Verification of Programmable Logic Controllers for Critical Infrastructures

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CS 584
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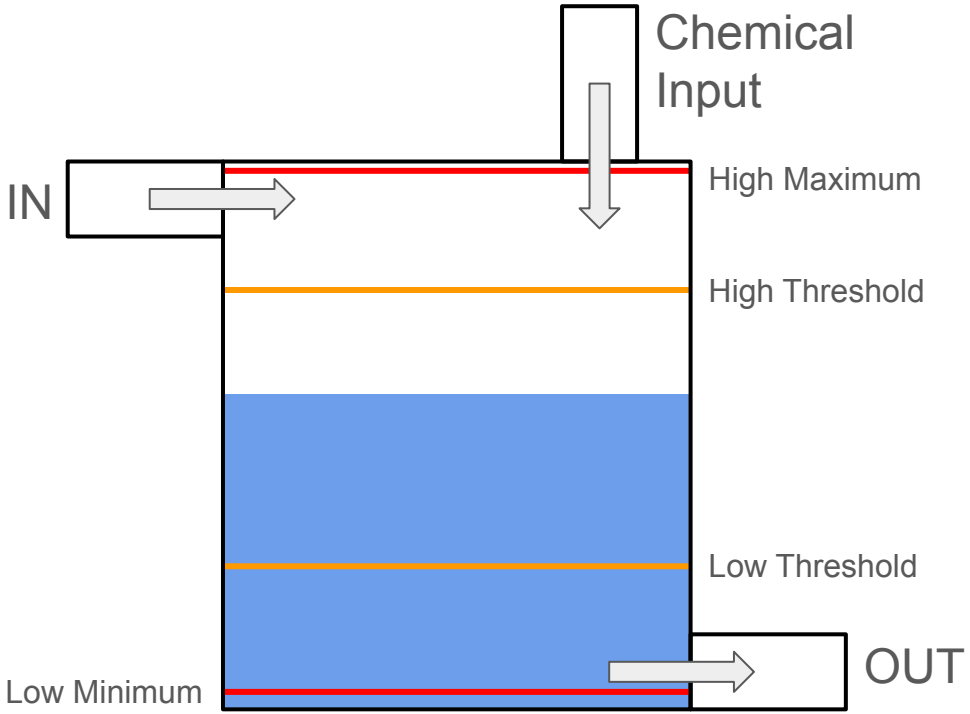
Background & Problem Statement

Programmable Logic Controllers (PLCs) are computers specifically designed to **manage and run industrial plant processes** reliably and repeatedly.

PLC programs must **operate safely** and **adhere to strict safety principles** assigned by system operators.

<u>Goal:</u> verify simple PLC controller code in a simplified system.

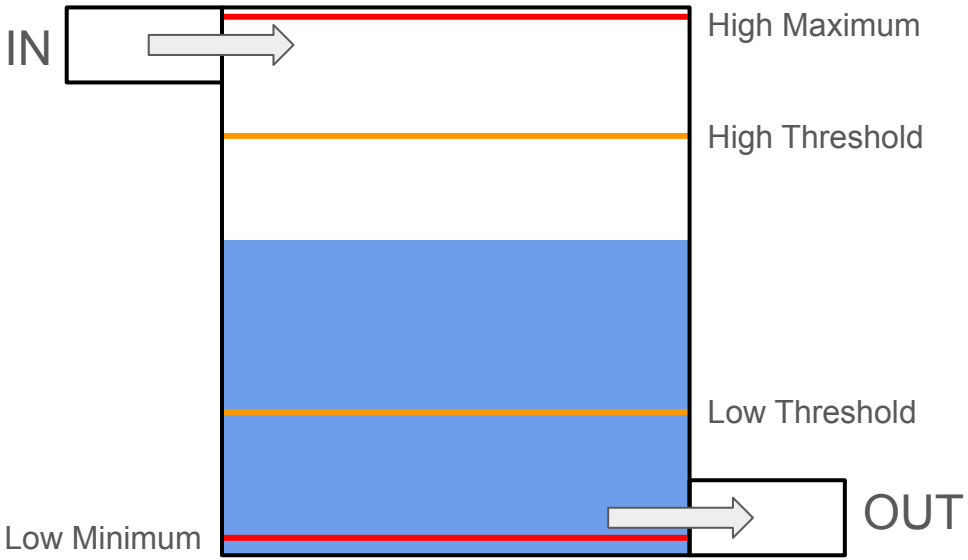
Problem Setting: Water Treatment Facility

