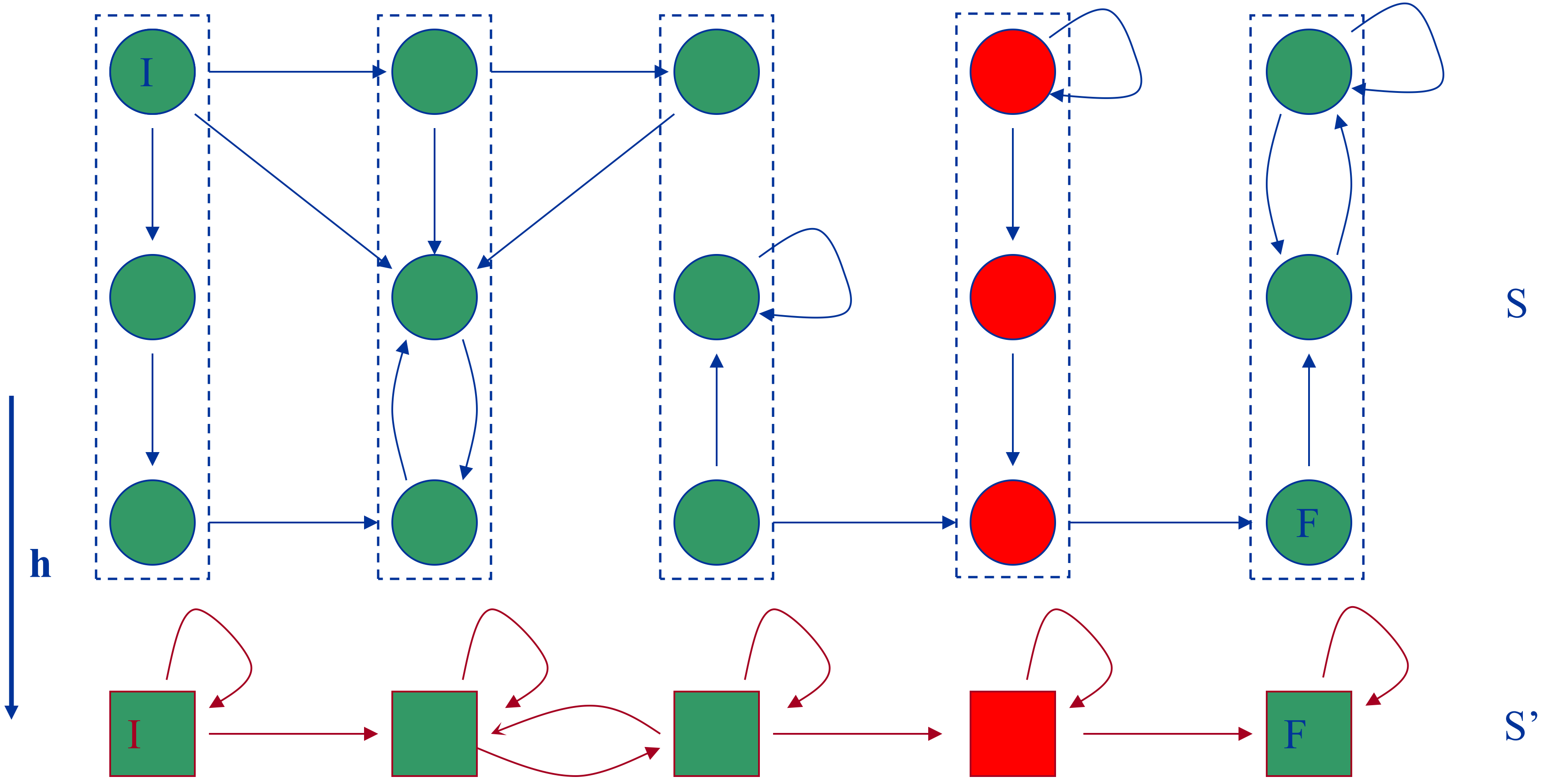
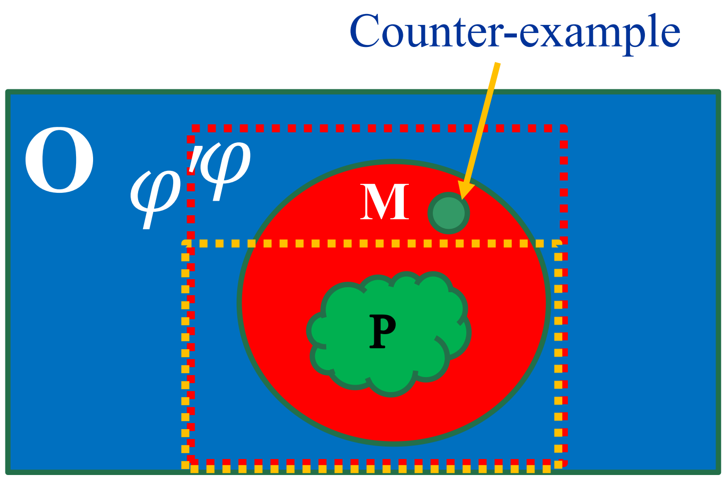
Model abstraction/approximation

Existential Abstraction (Over-approximation)

