Formal Verification of Intelligent Systems Modeled as Decision Procedures

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Motivation

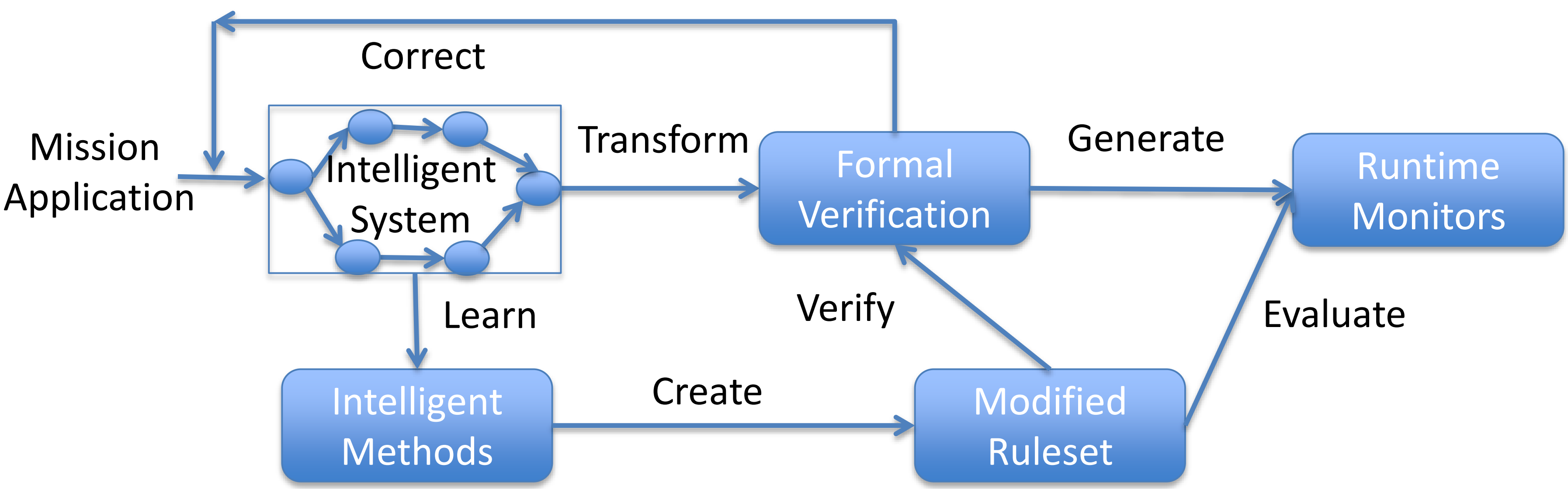
- Autonomous agents are controlling or coordinating autonomous systems to autonomously execute missions in battle space, civil airspace, cyber space
- Autonomous agents can be designed as
  - Cognitive architecture (Soar, ACT-R)
  - Perception, production system, memory
- Autonomous agents need to be rigorously analyzed to guarantee satisfaction of requirements, correctness to build trust on them

Research Challenges

- Cognitive architecture provides a simulation environment but lacks rigorous analytical capability
  - Translation into formal environment enables analytical capability
- Addressing the differences in the cognitive model and formal verification
  - Lack of visibility into algorithmic methods
  - Use of complex constructs
  - Dynamic nature of autonomy (rules modified at runtime)

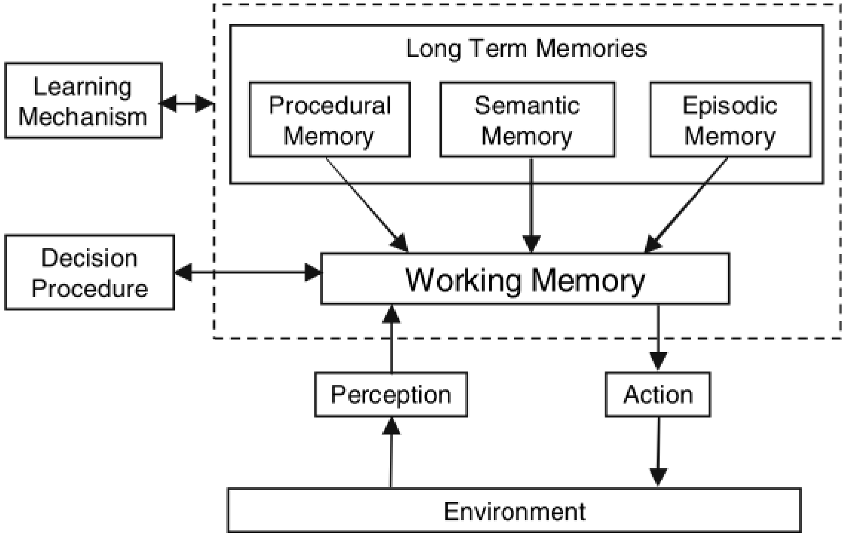
Cognitive Model with Formal Verification Flow

