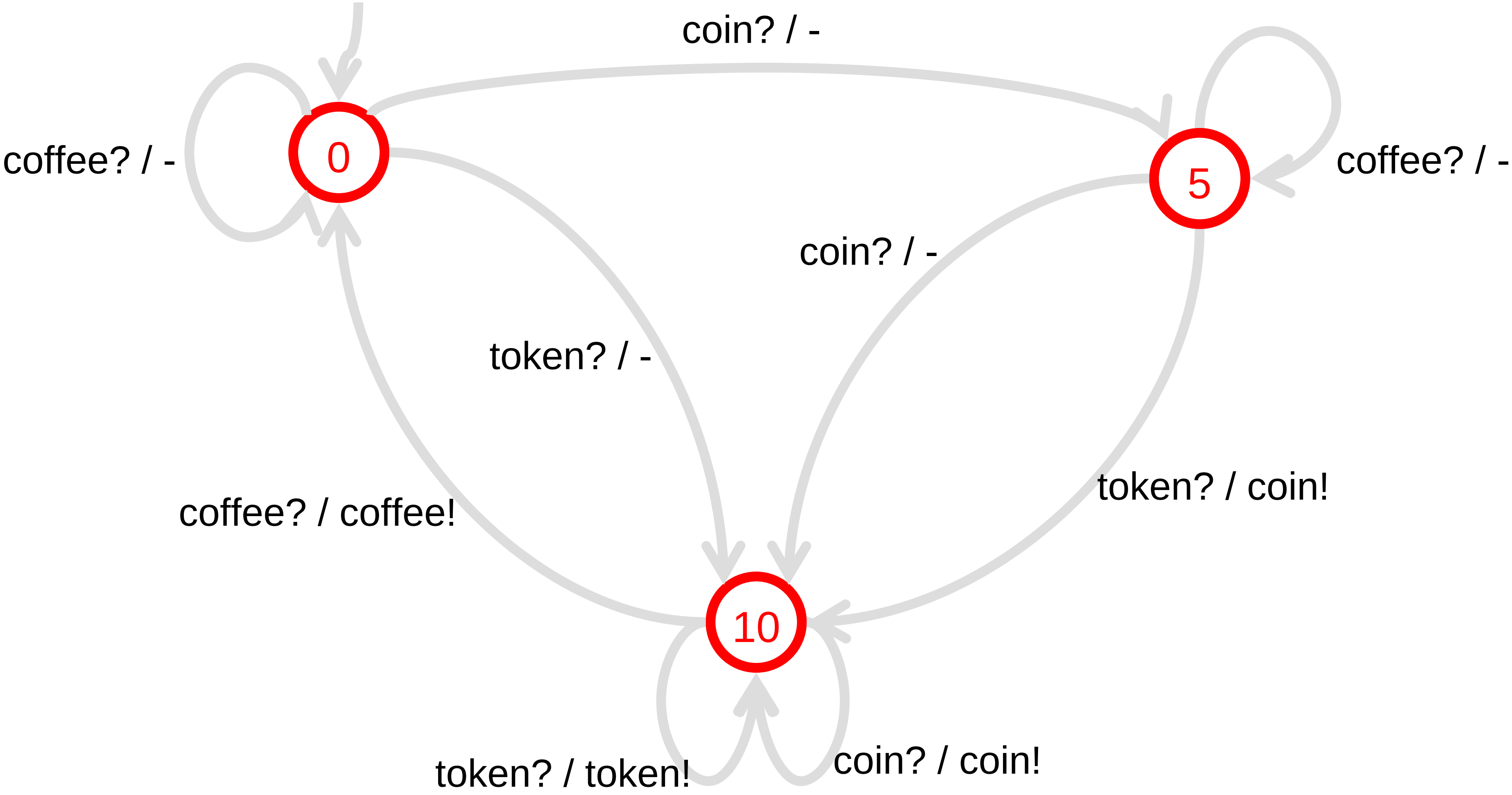
FSM Transition Testing

- Make test case for every transition in spec separately:



- Test transition :
  1. Go to state S1
  2. Apply input a?
  3. Check output x!
  4. Verify state S2 (optionally)
- *Test purpose: “Test whether the system, when in state S1, produces output x! on input a? and goes to state S2”*

Coffee Machine FSM Model



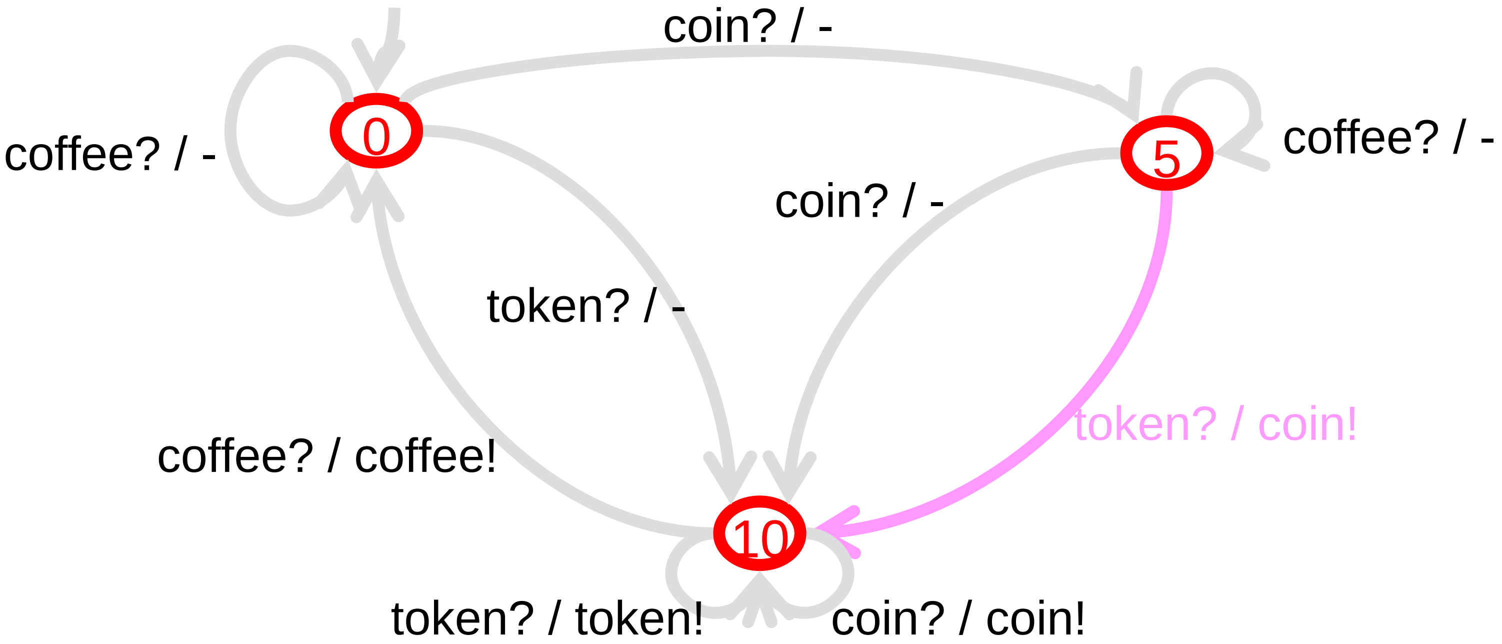
Transition Testing –1

- To test token? / coin! :

  go to state 5 : set-state 5

  give input token? check output coin!