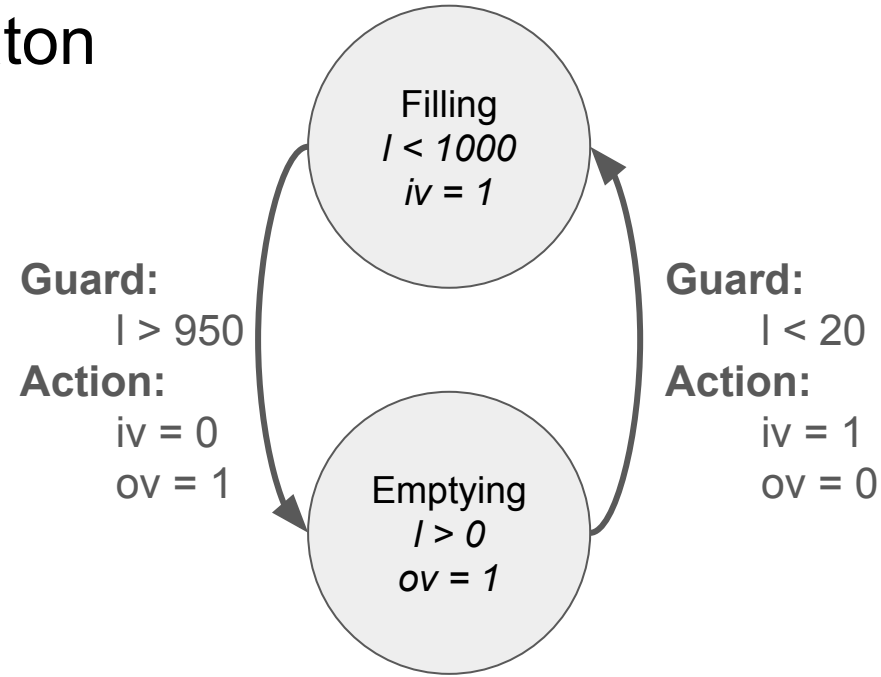


- Sensor's monitor the thresholds, maximums, and chemical input rate
- Valve actuators enable opening/closing of all input and output valves

- Focus on water thresholds, flow rates first; then add in chemical dosing if time allows