- Requirements are coded into a Soar cognitive agent
- Agent is transformed into formal environment for verification
  - Generates runtime monitors
  - Corrects the present design
- Soar agent can learn efficient ways
  - Creates or modifies rules which are evaluated and/or verified



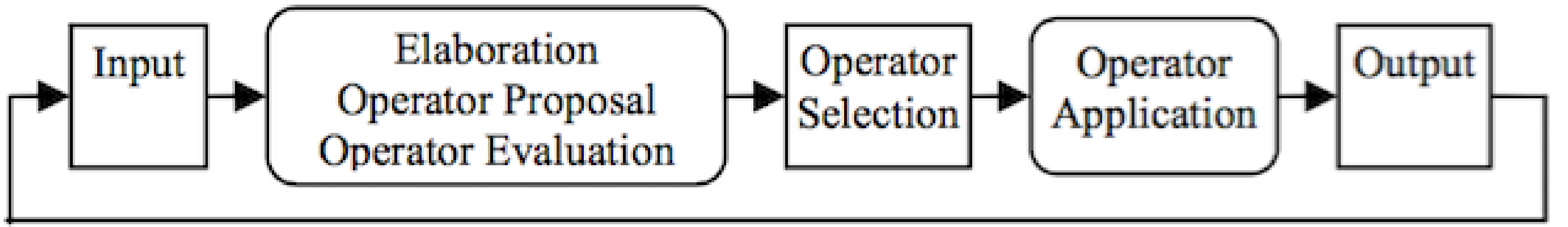
Cognitive Architecture

- Agent architecture
  - Integration of several components
    - Perception
    - Memory
    - Production systems (decision procedures)