  verify state: send status? check status=10

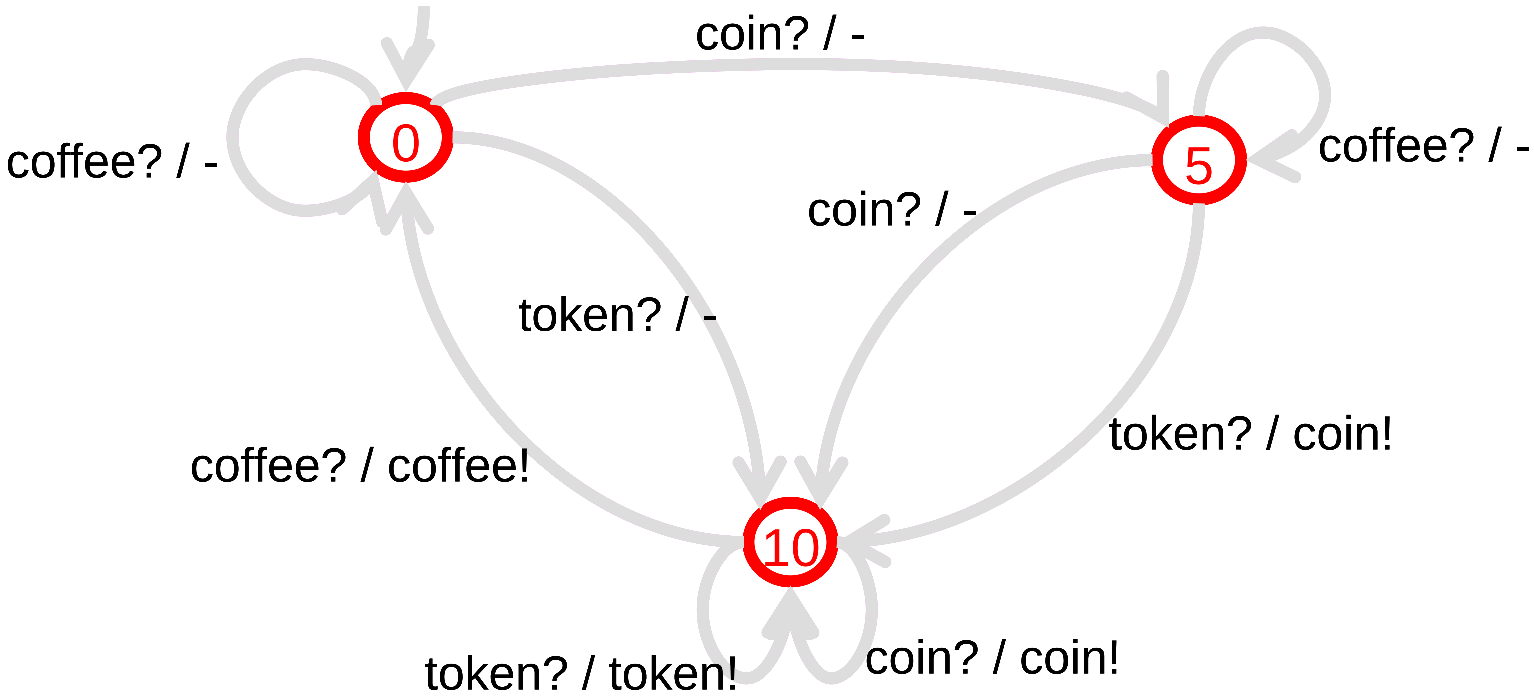


Test case : set-state 5/ * - token? / coin! - status? / 10!

|S| * | I | test cases remaining

FSM Transition Tour

- Make Transition Tour that covers every transition (in spec)



Test input sequence :

reset? coffee? coin? coffee? coin? coin? token? coffee? token? coffee? coin? token? coffee?

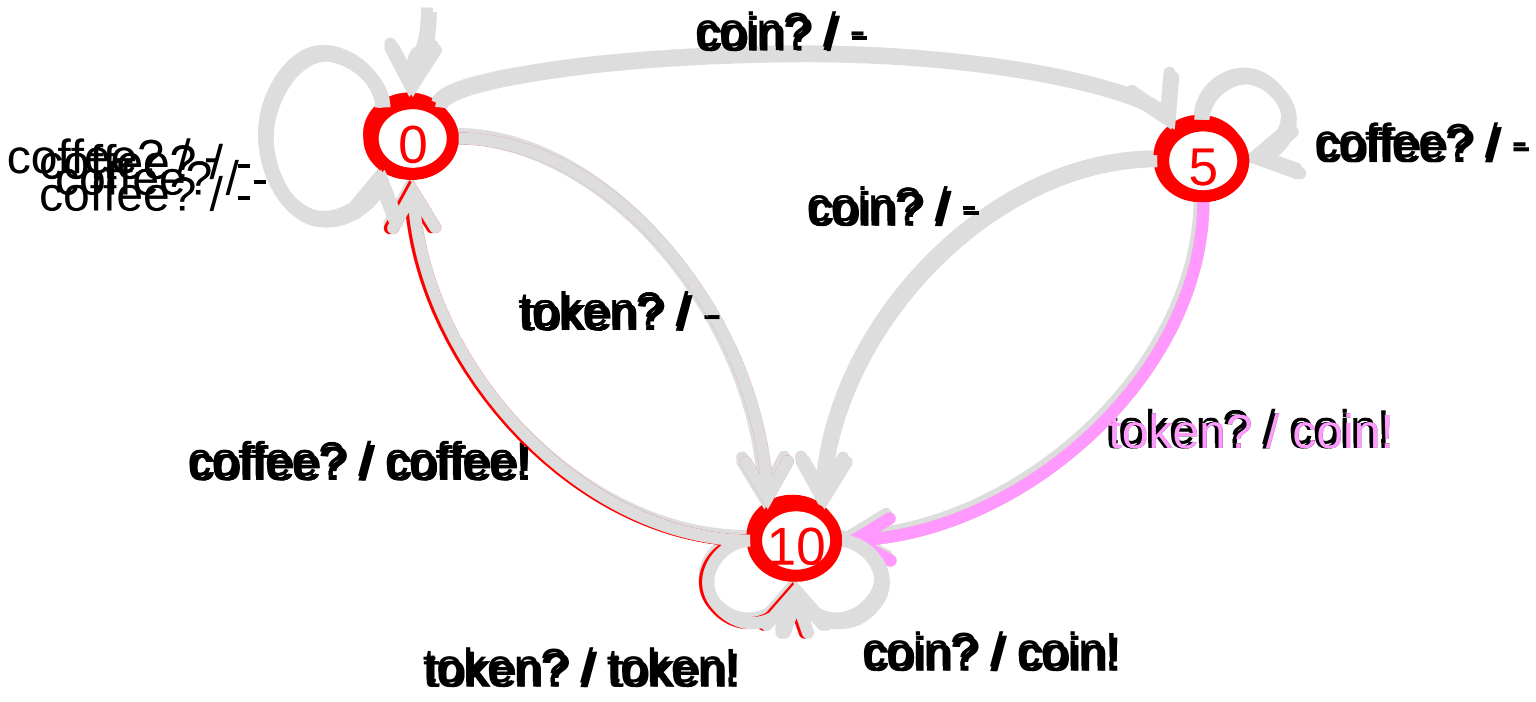
+ check expected outputs and target state by status message