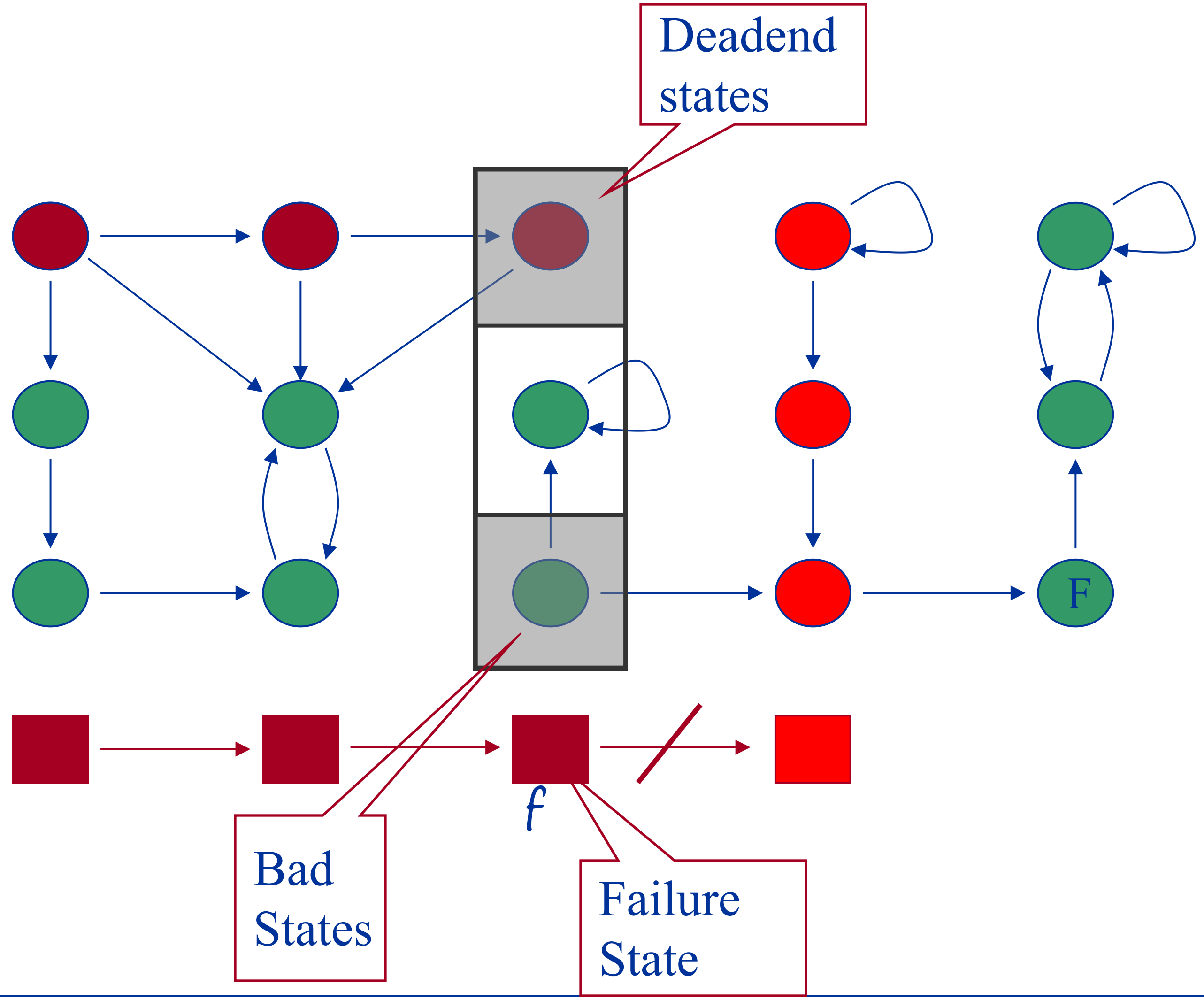


Pros and Cons of Over-approximation

- Properties satisfied by M are also satisfied by P
  - Can model check a less complex model
- M has more behaviors than P
- If a counter-example returns, it may not be a behavior of P



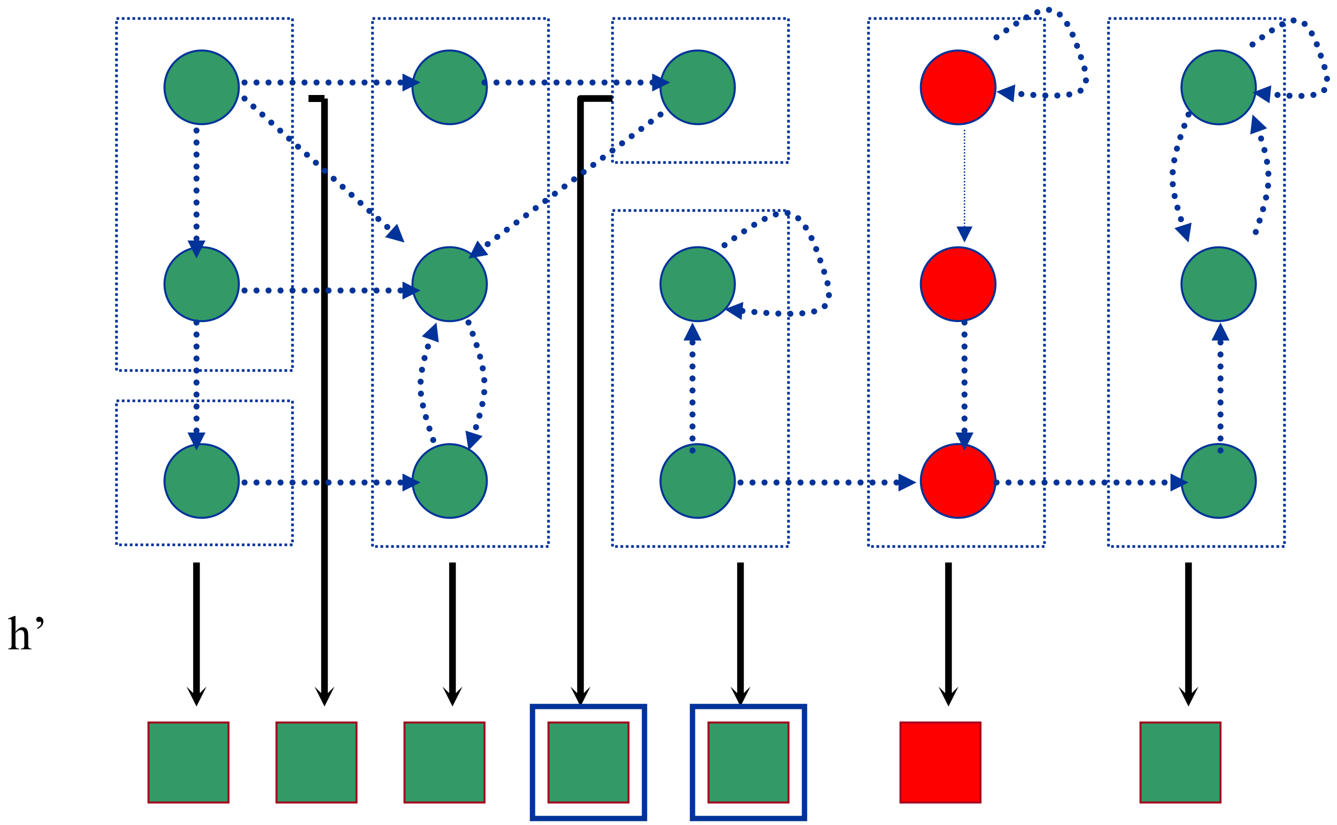
Why spurious counterexample?



Refinement

- Problem: Deadend and Bad States are in the same abstract state.
- Solution: Refine abstraction function.
- The sets of Deadend and Bad states should be separated into different abstract states.

Refinement

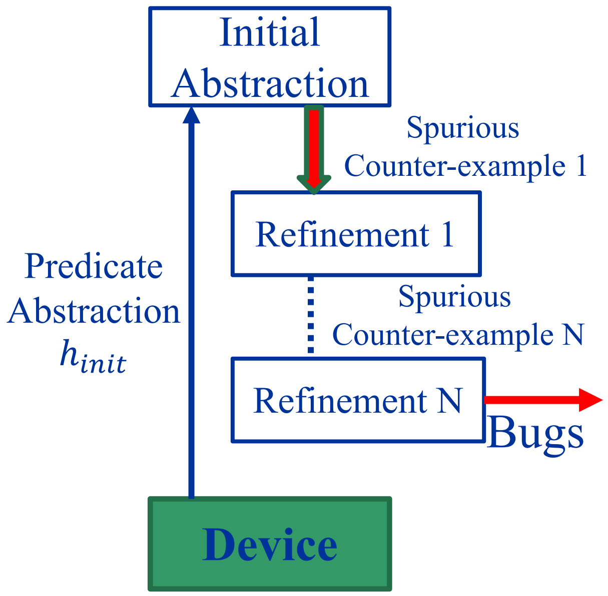


Refinement : h’

Counter-Example-Guided Abstraction and Refinement (CEGAR)

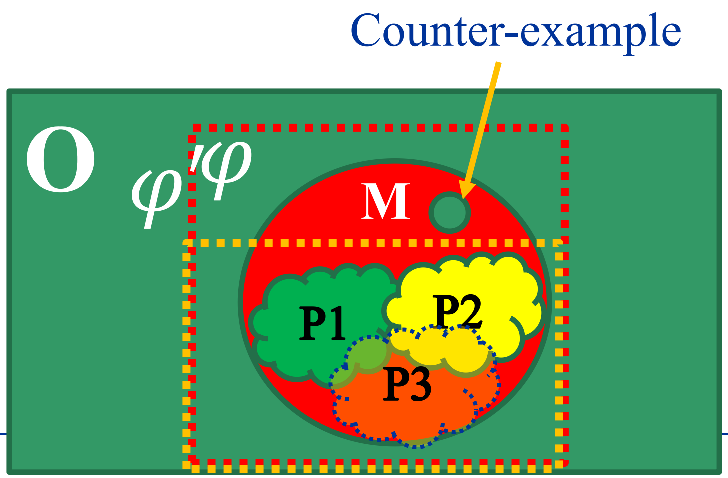
- Obtain initial abstraction

1. Model checking
2. Property satisfied -> no bugs
3. Property unsatisfied -> counter-examples
4. Check whether the CE is spurious
5. If not, bug found
6. If yes, refine the model and start from 1 again



Capture Environmental Variability With Over-approximation

- Properties satisfied by M are also satisfied by P1, P2
- Behaviors not exist in P1, P2 may also be physiologically-valid
- Is this a valid counter-example?
- Need a framework to provide context for counter-examples



Lecture 10: UPPAAL Tutorial

Partially referenced Prof. Insup Lee’s course at UPenn

UPPAAL??!!