Ref: http://educatech.sytes.net/wiki/Soar

Soar Processing Cycle

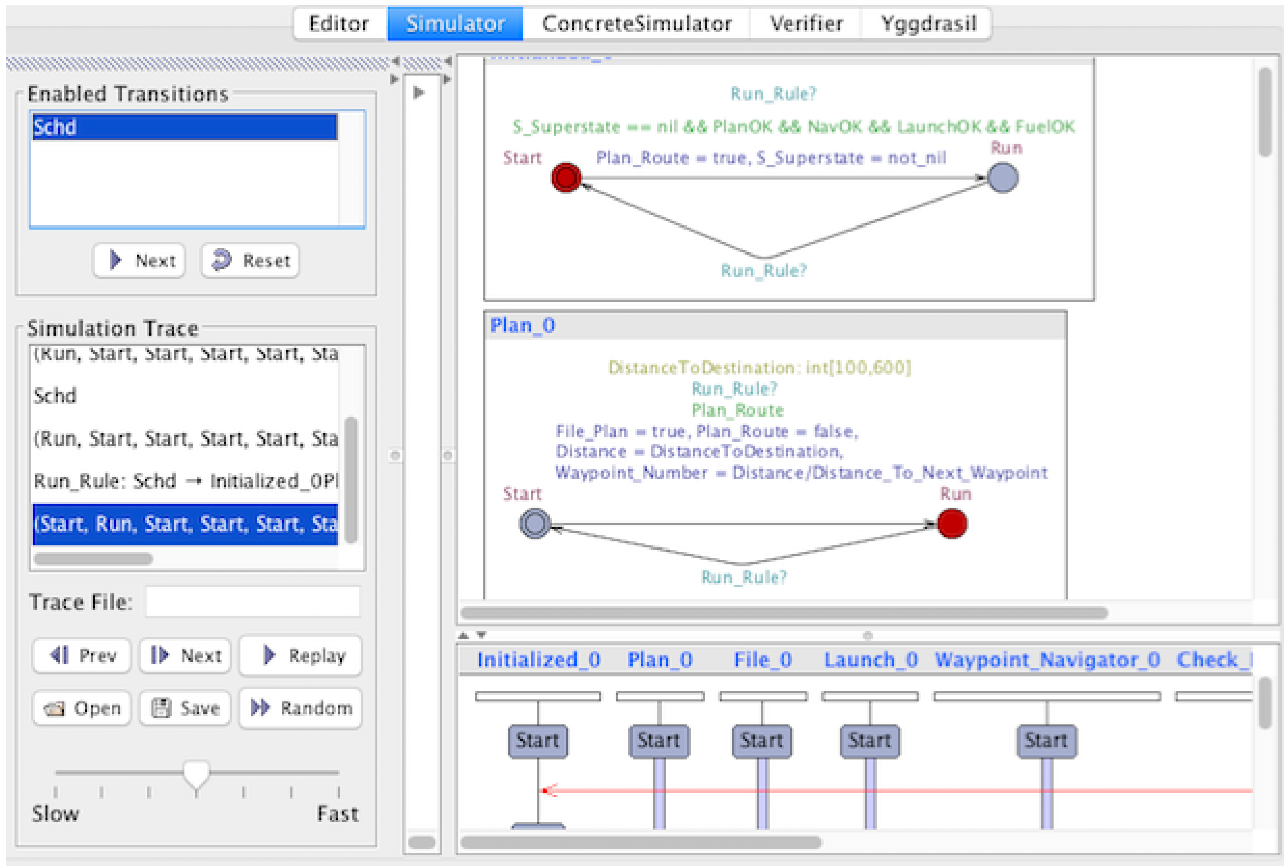


Proposed Soar processing cycle (refs: 3)

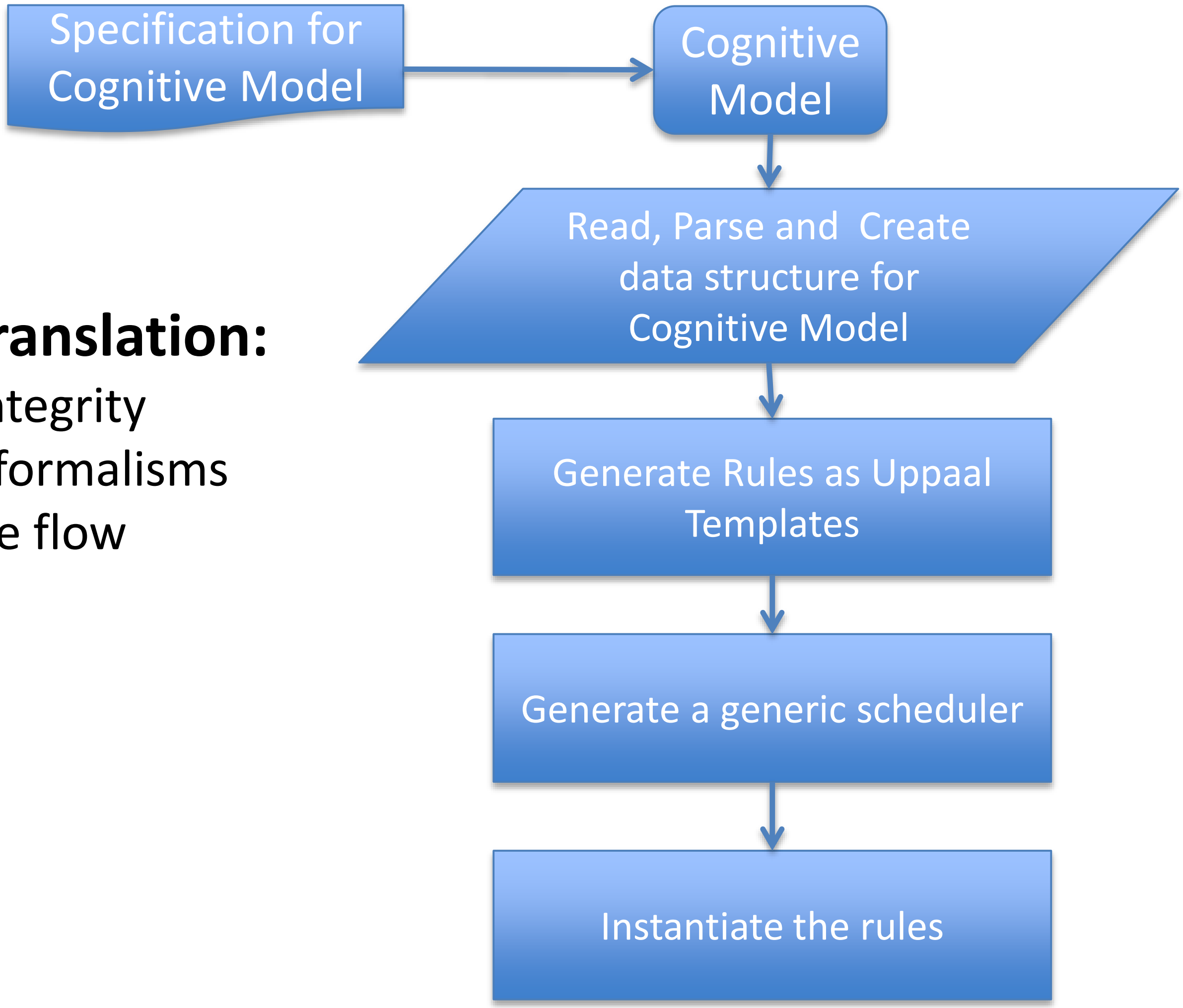
- Proposed soar processing cycle
- Generic representation
  - Any rule that is true can be executed
    - Satisfies diverse range of cognitive models