Transition Testing -1

- Go to state S5 :
- No Set-state property???
  - use *reset property* if available
  - go from S0 to S5
    (always possible because of determinism and completeness)
  - or:
  - *synchronizing sequence* brings machine to particular known state, say S0, from any state
  - (but synchronizing sequence may not exist)

Transition Testing -1

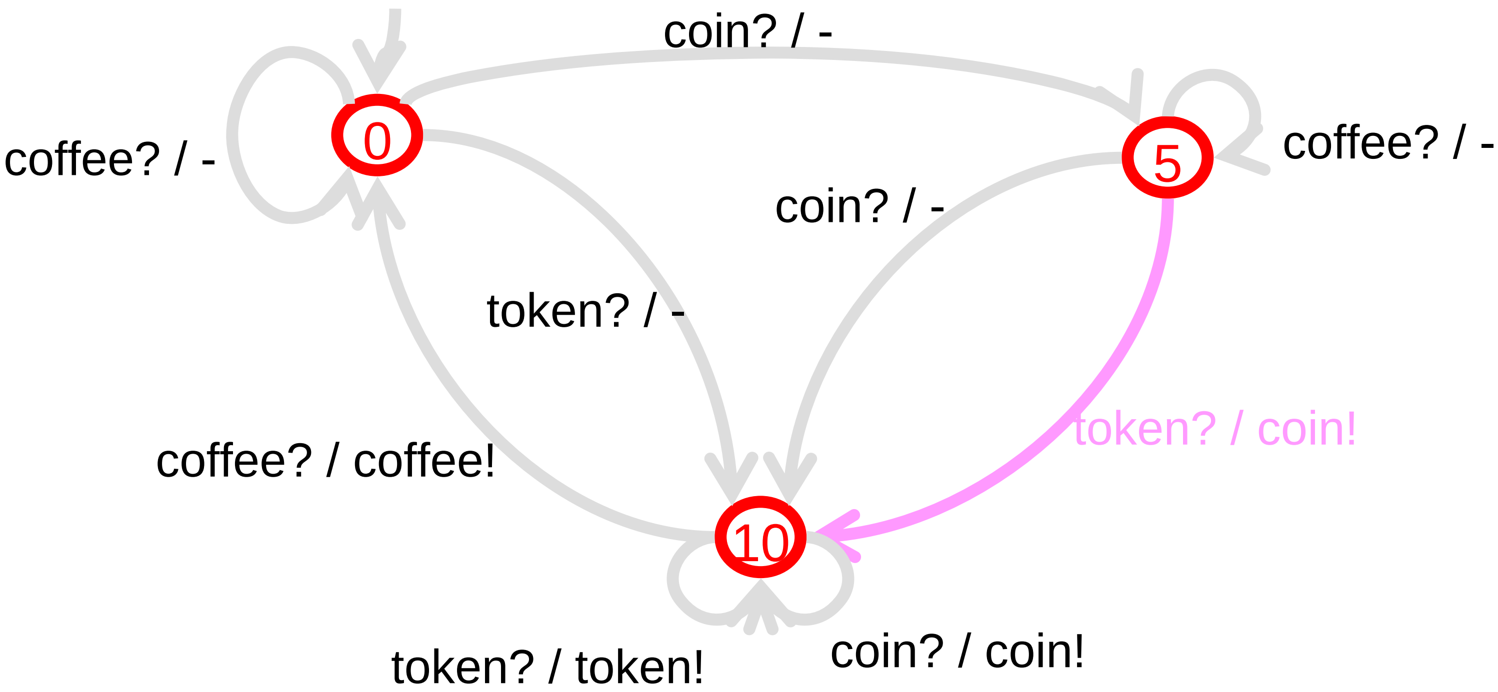
synchronizing sequence : token? coffee?



To test token? / coin! : go to state 5 by : token? coffee? coin?

Transition Testing –2,3

- To test token? / coin! :
  1. go to state 5 by : token? coffee? coin?
  2. give input token?
  3. check output coin!
  4. verify that machine is in state 10



Transition Testing-4

- No Status Messages??
- **State identification: What state am I in??**
- **State verification : Am I in state s?**
  - Apply sequence of inputs in the current state of the FSM such that from the outputs we can
    - identify that state where we started; or
    - verify that we were in a particular start state
  - Different kinds of sequences
    - UIO sequences (Unique Input Output sequence, SIOS)
    - Distinguishing sequence (DS)
    - W - set (characterizing set of sequences)
    - UIOv
    - SUIO
    - MUIO
    - Overlapping UIO