- Model checking tool for Timed-automata
- Developed by Uppsala University and Aalborg University

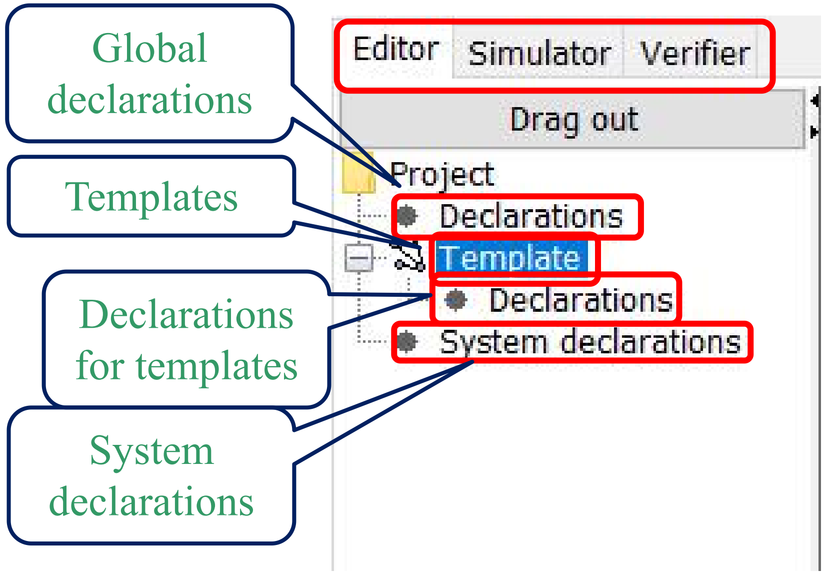
- **SWE**den + **DEN**mark = SWEDEN
  - REJECTED
- swe**DEN** + den**MARK** = DENMARK
  - REJECTED
- **UPP**sala + **AAL**borg = UPPAAL
  - ACCEPTED

UPPAAL Tool Parts

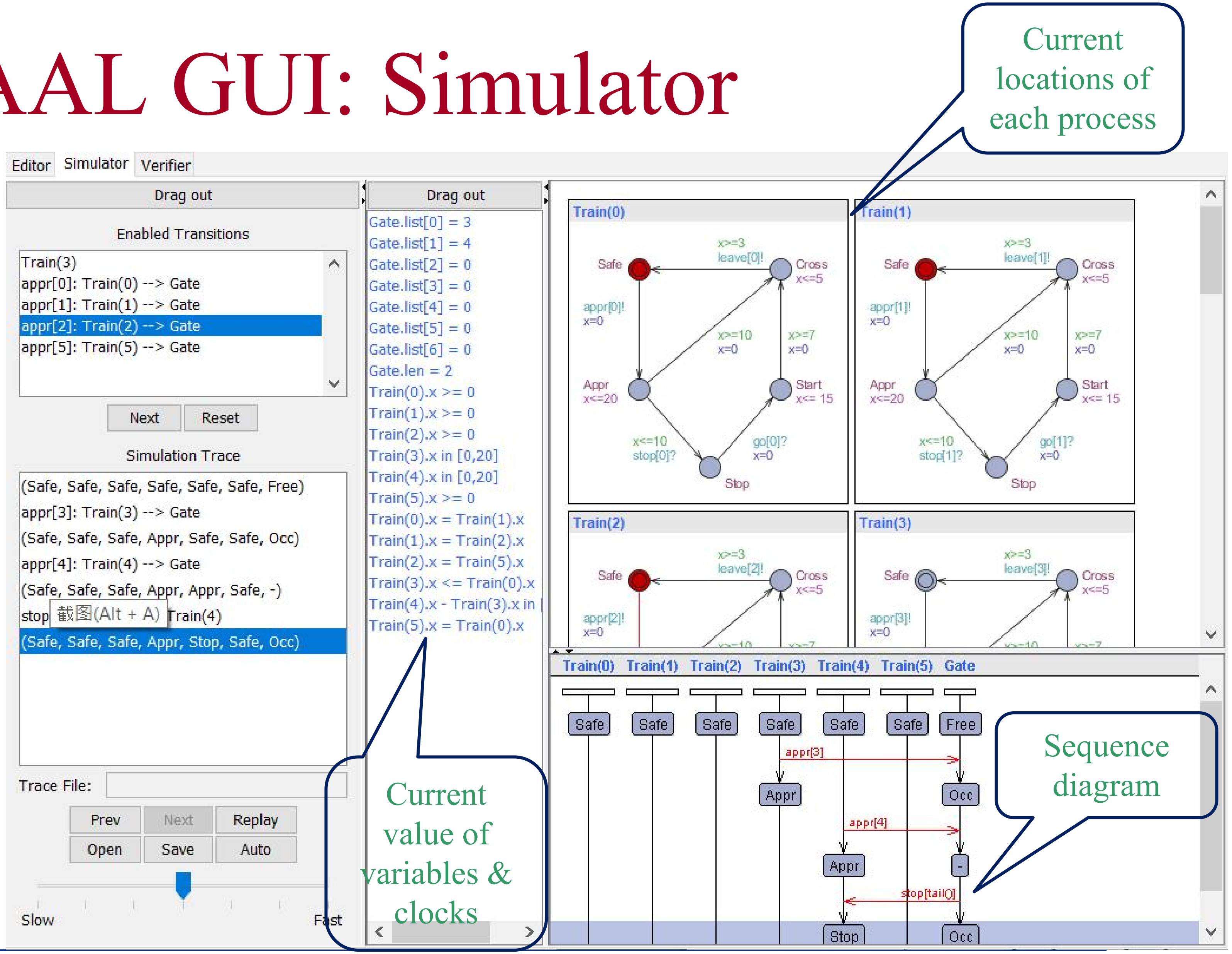
- Graphical user interface (GUI)
  - Used for modeling, simulation, and verification. Uses the verification server for simulation and verification.
- Verification server
  - Used for simulation and verification. In simulation, it is used to compute successor states.
- A command line tool
  - A stand-alone verifier, appropriate for e.g. batch verifications.