Uppaal a Real Time Verification Tool

- Modeling, validation and verification of real-time systems modeled as networks of timed automata, extended with data types (bounded integers, arrays, etc.)
  - Editor
  - Simulator
  - Verifier



Translation from Cognitive Model to Uppaal



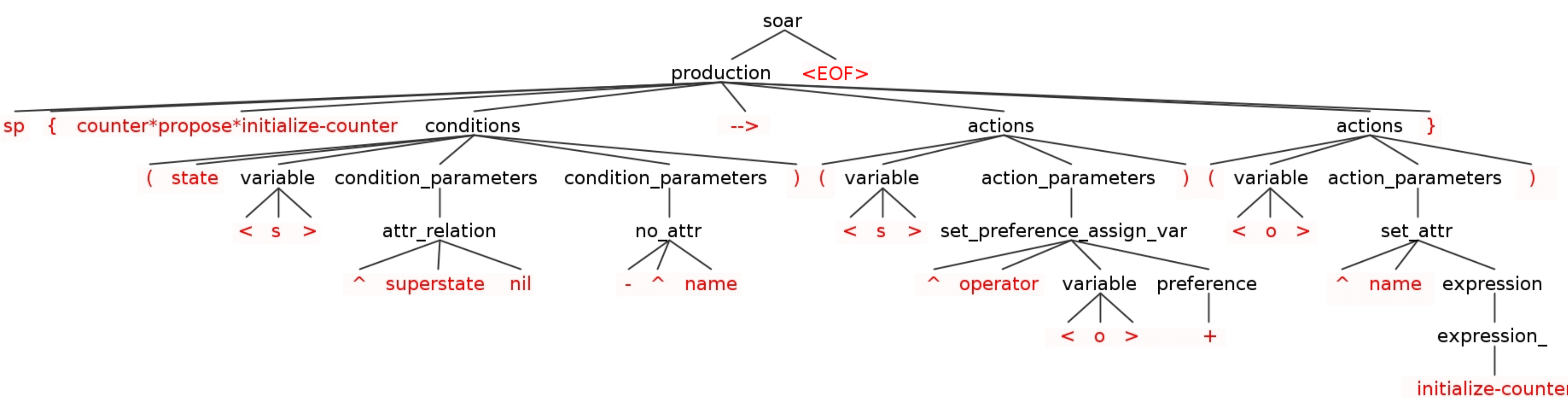
Challenges in translation:

- Architectural Integrity
- Rule execution formalisms
- Cognitive engine flow

Soar Parsing for Translation

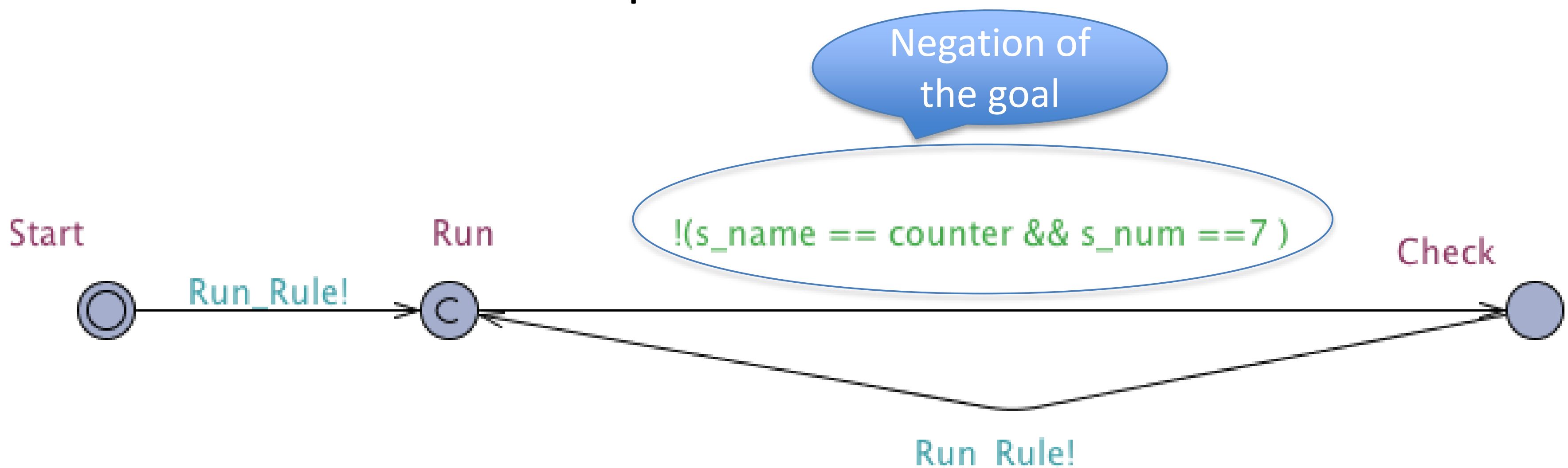
1. Create Antlr grammar for Soar
2. Generate the Soar parser
3. Create the data structure
4. Generate the xml for Uppaal

```
sp {counter*propose*initialize-counter
   (state <s> ^superstate nil
              -^name)
-->
   (<s> ^operator <o> +)
   (<o> ^name initialize-counter)
}
```