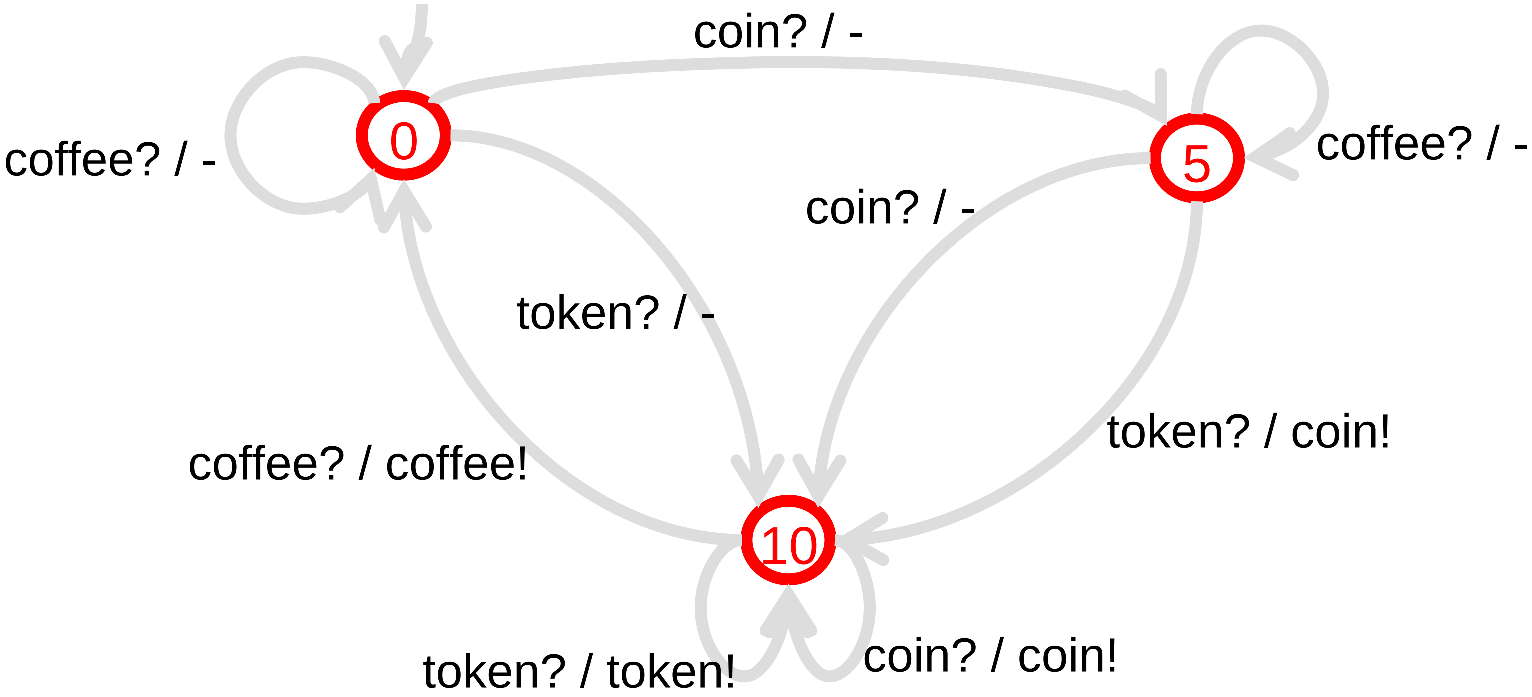
Transition Testing-4

State check :

- UIO sequences (verification)
  - sequence x_s that distinguishes state s from all other states : for all $t \neq s$: $\lambda (s, x_s) \neq \lambda (t, x_s)$
  - each state has its own UIO sequence
  - UIO sequences may not exist
- Distinguishing sequence (identification)
  - sequence x that produces different output for every state : for all pairs t, s with $t \neq s$: $\lambda (s, x) \neq \lambda (t, x)$
  - a distinguishing sequence may not exist
- W - set of sequences (identification)
  - *set of* sequences W which can distinguish any pair of states : for all pairs $t \neq s$ there is $x \in W$: $\lambda (s, x) \neq \lambda (t, x)$
  - W - set always exists for reduced FSM

Transition Testing-4: UIO

UIO sequences



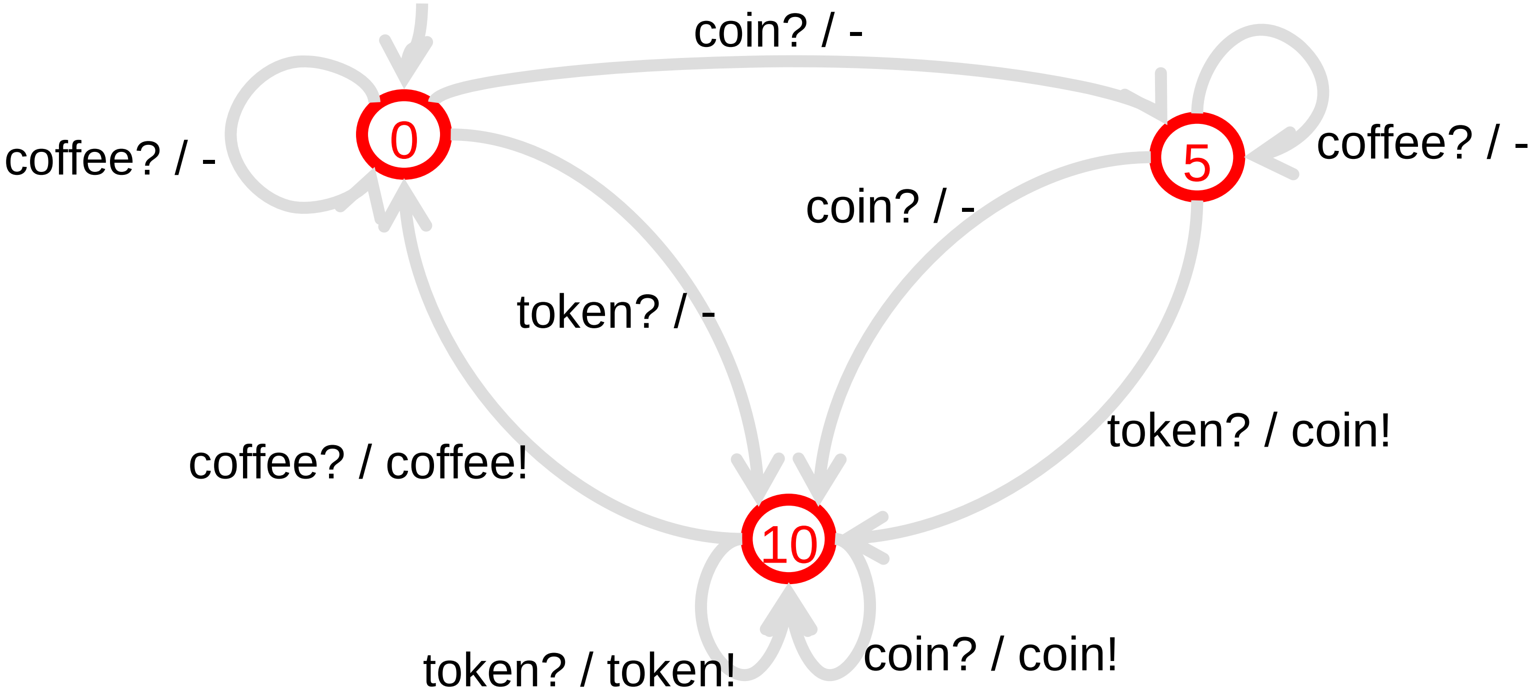
state 0 : coin? / - coffee? / -

state 5 : token? / coin!

state 10 : coffee? / coffee!

Transition Testing-4: DS

DS sequence



DS sequence : token? output state 0 : -

output state 5 : coin!

output state 10 : token!