Converting to a Simple Automaton

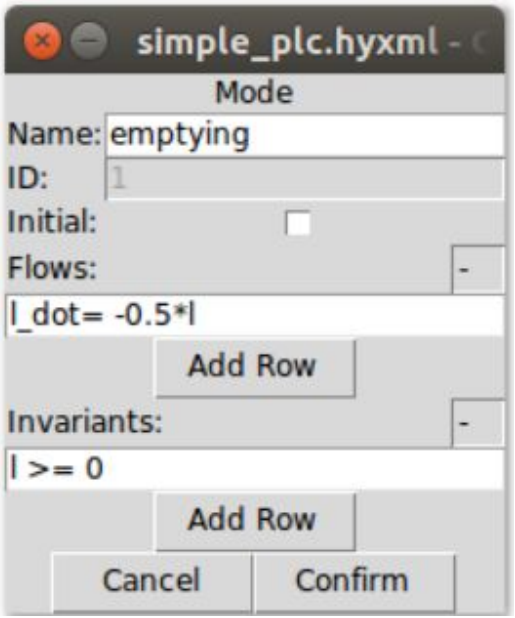


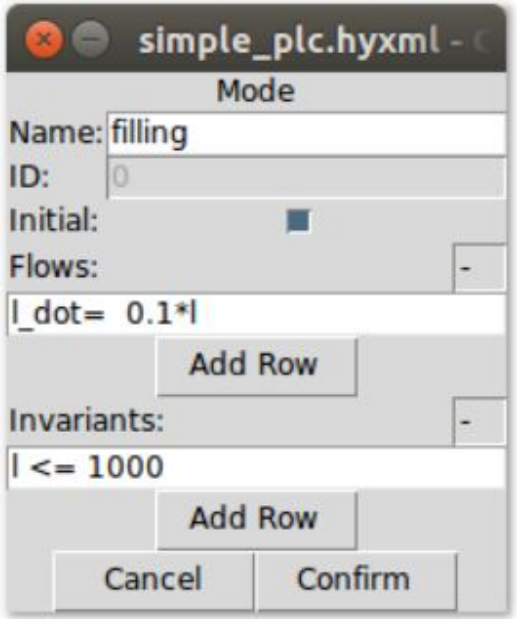


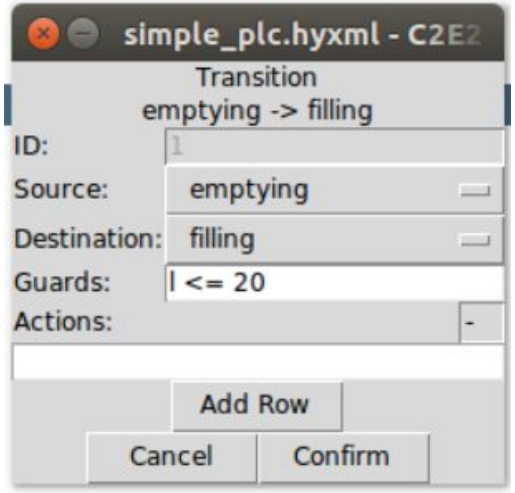
Explored adding an *'Idle'* state where the '*iv=0*' and '*ov=0*' but ran into C2E2 difficulties