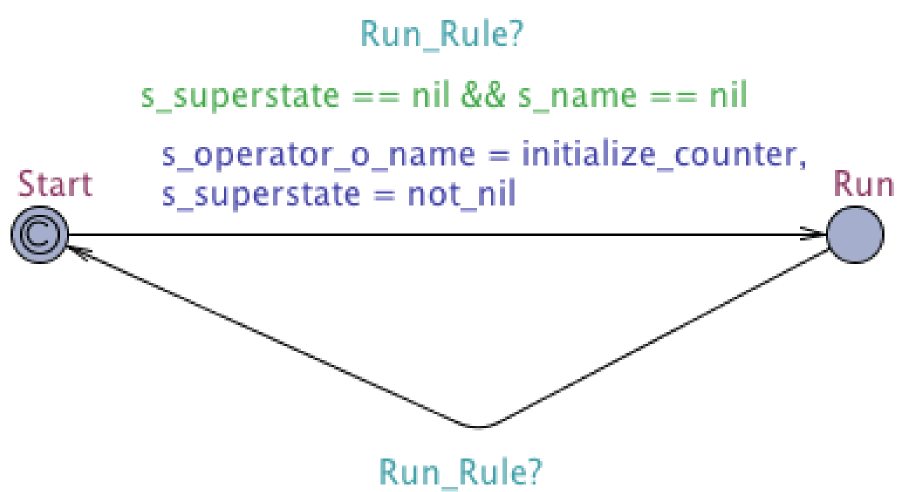
Scheduler: Maintaining Generic Processing Cycle

- Notion of implementing a scheduler that executes a more generic representation
  - Do not need to differentiate between propose, apply and other phases
  - The satisfaction of the precondition selects the rule to be executed

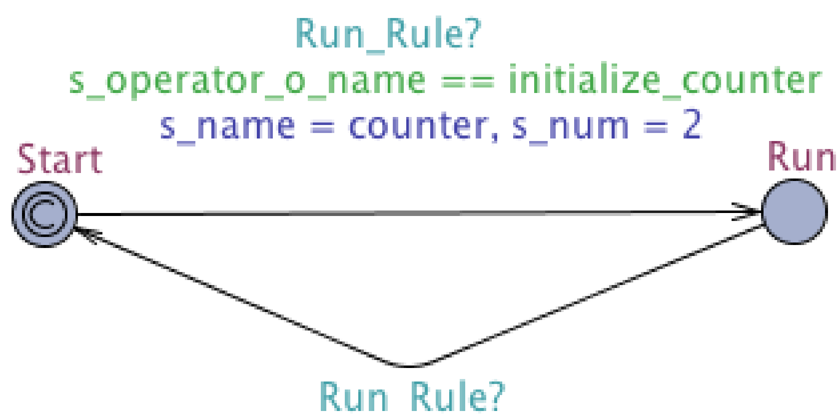


Mapping Soar to Uppaal with Counter

```
sp {counter*propose*initialize-counter
   (state <s> ^superstate nil
             -^name)
-->
   (<s> ^operator <o> +)
   (<o> ^name initialize-counter)
}
```