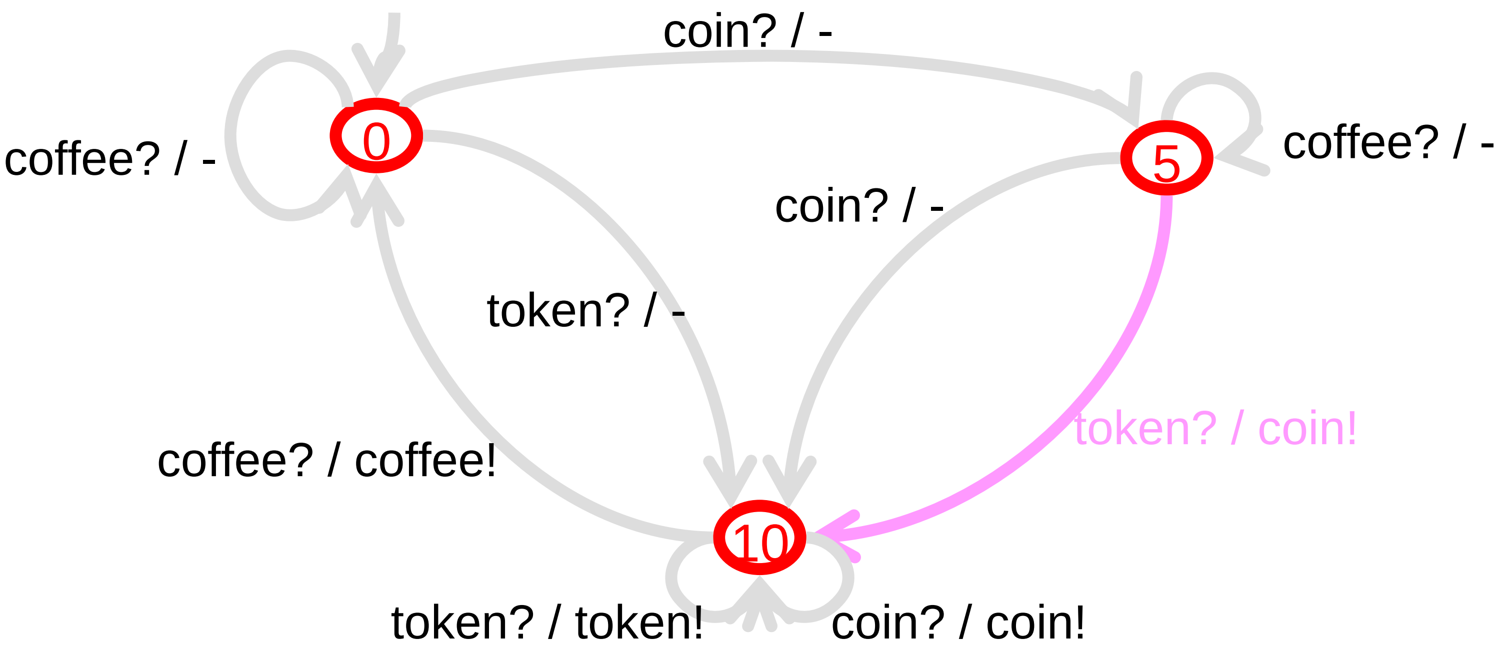
Transition Testing – 4 done

- To test token? / coin! :

  go to state 5 : token? coffee? coin?

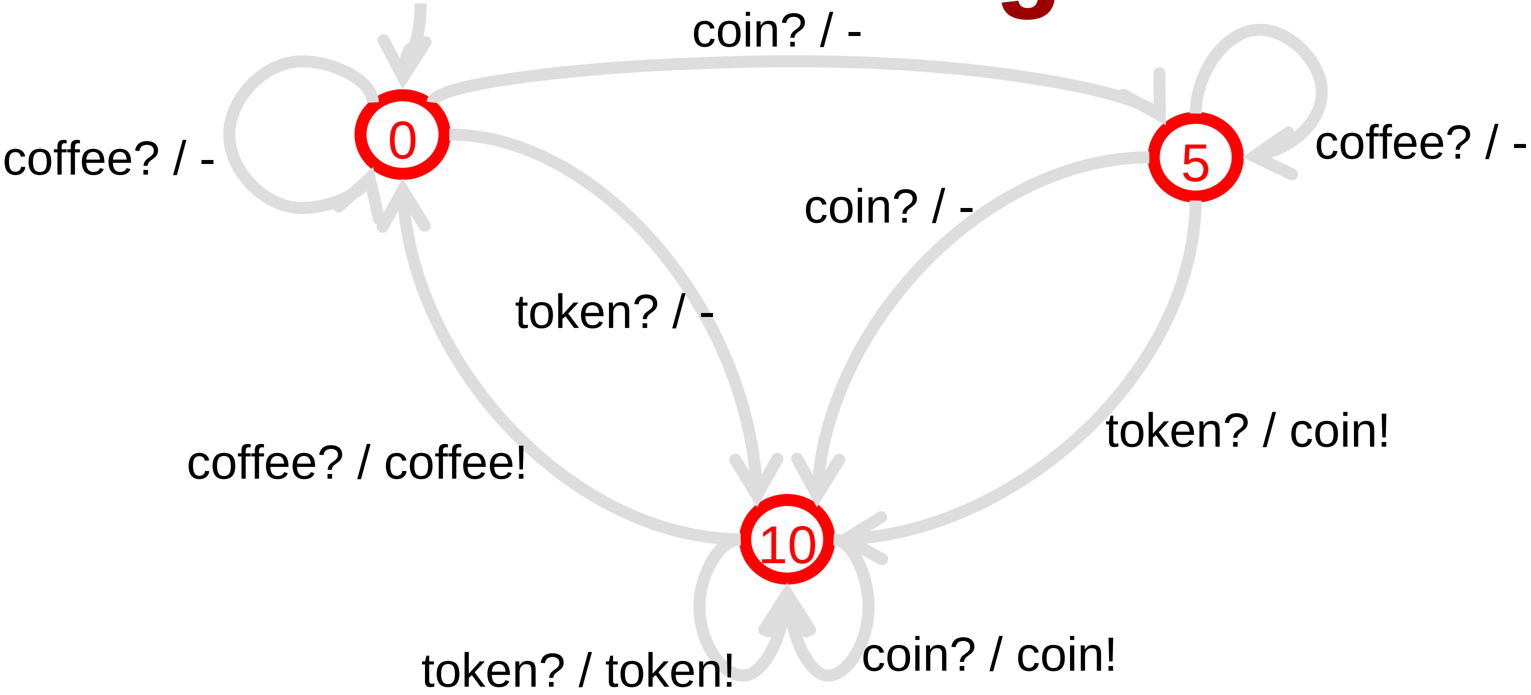
  give input token? check output coin!

  Apply UIO of state 10 : coffee? / coffee!



Test case : token? / * coffee? / * coin? / - token? / coin! coffee? / coffee!

Transition Testing - done



- 9 transitions / test cases for coffee machine
- if end-state of one corresponds with start-state of next then concatenate
- different ways to optimize and remove overlapping / redundant parts
- there are (academic) tools to support this

FSM Transition Testing

- Test transition :
  - Go to state S1
  - Apply input a?
  - Check output x!
  - Verify state S2
- Checks every output fault and transfer fault (to existing state)
- **If** we assume that

  the number of states of the implementation machine M_I

  is less than or equal to

  the number of states of the specification machine to M_S.

  then testing all transitions in this way

  leads to equivalence of reduced machines,

  i.e., **complete conformance**
- If not: exponential growth in test length in number of extra states.