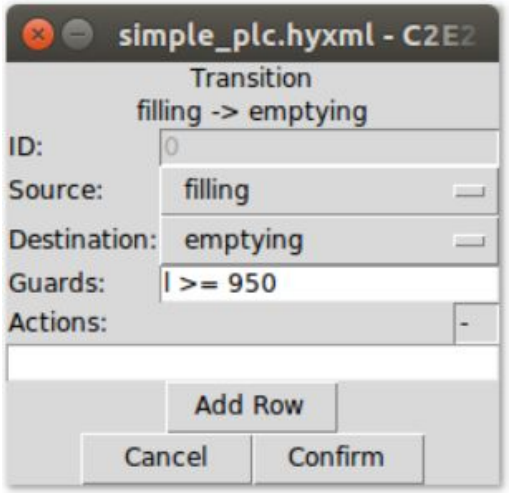
C2E2 Conversion – Sanity Check

- Most simple automaton with one variable, two modes









C2E2 Conversion – Sanity Check

Requirement

Name: low_level

◆ Safety

Time step: 0.1

Time horizon: 20.0

K value: 0.0

Simulator: ODEINT: fixed step

Refinement: Default Strategy

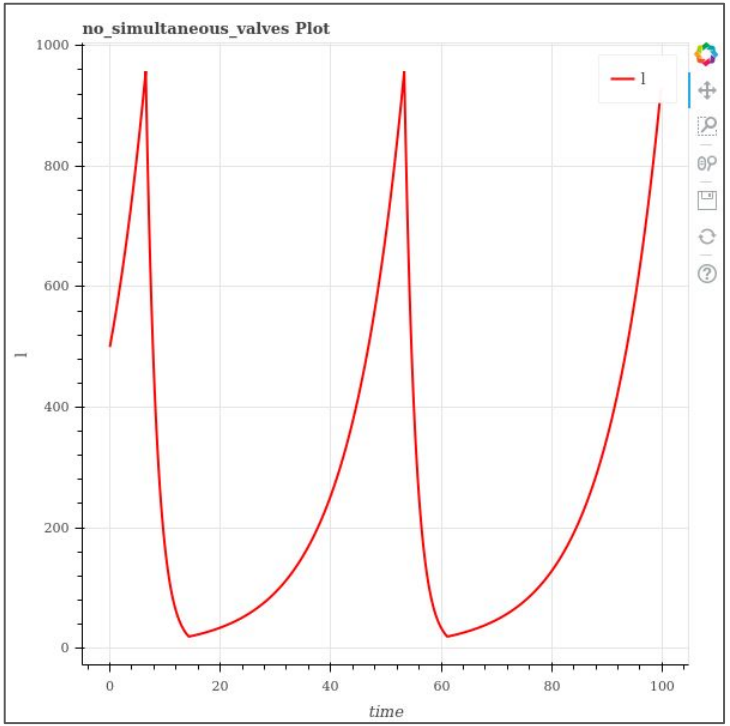
Linear Model: Generalized Star

Initial set:

```
filling: l == 50
```

Unsafe set:

```
l < 0
```

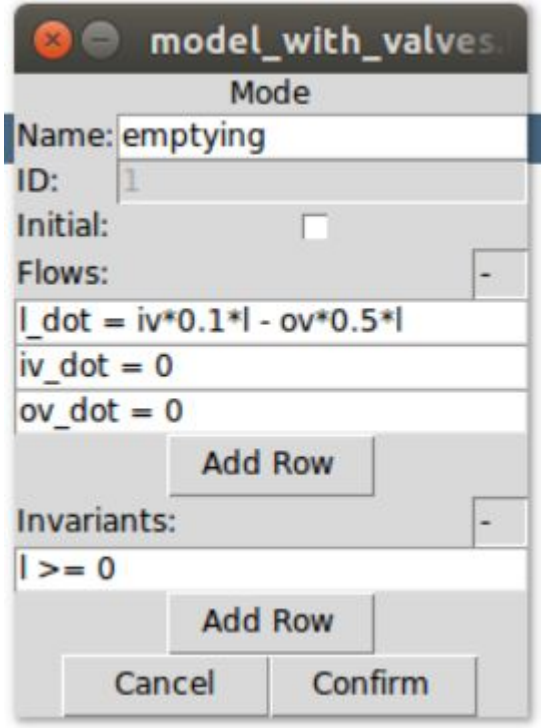


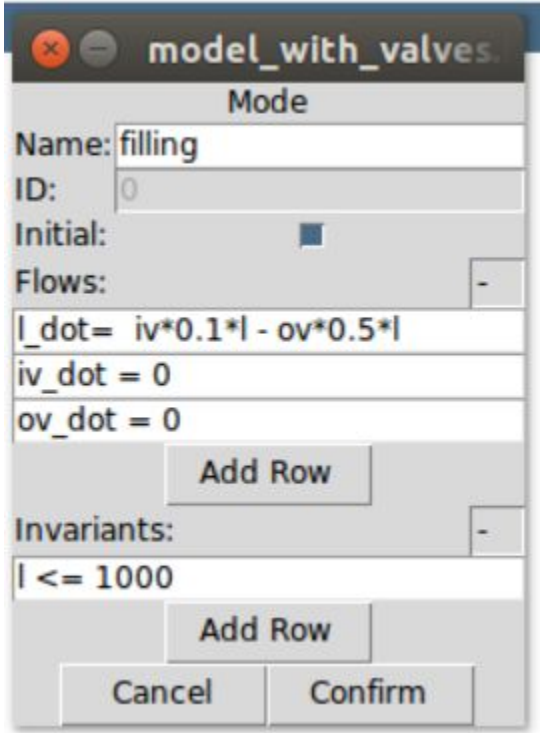
Requirement List

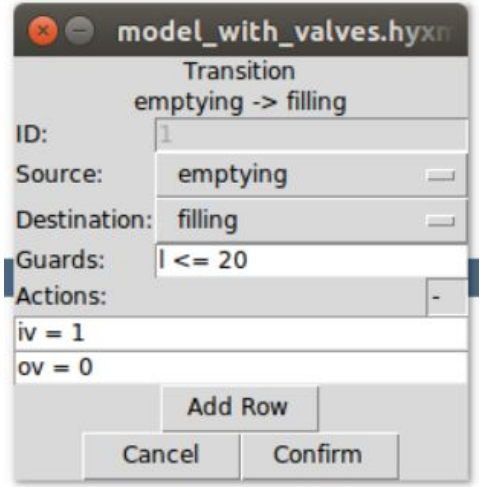
Requirement	Status	Result
high_level	Verified	Safe
low_level	Verified*	Expired

