Analyzing Unsynthesizable High-Level Robot Specifications in LTLMoP

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High -Level Tasks:

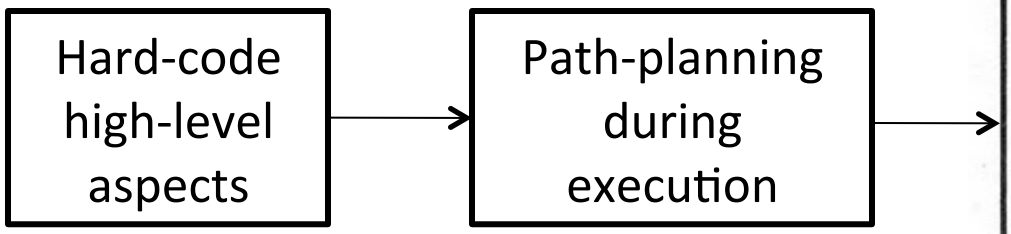
- Patrolling a workspace for an indefinite period
  (**infinite** behaviour)
- Responding to signals or objects of interest
  (**reactive**)

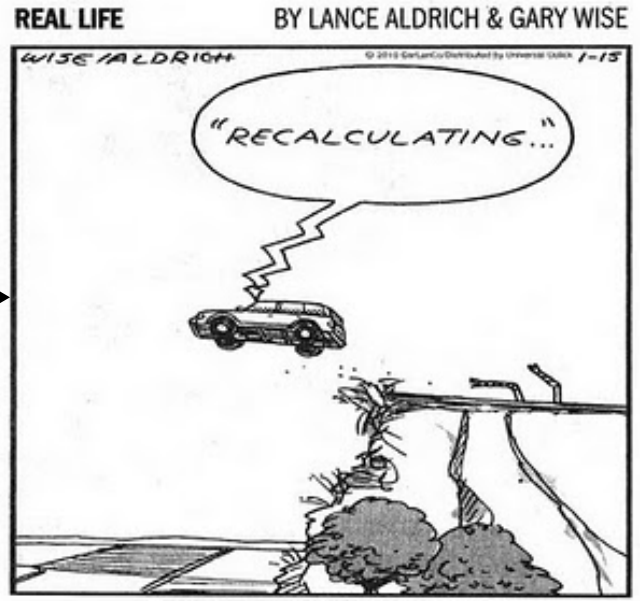
Examples:

Search and rescue missions
Autonomous Unmanned Vehicles
e.g. DARPA Urban Challenge
Firefighting robots
Household chores (laundry, cleanup)
Restocking supermarket shelves

AUTOMATED HIGH-LEVEL ROBOT CONTROL :

Usual Approach





- Need to plan for a large number of contingencies.
- Does the implementation capture the high level requirements?
- Is the intended behavior even achievable?

  Do there exist robot controllers that guarantee fulfillment of the task?

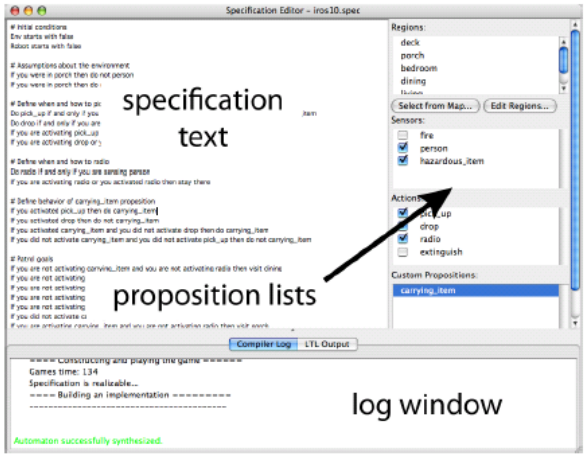
FORMAL GUARANTEES:

Verifiable integration of high-level planning with continuous control.

LINEAR TEMPORAL LOGIC MISSION PLANNING TOOLKIT (LTLMOP)

- Discretized problem abstraction
- Structured English specifications ⇔ GR(1) formulas in LTL.
  - environment assumptions
  - desired system behaviour
- Synthesis of correct-by-construction controllers.