Object Testing-1

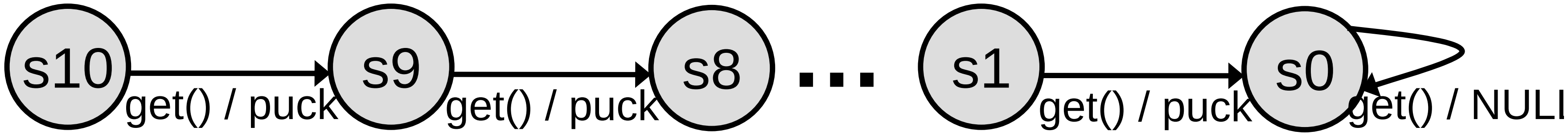
```
Class PuckSupply{
 int _count=10;
Public:

  puck * get(){
         if(_count>0) {
           _count--;return get_puck();
         } else {
           return NULL;
          }

};
```

- A Test case

```
s=new PuckSupply;
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()== aPuck);
Assert(s.get()==NULL);
Assert(s.get()==NULL);
```



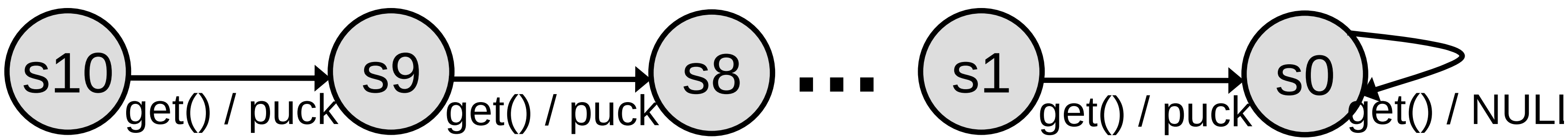
Object Testing-2

```
Class PuckSupply{
 int _count=10;
Public:
  //test helpers
  int getState() {return _count;}
  void setState(int count) {

         _count=count;
         alloc_puks();
         }
  puck * get(){
         if(_count>0) {
           _count--;return new puck();
          } else {
            return NULL;
           }

};
```

```
Assert(s.get()==aPuck);
Assert(s.getState()==9);
s.setState(1);
Assert(s.get()==aPuck);
Assert(s.getState()==0);
Assert(s.get()==NULL);
Assert(s.getState()==0);
Assert(s.get()==NULL);
Assert(s.getState()==0);
```



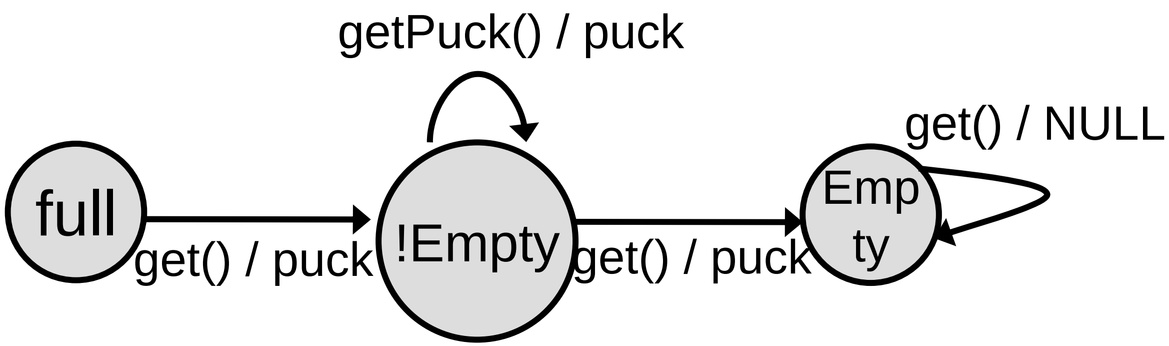
Object Testing: Abstraction

```
Class PuckSupply{
 int _count=10;
Public:

  puck * get(){
         if(_count>0) {
           _count--;return new puck();
          } else {
            return NULL;
          }

};
```

How many states in corresponding FSM?

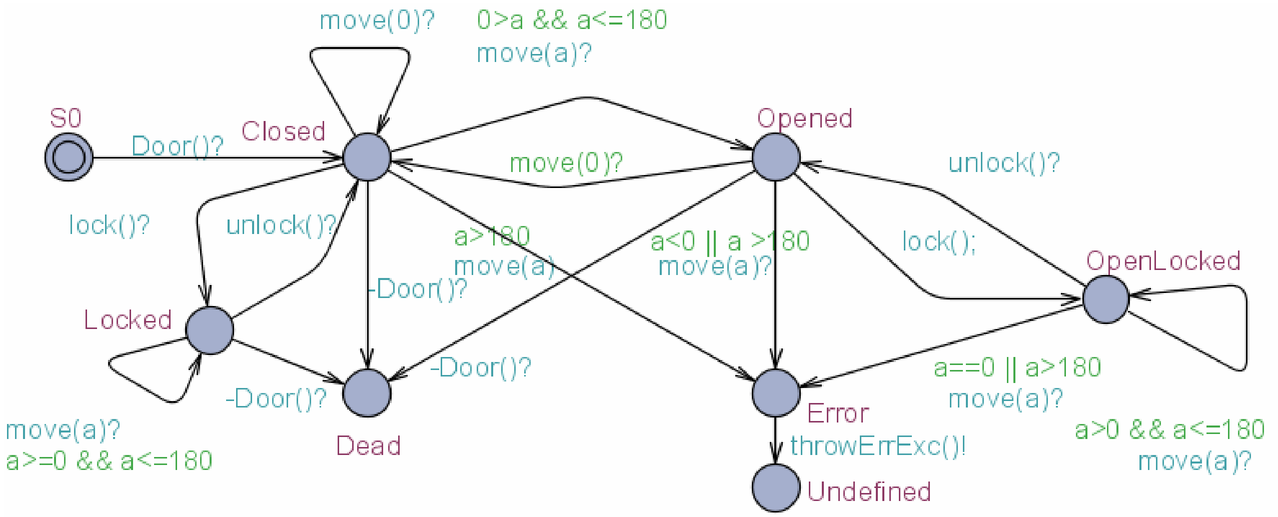


- ⇒ Generate tests systematically from **abstract** descriptions to **select** reasonably number of tests

Object Tests

```
Class Door{
Private:
  //state variables
  //methods
Public:
  Door();
  ~Door();
  Lock()
  Unlock();
  Move(Angle a) throws ErrorExc;
//test Helpers?
  State getState();
  void setState(State);
  void reset();}
```

- D=new Door();

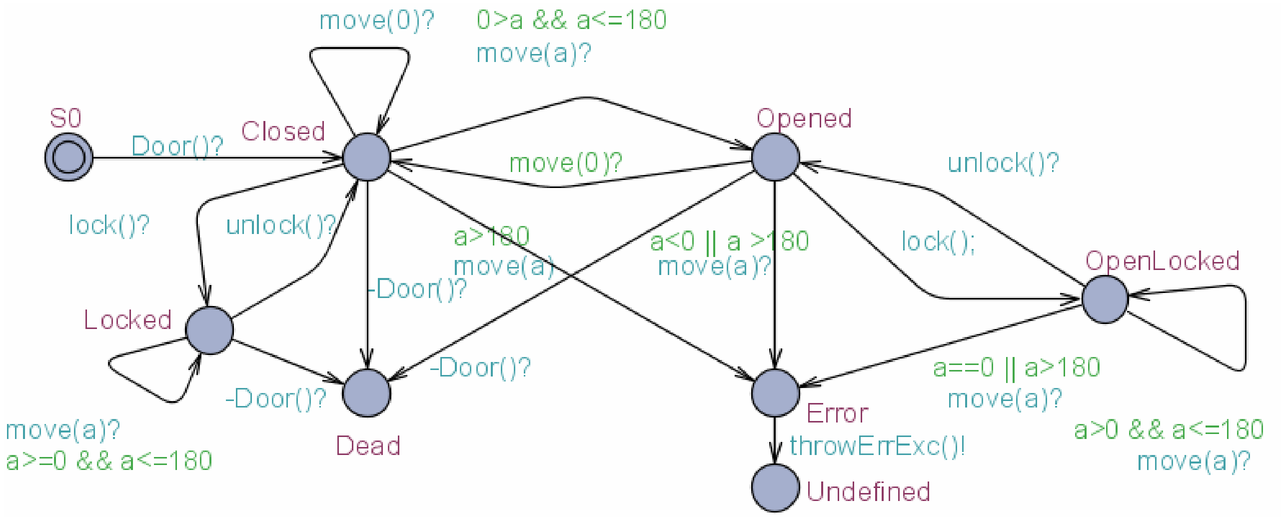


Object Tests

Test Purpose: A specific test objective (or observation) the tester wants to make on SUT