UPPAAL GUI: Editor

- Global declarations
  - Accessible to all system processes
- Templates
  - Can be parameterized
- Declarations for templates
  - Only accessible locally
- System declarations
  - Declare processes and system composition

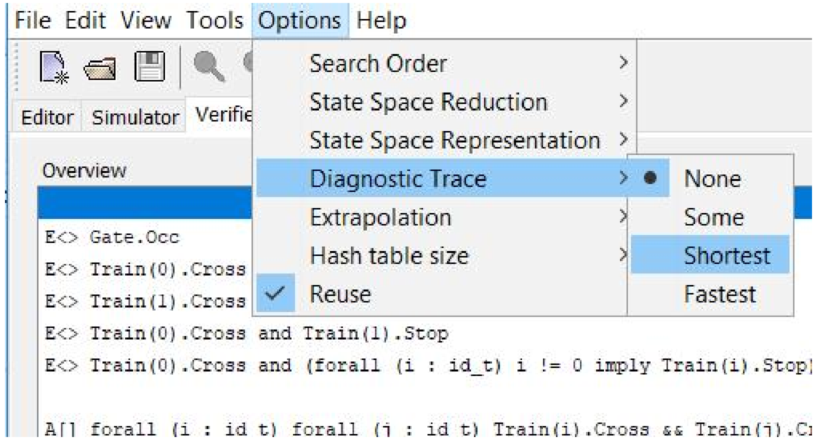


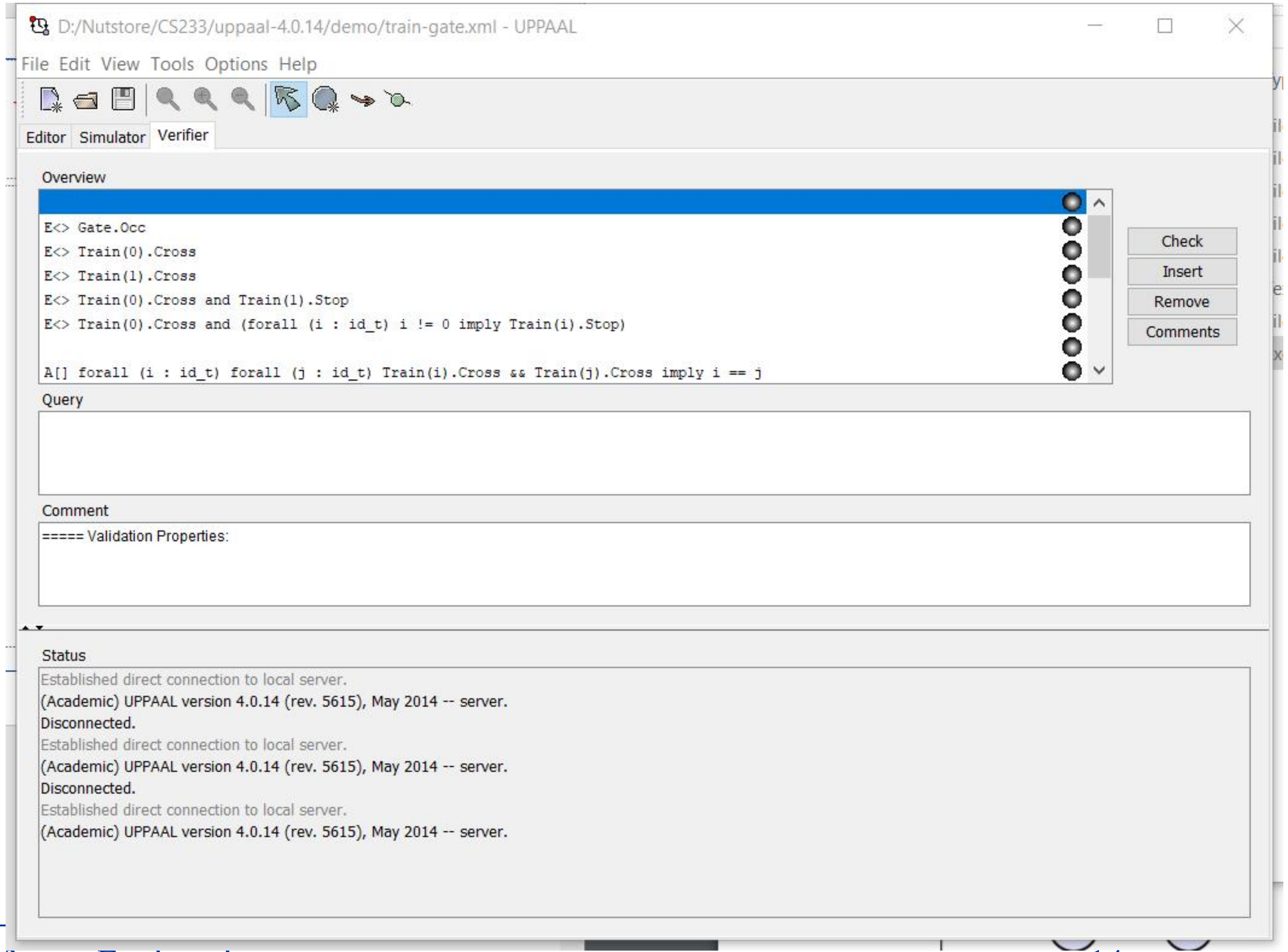
UPPAAL GUI: Simulator



UPPAAL GUI: Verifier

- Turn on diagnostic trace to view counter-examples in the simulator





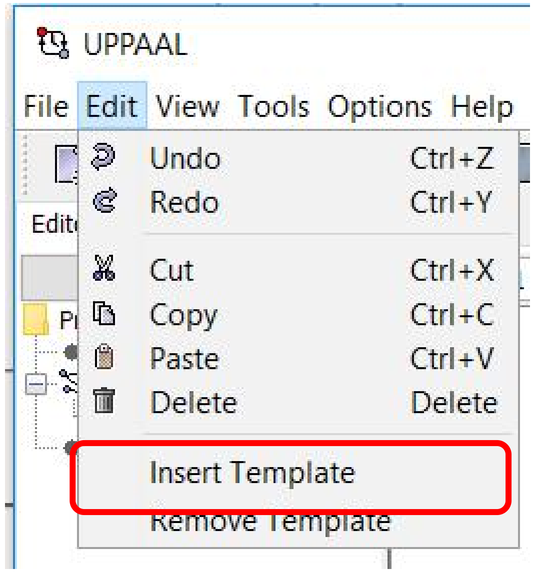
UPPAAL Syntax

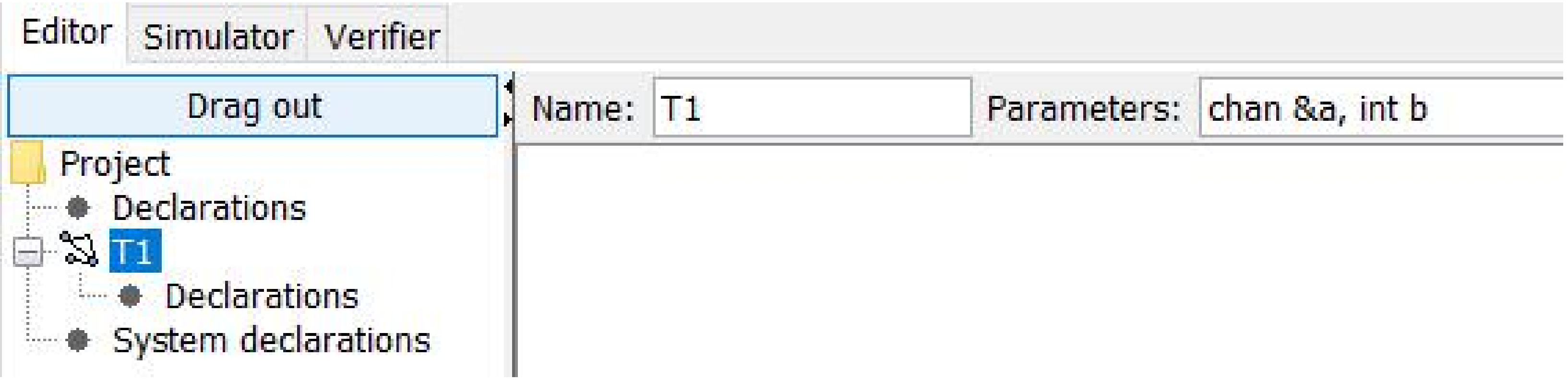
UPPAAL Syntax

- Global declarations
  - Clocks:
    - clock x1,…xn;
  - Data variables
    - int n1,…; integer with default domain
    - Int[l,u] n1,… ; integer with domain defined by [l,u]
    - Int n1[m],…; array with elements n1[0] to n1[m-1]
  - Channels
    - Chan a, … ;
    - Urgent chan b … ;
    - Broadcast chan c … ;
  - Constants
    - Const int c1=n1;

UPPAAL Syntax (cont.)