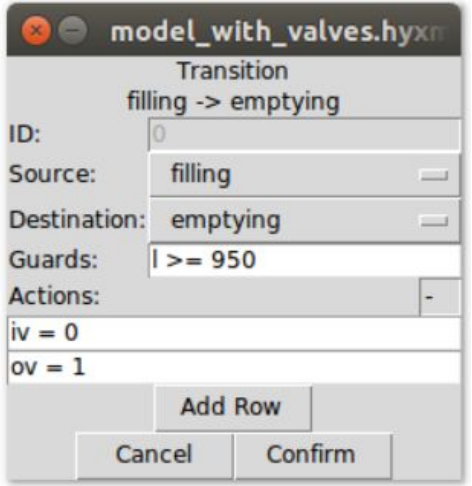
C2E2 Conversion – Adding in Valves

Updated Modes: 3 variables









C2E2 Conversion – Adding in Valves

- Need initial states for the valves and a new unsafe set
- Checking that *'iv'* and *'ov'* aren't open at the same time

Requirement List

Requirement	Status	Result
level_w_valves	Simulated	Safe
valve_states	Simulated	Safe

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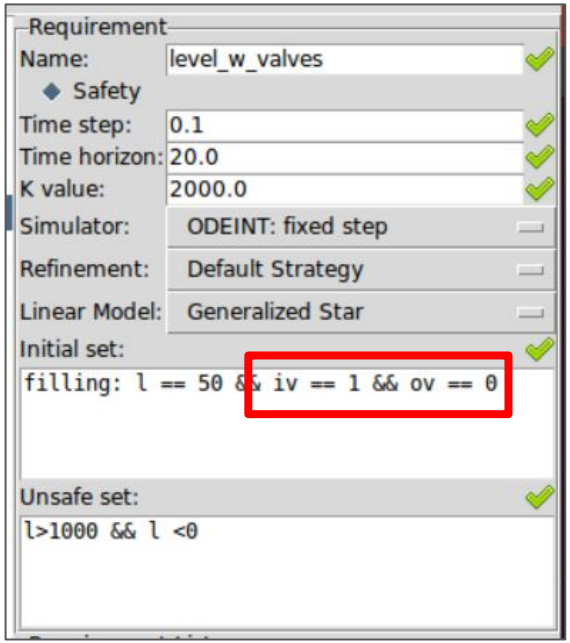

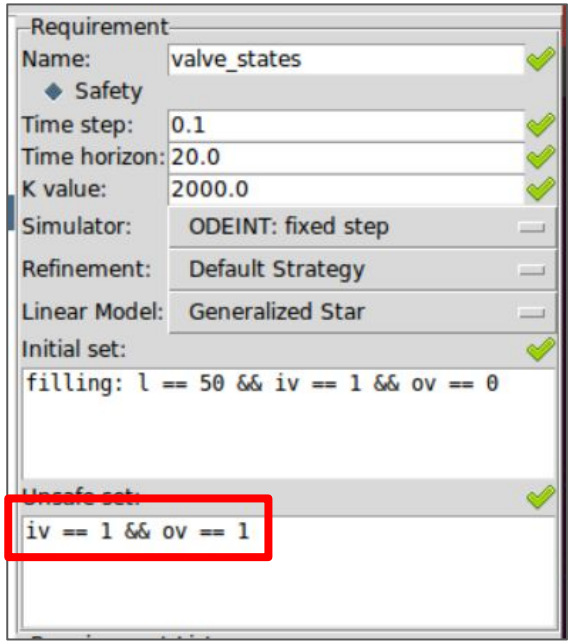

C2E2 Simulation

"Sequence of initial states are drawn randomly from the starting set. Once the simulation is computed, the result is checked to see if any guards are hit"