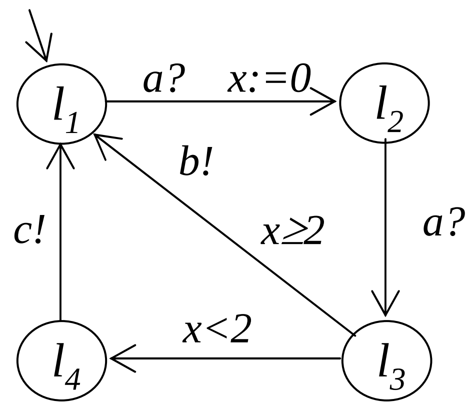
TP1: check that door can be open and locked?

- E<> door.OpenLocked
- Shortest Trace: Door()?.move(1)?.lock()?



Coverage Based Test Generation

- Multi purpose testing
- Cover measurement
- Examples:
  - Location coverage,
  - Edge coverage,
  - Definition/use pair coverage



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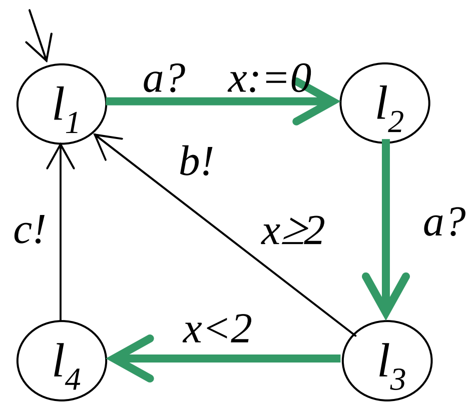

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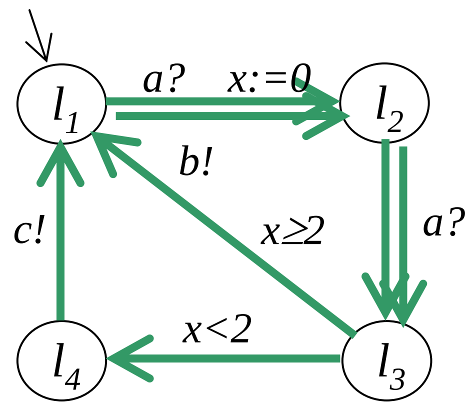

Coverage Based Test Generation

- Multi purpose testing
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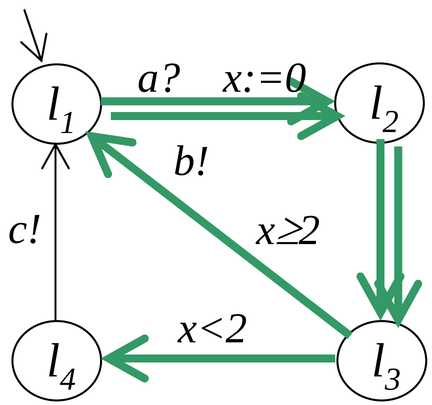
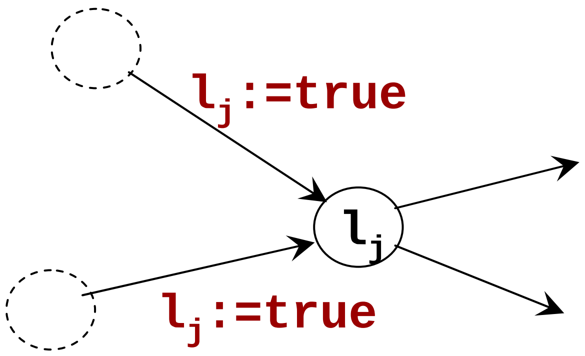
- Examples:
  - Location Coverage,
  - Edge Coverage,
  - **Definition / Use Pair Coverage**



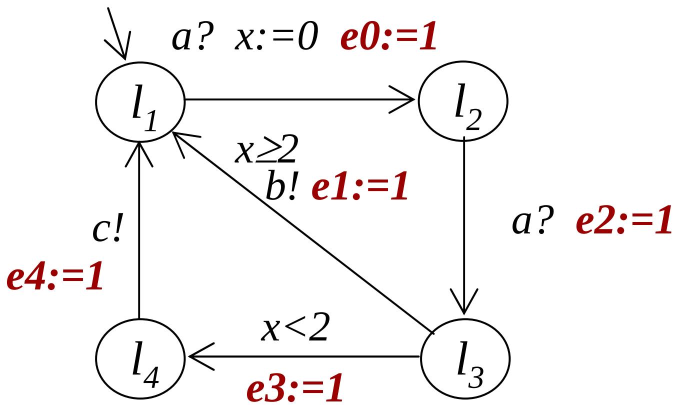
Location Coverage

- Test sequence traversing all locations
- Encoding:
  - Enumerate locations $\mathtt{l}_0,\ldots,\mathtt{l}_n$
  - Add an auxiliary variable $\mathtt{l}_i$ for each location
  - Label each ingoing edge to location i $\mathtt{l}_i\mathtt{:=true}$
  - Mark initial visited $\mathtt{l}_0\mathtt{:=true}$
- Check: $\mathtt{E<>(}\ \mathtt{l}_0\mathtt{=true} \wedge \ldots \wedge \mathtt{l}_n\mathtt{=true}\ \mathtt{)}$



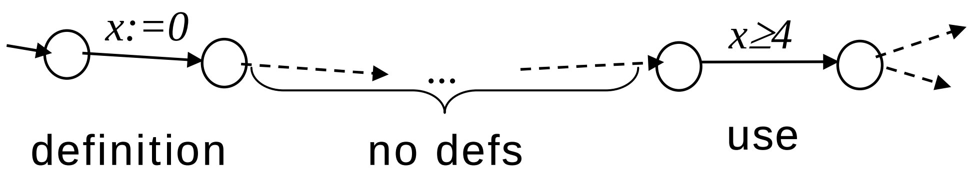
Edge Coverage

- Test sequence traversing all edges
- Encoding:
  - Enumerate edges $\mathbf{e_0,\ldots,e_n}$
  - Add auxiliary variable $\mathbf{e_i}$ for each edge
  - Label each edge $\mathbf{e_i}$`:=true`
- Check: `E<>(` e_0`=true` $\wedge \ldots \wedge$ e_n`=true )`