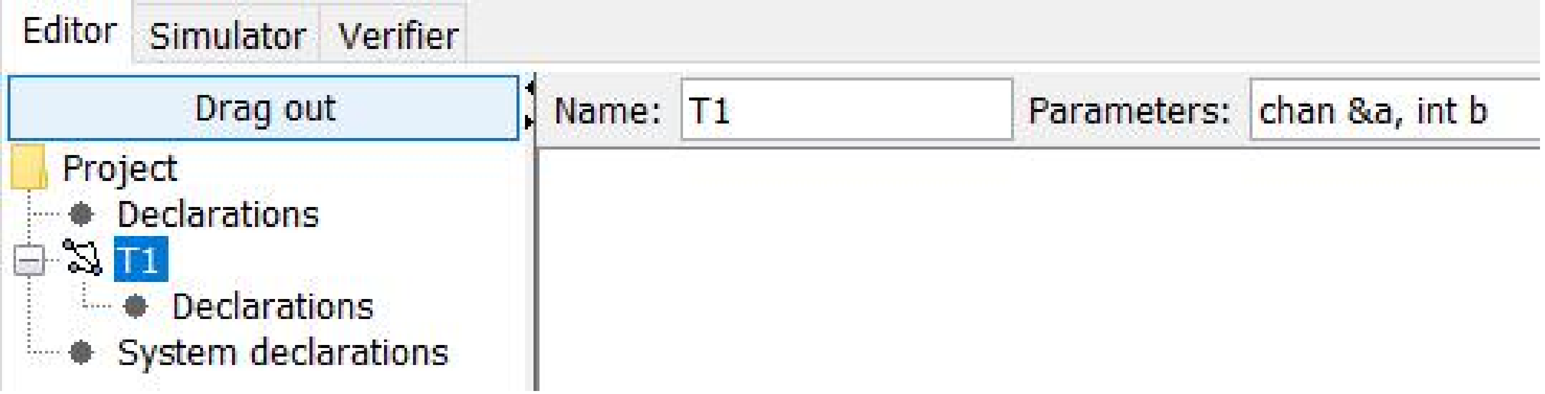
- Template
  - Names should be unique
  - Just like classes in UML, can be instantiated in system declaration
  - Channel declaration has a “&” in front

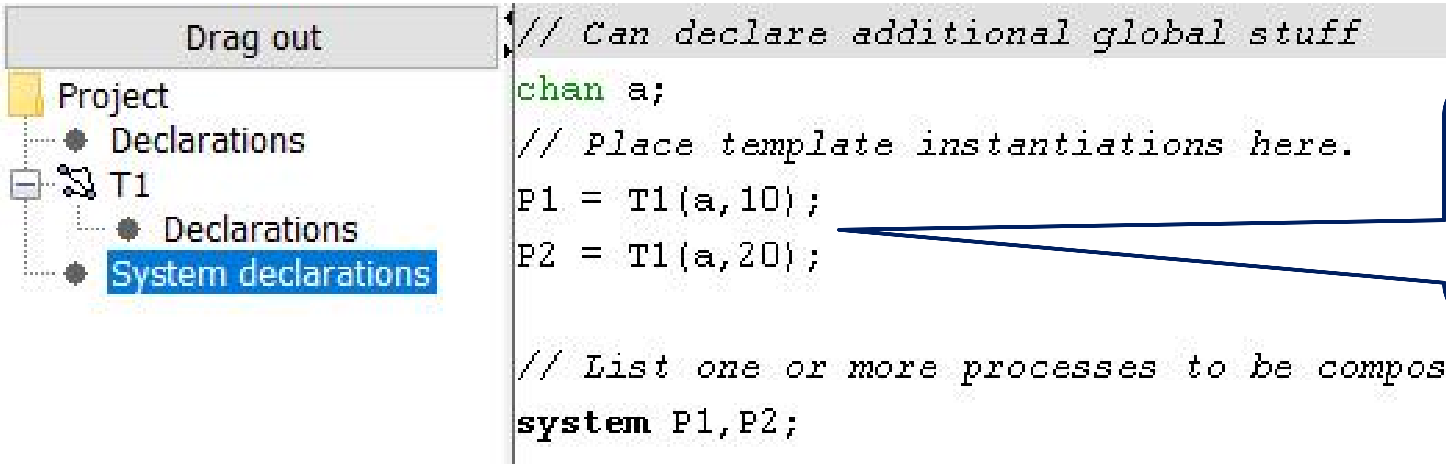




UPPAAL Syntax (cont.)

- System declaration



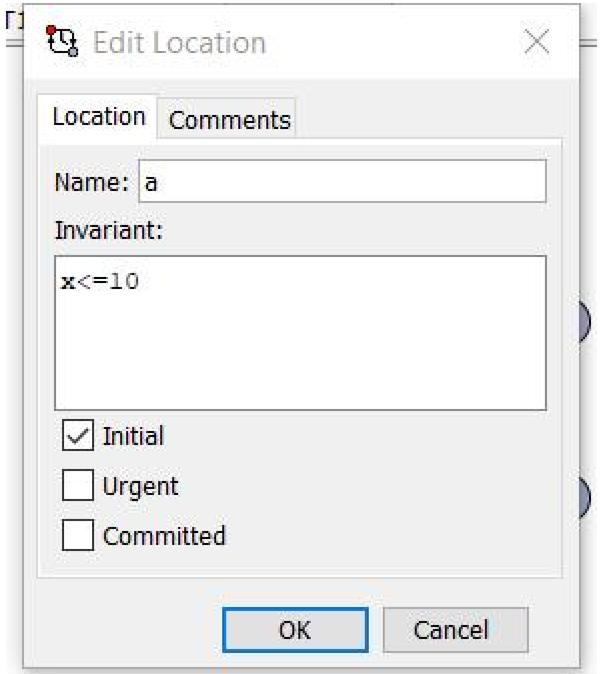


Can instantiate multiple processes from the same template

UPPAAL Syntax: Locations

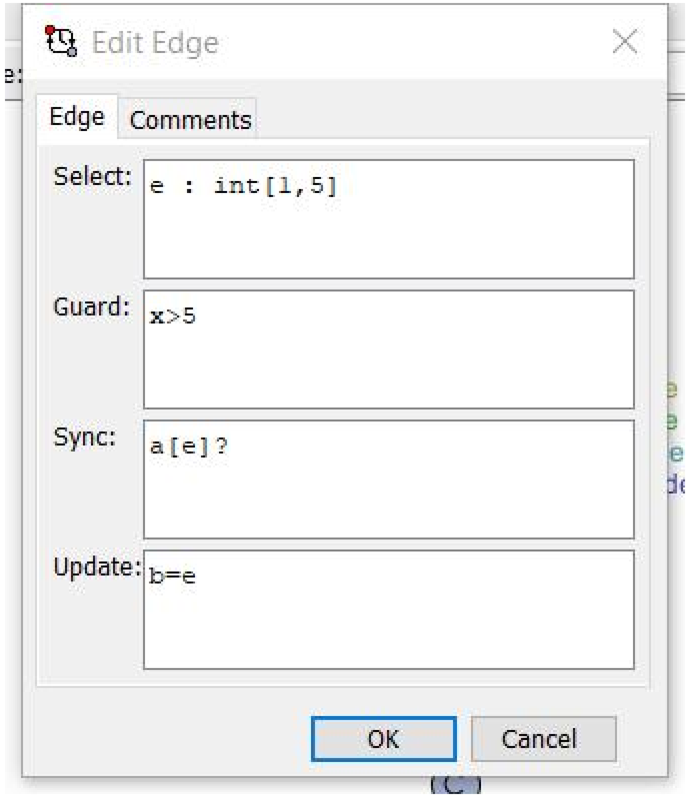
- Initial State 
  - Only one per template
- Urgent State 
- Committed State 