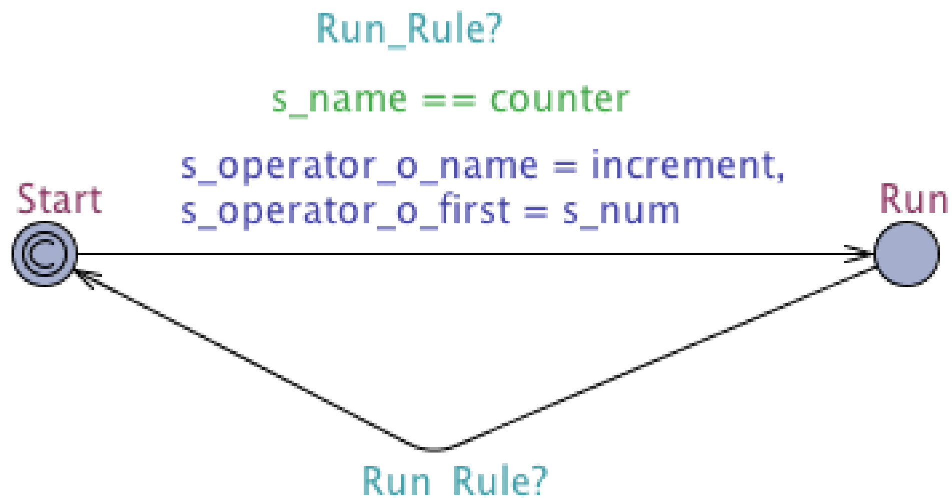


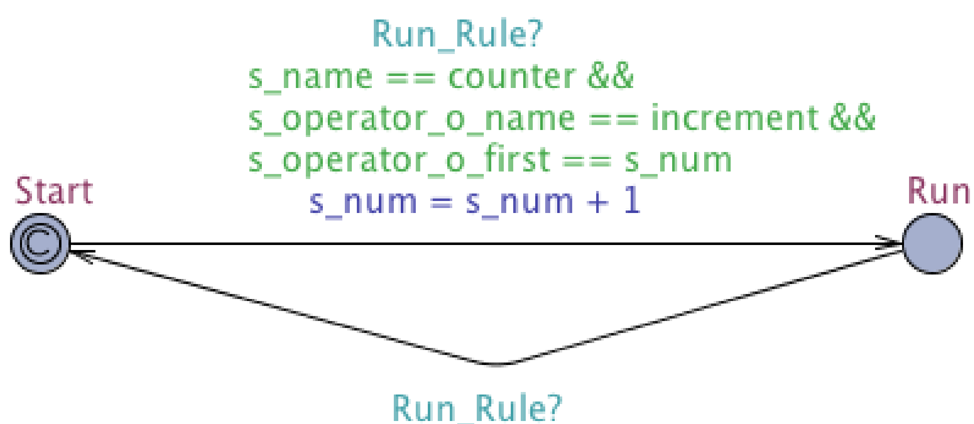

```
sp {counter*apply*initialize-counter
   (state <s> ^operator <op>)
   (<op> ^name initialize-counter)
-->
   (<s> ^name counter
        ^num 2)
```



Mapping Soar to Uppaal with Counter (contd.)

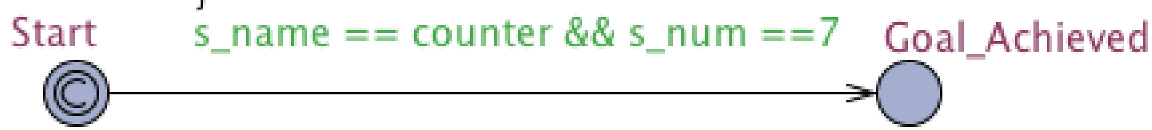
```
sp {counter*propose*increment
   (state <s> ^name counter
              ^num <c>)
-->
   (<s> ^operator <op> + =)
   (<op> ^name increment
         ^first <c>)
}

sp {counter*apply*increment
   (state <s> ^name counter
              ^operator <op>
              ^num <c>)
   (<op> ^name increment
         ^first <c>)
-->
   (<s> ^num (+ <c> 1)
        ^num <c> -)
}
```





Mapping Soar to Uppaal with Counter (contd.)

```
sp {counter*detect*goal*achieved
   (state <s> ^name counter
              ^num 7)
-->
   (write (crlf) | The number 7 has been reached.|)
   (halt)
}
```




```
// Place template instantiations here.
rule_1 = counter_propose_initialize_counter(); //cpic
rule_2 = counter_apply_initialize_counter();//caic
rule_3 = counter_propose_increment();//cpi
rule_4 = counter_apply_increment();//cai
goal = counter_detect_goal_achieved();//cdga
schd = scheduler();

// List one or more processes to be composed into a system.
system rule_1, rule_2, rule_3, rule_4, goal, schd;
```