- C2E2 User Manual

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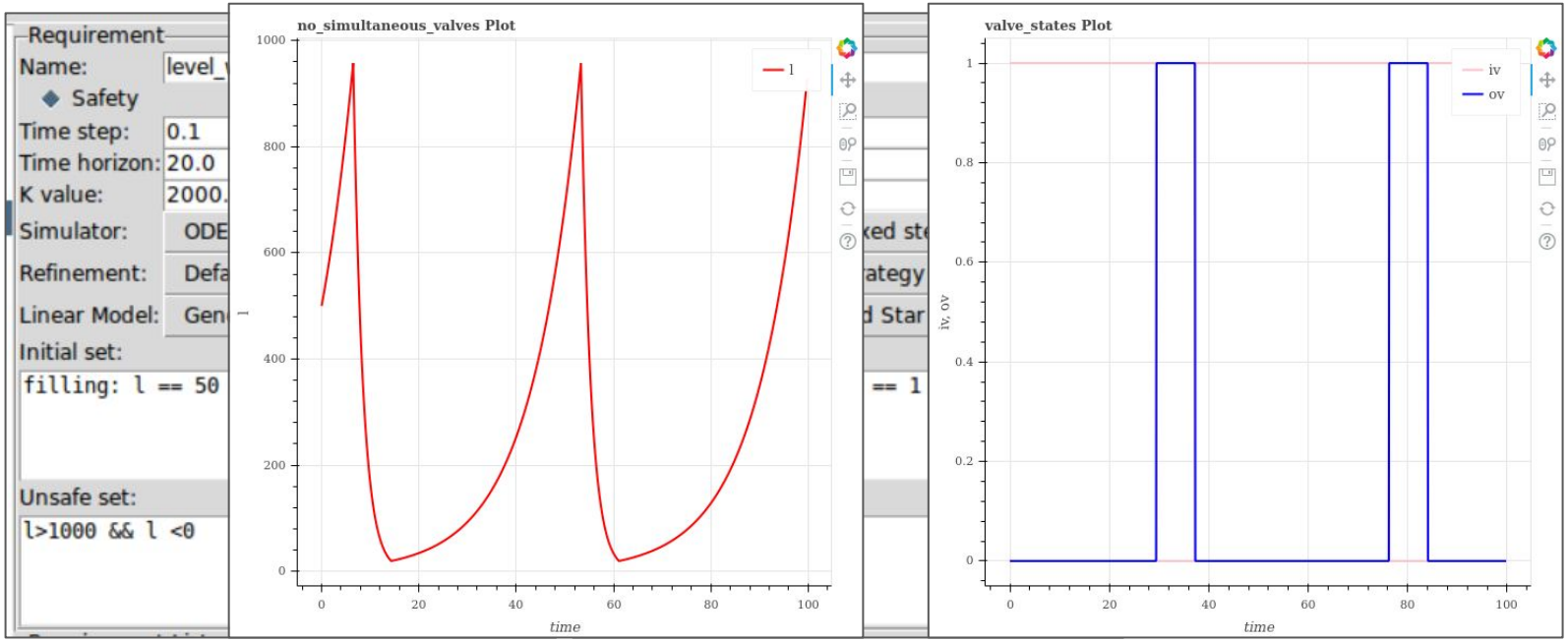
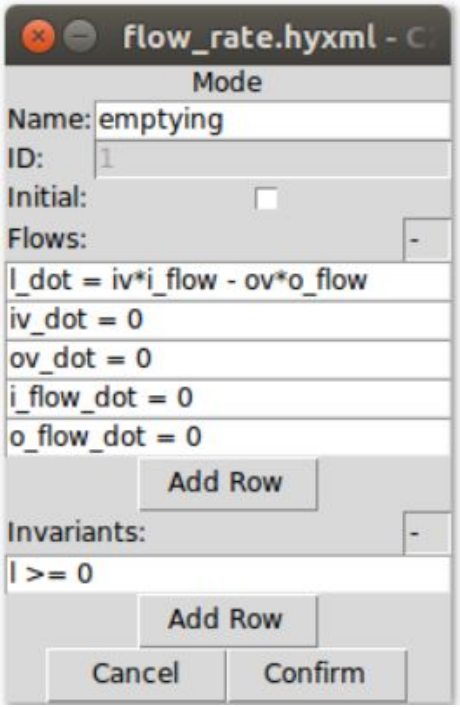
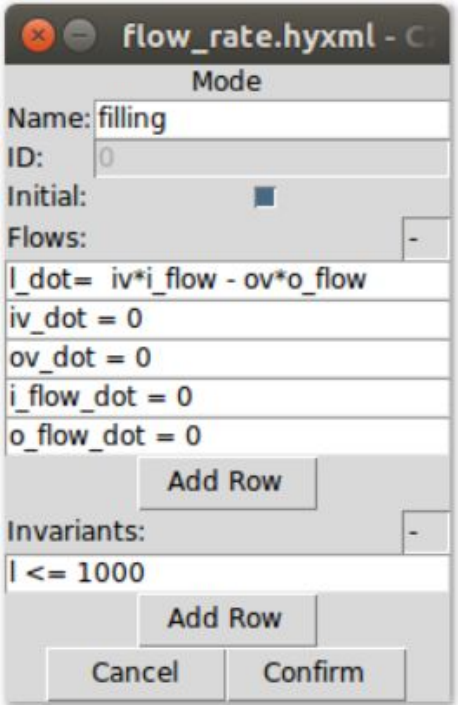
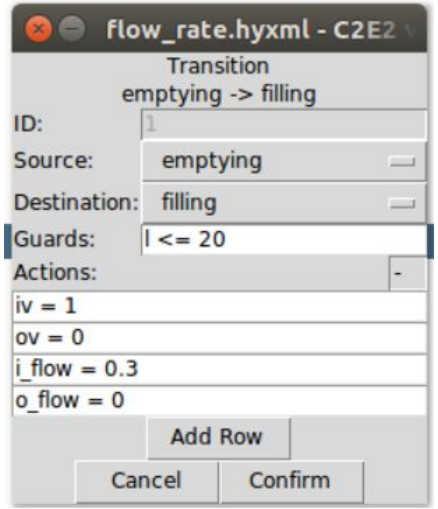