- Invariant
  - Conditions that need to be satisfied when in state a



UPPAAL Syntax: Edges

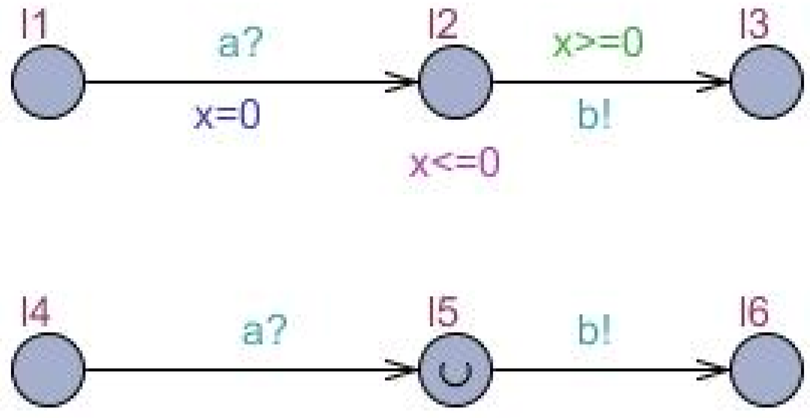
- Select
  - Defines multiple parameterized transitions
- Guard
  - Condition under which the edge is enabled
- Sync
  - a! for sending message
  - a? for receiving message
- Update
  - Actions taken during the transition



UPPAAL Semantics

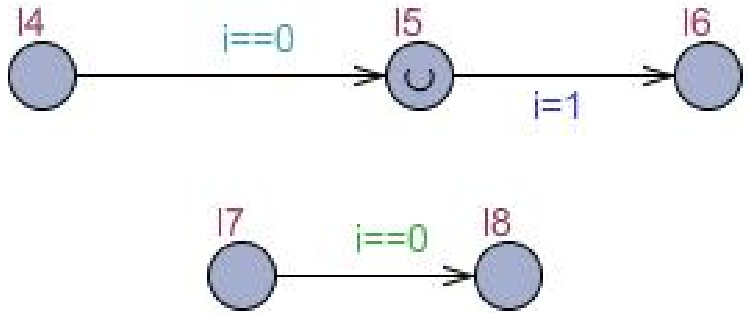
Urgent Location

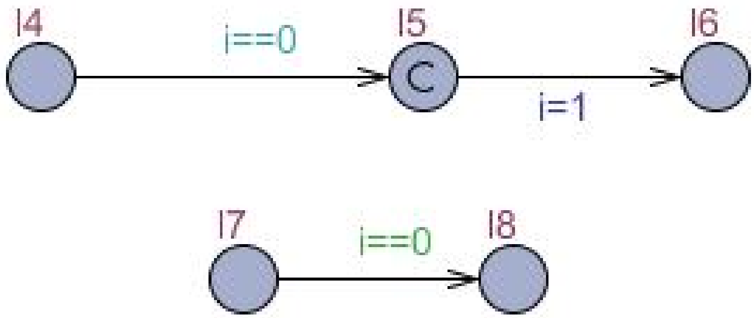
- No time pass in an urgent location
- The two automata is equivalent
- Save a clock thus reduce state space



Committed Location

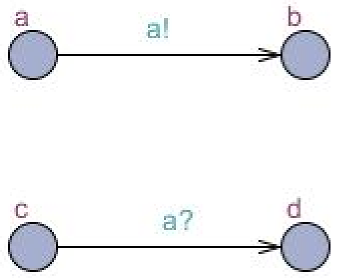
- Urgent location still allows interleaving
  - l7 -> l8 can happen before l5->l6, although no time has passed
- Committed states are stronger than urgent locations
- If multiple committed states reached at the same time, the transitions will interleave
- Reduce interleaving thus reduce complexity





Urgent channels

- Urgent channel definition
  - Urgent chan a;
- a! sent as soon as location a and c are reached
- No clock guard is allowed on the transitions with urgent channel components

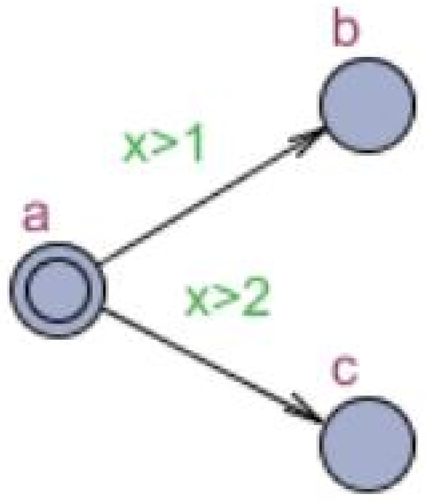


Broadcast channels

- Synchronize multiple processes
- If receiving channel a? is enabled, the transition must be taken
- Can send without any receivers ready

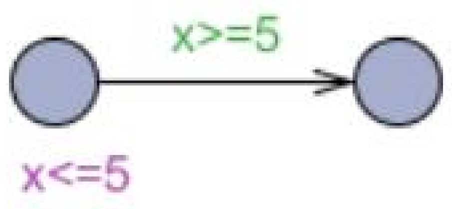
Non-determinism

- Transitions with guard evaluates true are only enabled
- Used to model variabilities of system environment
- Location a does not have an invariant, thus can stay forever
  - $x \in [0,1]$: location a
  - $x \in (1,2]$: location a or b
  - $x \in (2, \infty]$: location a or b or c



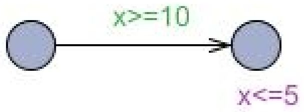
Want to do something at a particular time?

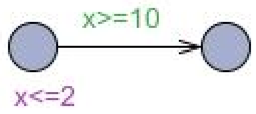
- The transition will take place when x==5

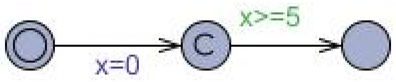


Deadlock

- No enabled transitions
- Common deadlock scenarios
  - Cannot enter a state
  - State invariant about to expire and no enabled transition available
  - Committed state does not have enabled outgoing transition

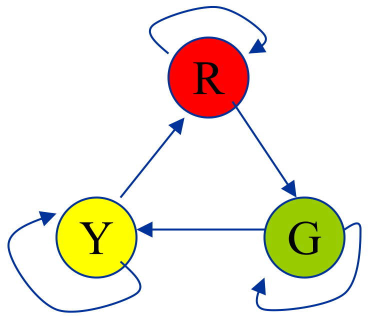




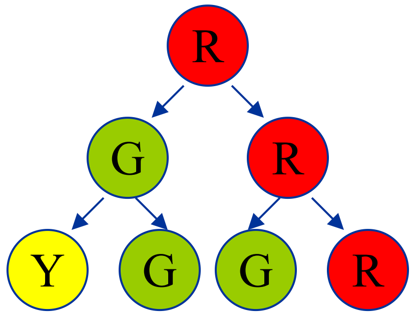


Computational Tree Logic (CTL)