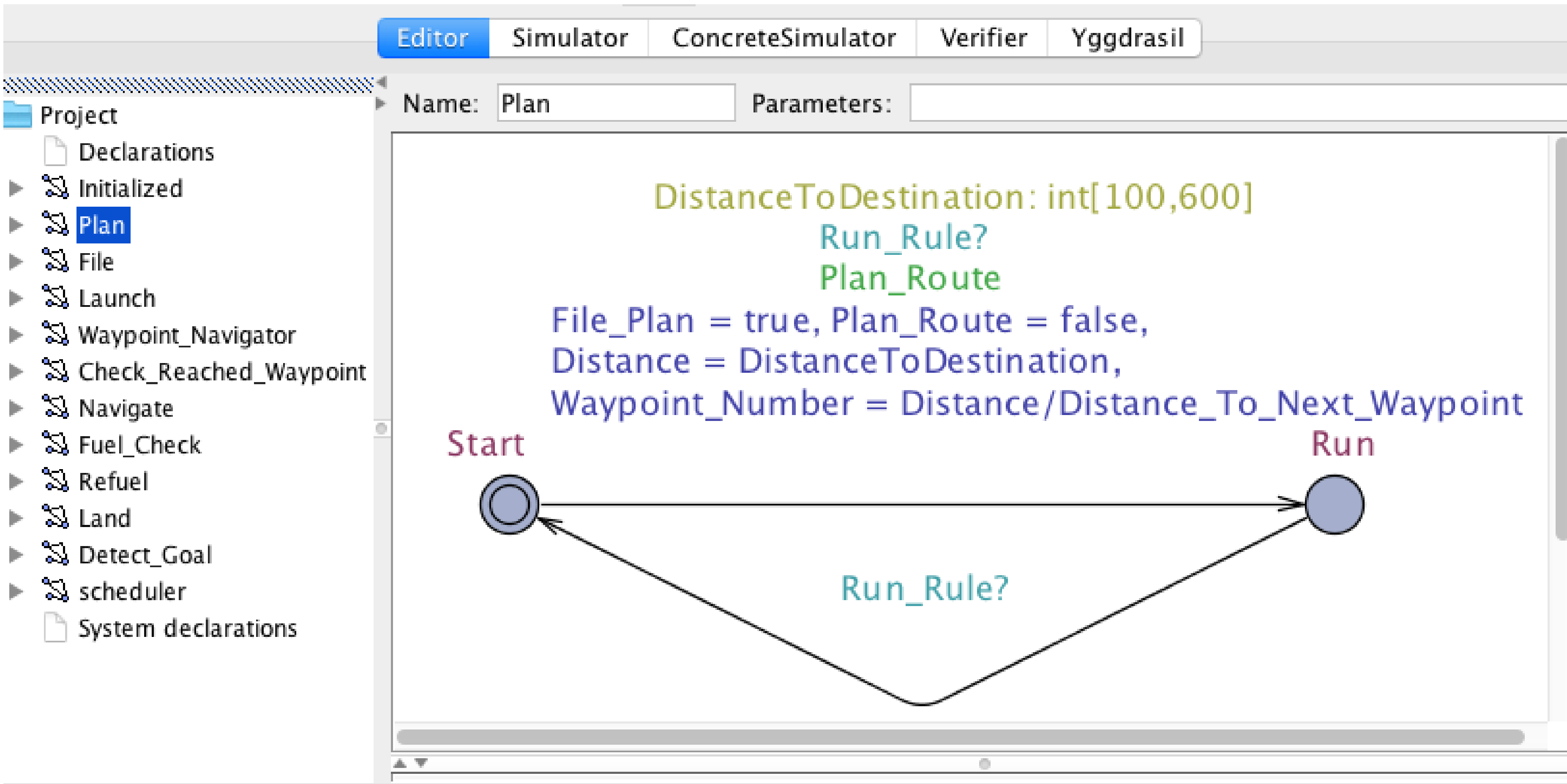
Properties checked:

For all paths eventually it reaches the goal: ***A<> s_num == 7***

For all paths eventually is the number is larger than the specified : ***A<> s_num>7***

Mapping Soar to Uppaal: Pilot Agent

Executes sequence of tasks for its mission: preflight checks, flight plan, file the plan, launch, navigate, refuel, land and reach destination



Mapping Soar to Uppaal: Pilot Agent (contd.)