Definition/Use Pair Coverage

- Dataflow coverage technique
- Def/use pair of variable x:



- Encoding:
  - $v_d \in \{\, false \} \cup \{\, e_0, \ldots, e_n \,\}$, initially false
  - Boolean array du of size $|E|$ x $|E|$
  - At definition on edge i: $v_d := e_i$
  - At use on edge j: if(v_d) then $du[v_d, e_j] := true$

Definition/Use Pair Coverage

- Dataflow coverage technique
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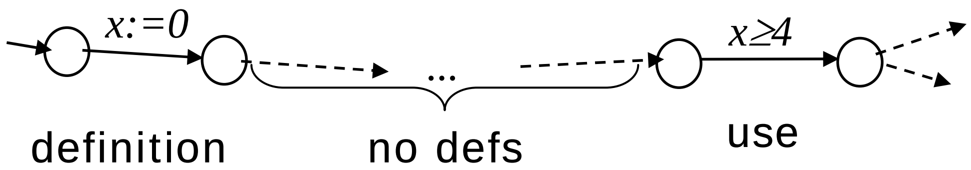
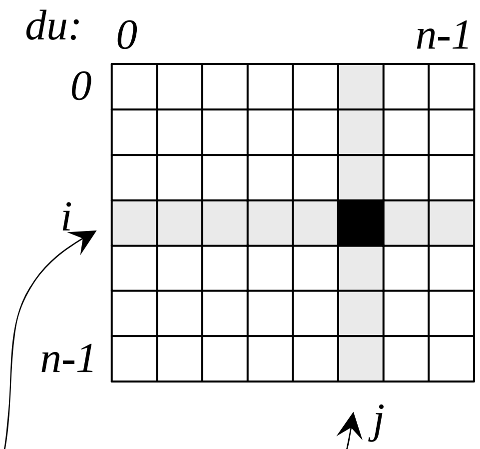
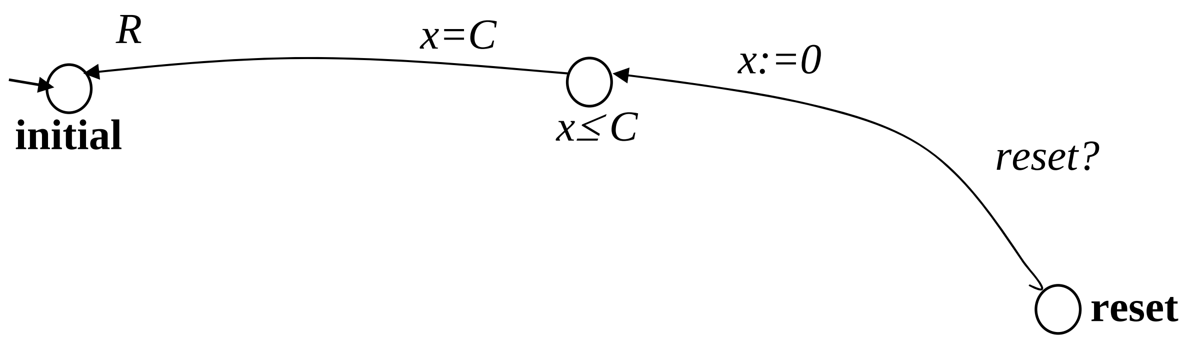




- Encoding:
  - $v_d \in \{ false \} \cup \{ e_0, \dots, e_n \}$, initially false
  - Boolean array du of size $|E|$ x $|E|$
  - At definition on edge i: $v_d := e_i$
  - At use on edge j: if(v_d) then $du[v_d, e_j] := true$
- Check:
  - E<>(all $du[i,j] = true$)

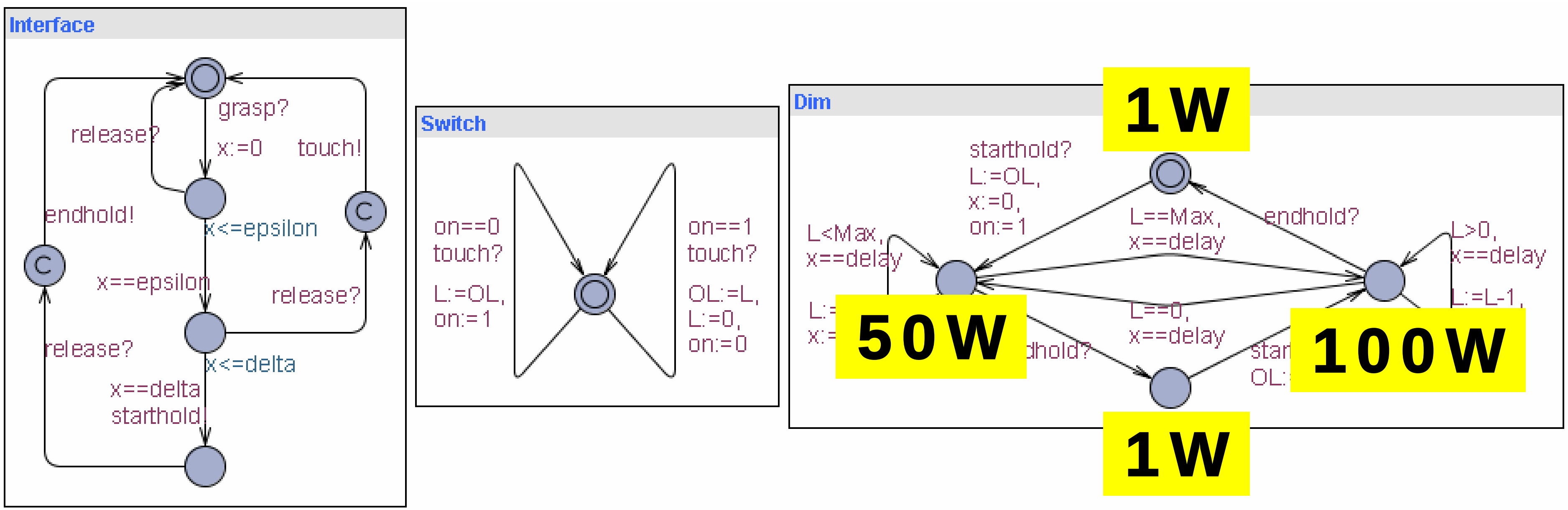
Test Suite Generation

- In general a set of test cases is needed to cover a test criteria
- Add global reset of SUT and environment model and associate a cost (of system reset)



- Same encodings and min-cost reachability
- Test sequence $\sigma = \varepsilon_0, i_0, \ldots, \varepsilon_1, i_1, \textbf{reset}\ \underbrace{\varepsilon_2, i_2, \ldots, \varepsilon_0, i_0}_{\sigma_i}, \textbf{reset}, \varepsilon_1, i_1, \varepsilon_2, i_2, \ldots$
- Test suite $T = \{\sigma_1, \ldots, \sigma_n\}$ with minimum cost

Optimal Tests



- ***Shortest*** test for max light??
- ***Fastest*** test for max light??
- ***Fastest*** edge-covering test suite??
- Least ***power*** consuming test??