- CTL is a logic used to express properties for model checking
- CTL is useful because there is an efficient technique to check it
- A temporal logic is a logic which can express aspects of time
- CTL makes statements about the computational tree of a state machine



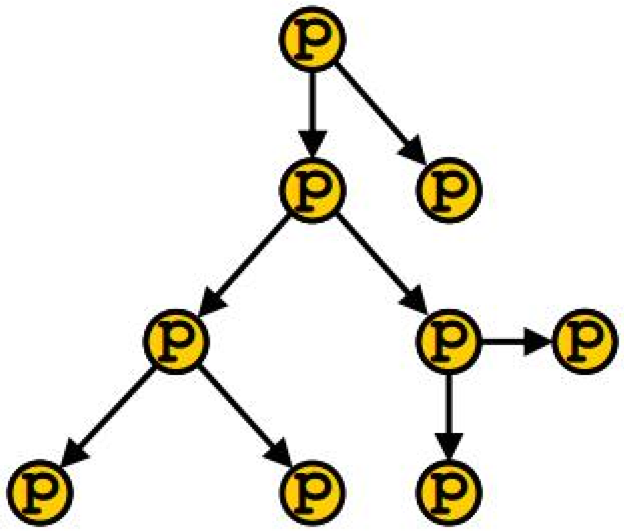
Traffic light FSM



Computational tree for FSM

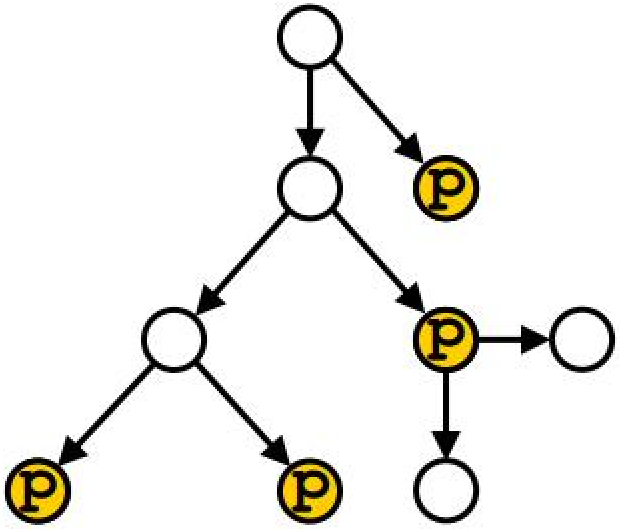
Temporal Computational Tree Logic (TCTL) Properties

- **A[] p** "Always globally p"
- For each (all) execution path p holds for all the states of the path



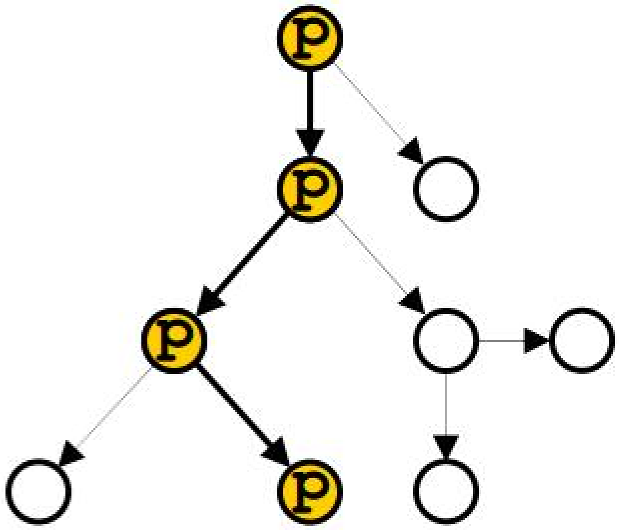
Properties

- **A<> p** “Always eventually p”
- For each (all) execution path p holds for at least one state of the path



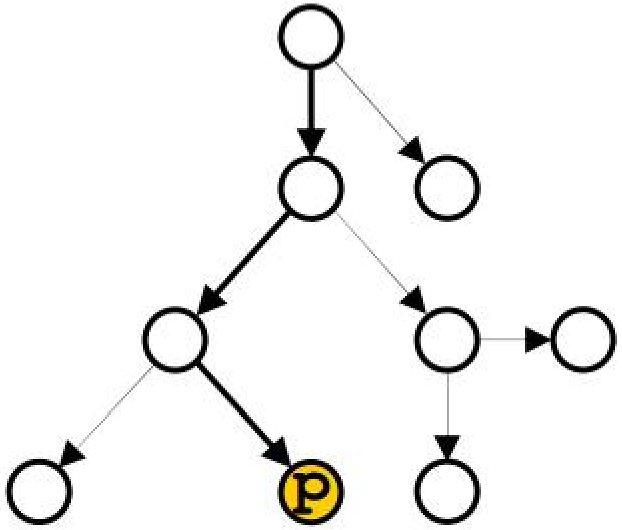
Properties

- **E[] p** "Exists globally p" meaning there is an execution path in which p holds for all the states of the path



Properties

- **E<> p** "Exists eventually p" meaning there is an execution path in which p eventually (in some state of the path) holds

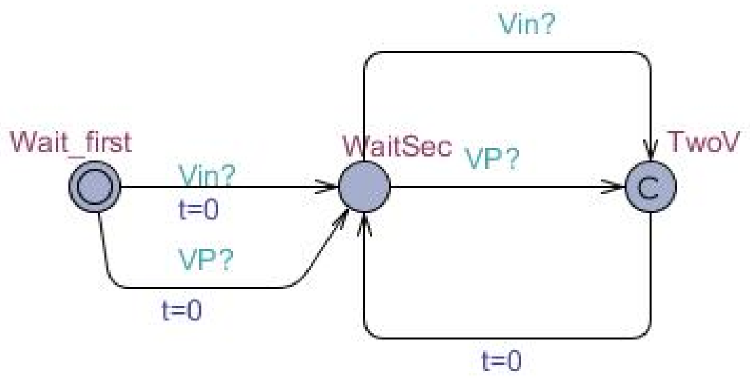


UPPAAL TCTL Properties

- A[]p, A<>p, E<>p, E[]p, p-->p’(p imply p’)
- p can be
  - Location of a process: a.l
  - Data guard
  - Clock guard
  - p and p’
  - p or p’
  - Not p
  - p imply p’

Monitors

- Sometimes we need assistance to express our requirements
- The maximum interval between two ventricular events (Vin,VP) should be no larger than 1000ms
- A[] (PM.TwoV imply PM.t<=1000)