Properties checked:

- All paths eventually lead to reaching destination
  A<> Goal.Goal
- Does there exist a point when next waypoint is not reached but the navigator says it has been reached
  E<> t< Time_To_Next_Waypoint and Navigate_0.Run
- Does there exist a condition where next waypoint is not reached but the UAV is trying to refuel
  E<>Waypoint_Navigator_0.Run and Refuel_0.Run
- Does there exist a path where fuel is not checked
  E[] Check_Fuel == false

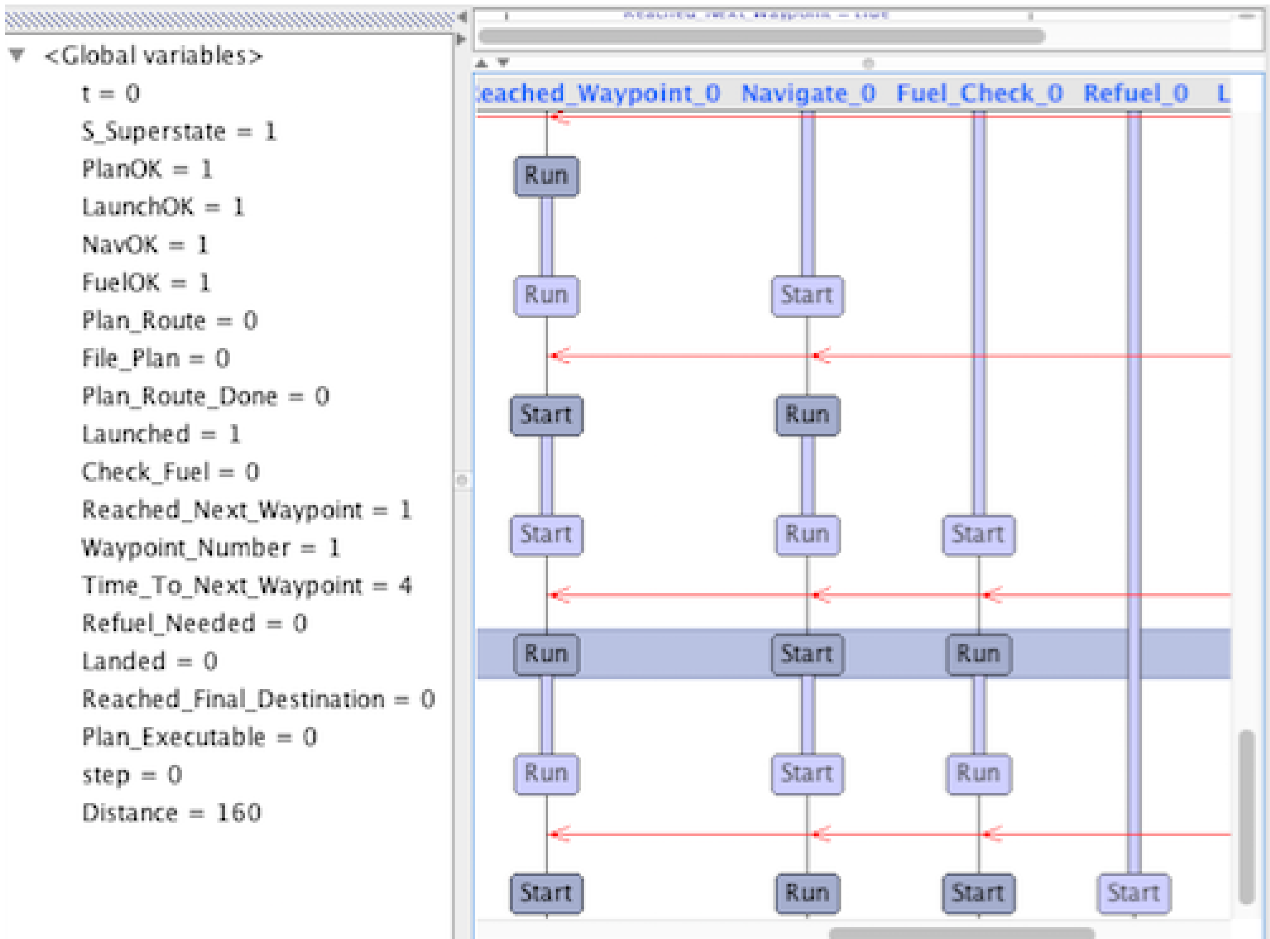
Uppaal's new feature generates test cases to indicate coverage based on states and edges traversed through the properties checked

Counterexample

Does there exist a point when next destination is not reached but the navigator says it has been reached

Property spec: E<> t< Time_To_Next_Waypoint and Navigate_0.Run

Correction: adding guard **Check_Fuel = false**



Conclusion and Future Work

- Developed automated translator from Soar to Uppaal
- Performed formal verification of cognitive model designed in Soar
- Method can be extended to other similar cognitive models with appropriate modifications
- Extend the translator to handle other relevant constructs in cognitive models
- Evaluate the translation going back from Uppaal to Soar
- Extend the framework to integrate learning and the associated verification

References

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