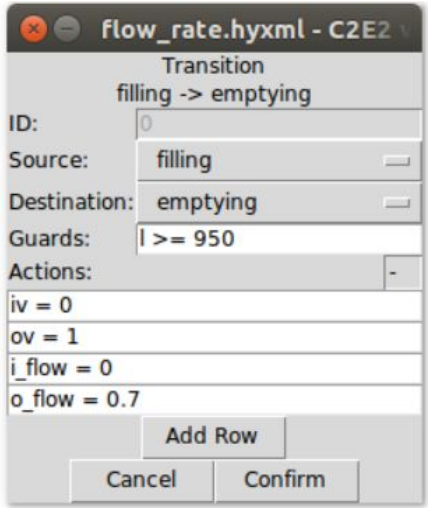
C2E2 Conversion – Adding in Flow Rates

- Update model to reflect variable flow rates (5 vars)



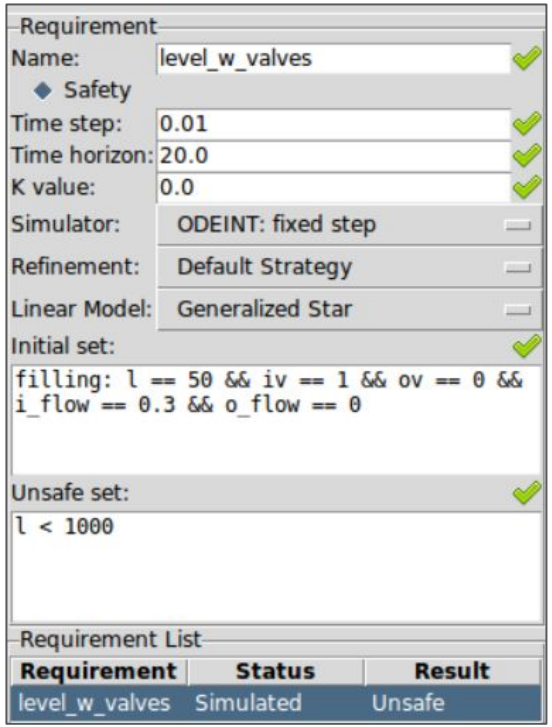


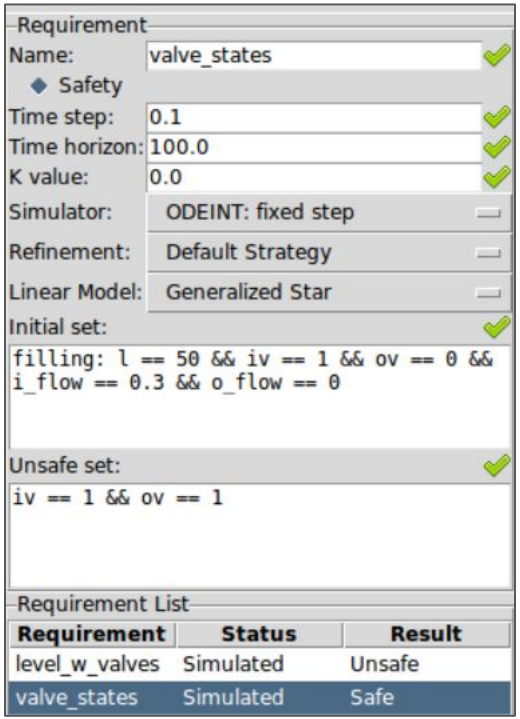


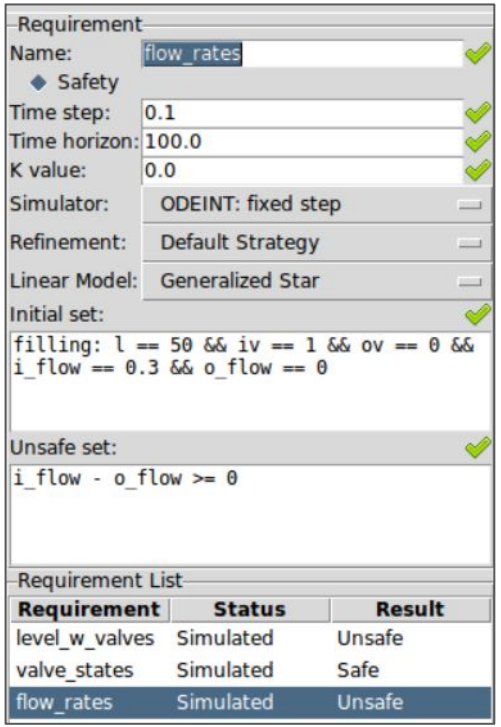


C2E2 Conversion – Adding in Flow Rates

- Update initial set and check a new condition

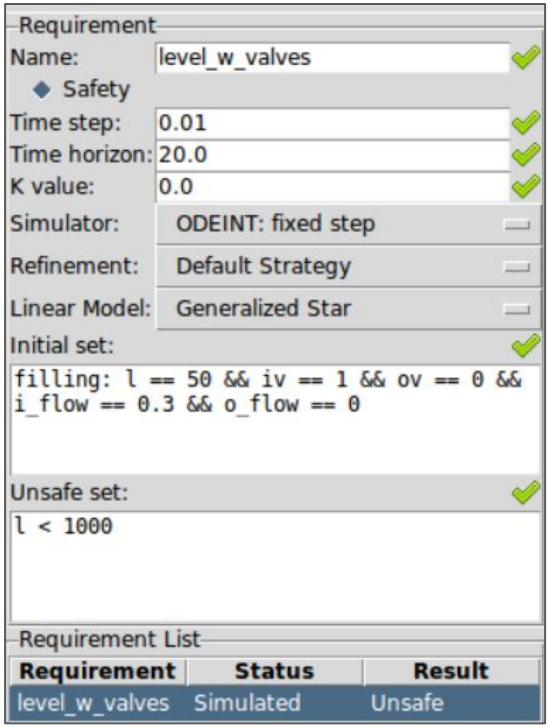






C2E2 Conversion – Adding in Flow Rates

- The issue:
  - Values quickly bypass the *l < 1000* condition
  - Appears to never make the transition from *filling -> emptying*
  - Implies there is some error in the transition between modes which I have yet to debug
    - User manual not too helpful
    - ChatGPT suggested it may be an issue with the time step granularity and how C2E2 progresses – not too convinced of this though



Challenges

- Interaction between transition guards/actions and mode invariants
- Software would buffer *for a while* if too many variables were added at once
- C2E2 documentation was not very helpful—lots of trial and error
- Poor warning/error messages made debugging a pain

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Next Steps

- Finish integrating the flow rate variables with a possible third *‘Idle’* state
- Add a *timer* variable to ensure that the valves don’t change state too frequently
- Attempt to add chemical dosing [if time allows]

Questions?