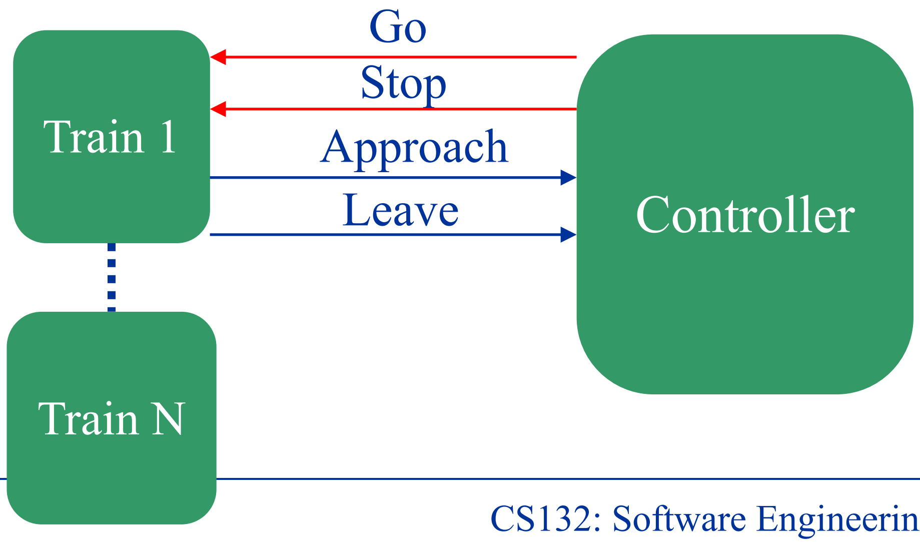
UPPAAL Examples

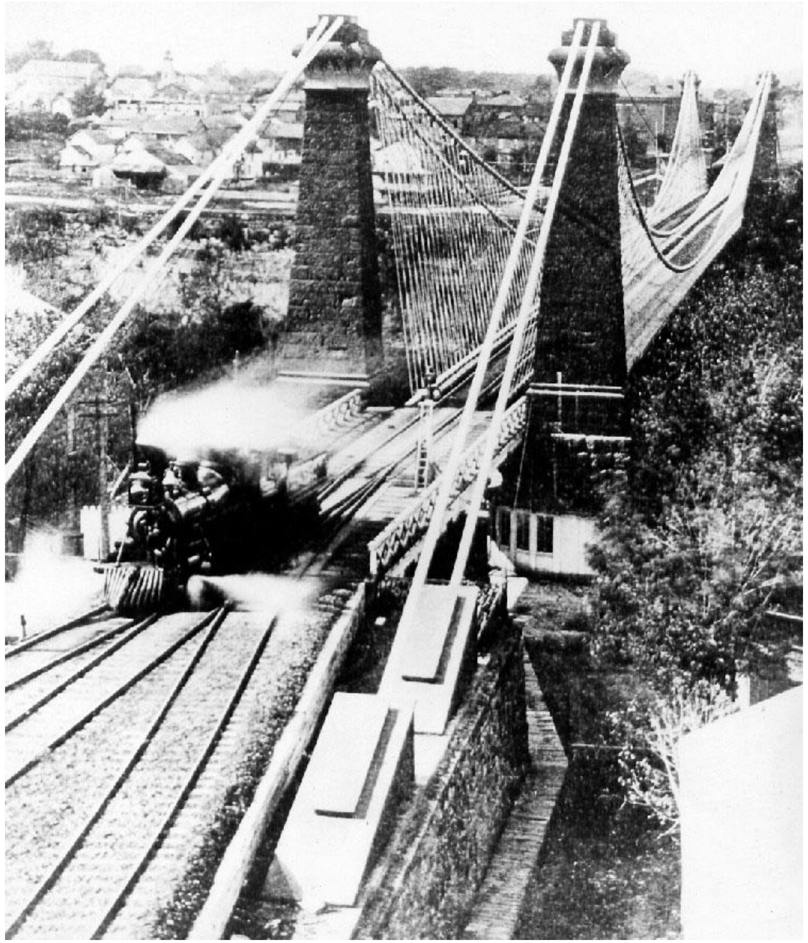
Reference

- Download
  - www.uppaal.org
- Tutorials
  - On the same webpage
  - Recommended:
    - UPPAAL 4.0: Small Tutorial.
    - Uppaal SMC Tutorial

Example: Train-Gate

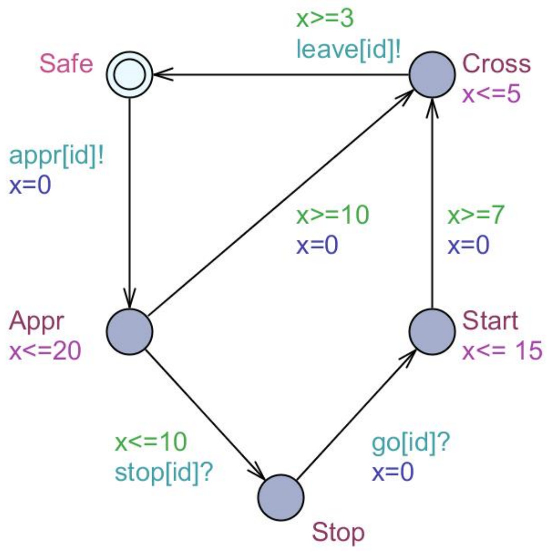
- Niagara Falls Suspension Bridge
- One passage, multiple entries
- Design a software controller that makes sure:
  - Every train arrives the bridge eventually crosses
  - Only one train on the bridge at the same time





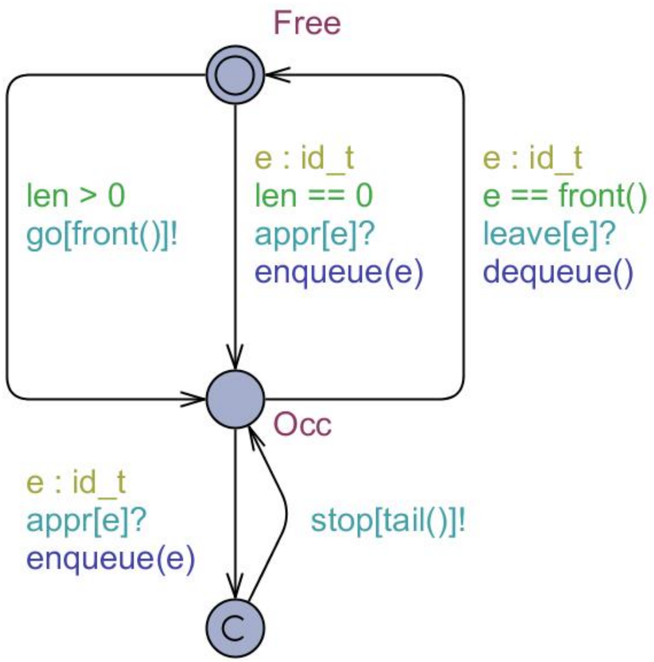
Modeling Trains (Environment)

- Each train has an id
- Each train can approach the gate at any time
- Approaching takes 10-20 sec
- The gate controller can stop a train within 10 sec after its approaching, otherwise the train will cross
- After receive a GO signal, the train will start within 7-15 sec
- Crossing takes 3-5 sec



Example: Train-Gate (cont.)

- Gate controller maintains a queue
- If queue empty and a train approaches, gate stay occupied
- If the gate is occupied and a train approaches, stop the last one in queue
- If the train at the front of the queue leaves, remove it from the queue
- If the gate is free and there are trains in queue, let the front one go




```
typedef int[0,N-1] id_t;

// Put an element at the end of the queue
void enqueue(id_t element)
{
        list[len++] = element;
}
```

```
// Remove the front element of the queue
void dequeue()
{
        int i = 0;
        len -= 1;
        while (i < len)
        {
                list[i] = list[i + 1];
                i++;
        }
        list[i] = 0;
}
```

```
// Returns the front element of the queue
id_t front()
{
   return list[0];
}

// Returns the last element of the queue
id_t tail()
{
   return list[len - 1];
}
```

Example: Train-Gate (cont.)

- Train 0 can eventually cross
  - E<> Train(0).Cross
- Train 0 can be crossing bridge while Train 1 is waiting to cross
  - E<> Train(0).Cross and Train(1).Stop
- Train 0 can cross bridge while the other trains are waiting to cross
  - E<> Train(0).Cross and (forall (i:id-t) i != 0 imply Train(i).Stop)
- There can never be N elements in the queue
  - A[] Gate.list[N] == 0
- There is never more than one train crossing the bridge
  - A[] forall (i:id-t) forall (j:id-t) Train(i).Cross && Train(j).Cross imply i == j
- Whenever a train approaches the bridge, it will eventually cross
  - Train(1).Appr -> Train(1).Cross
- The system is deadlock-free
  - A[] not deadlock