LTLMoP Overview



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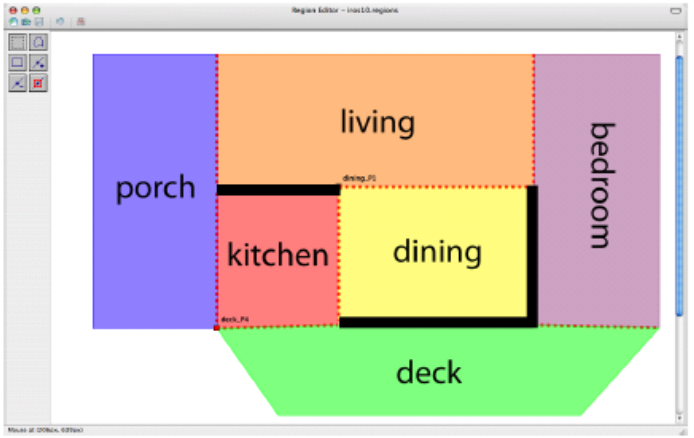
Robot Capability Definitions (Sensors/Actions)



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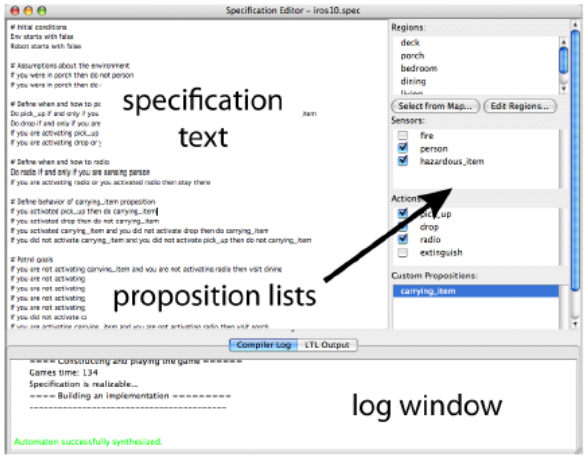

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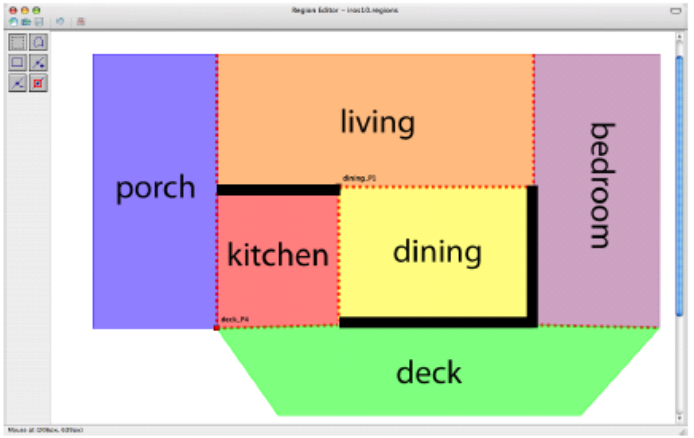

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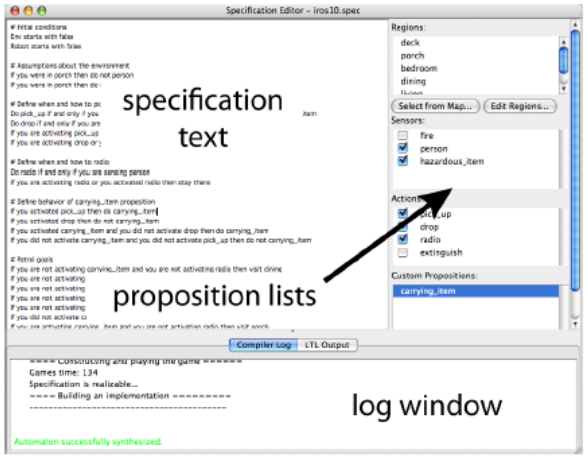
Structured English-to-LTL Parser

LTLMoP Overview



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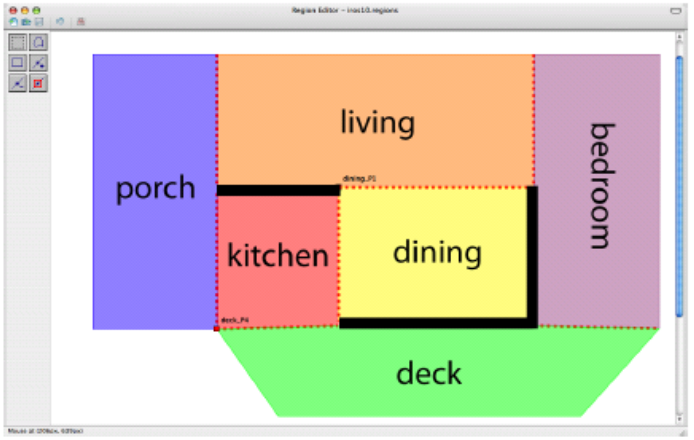

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Synthesis

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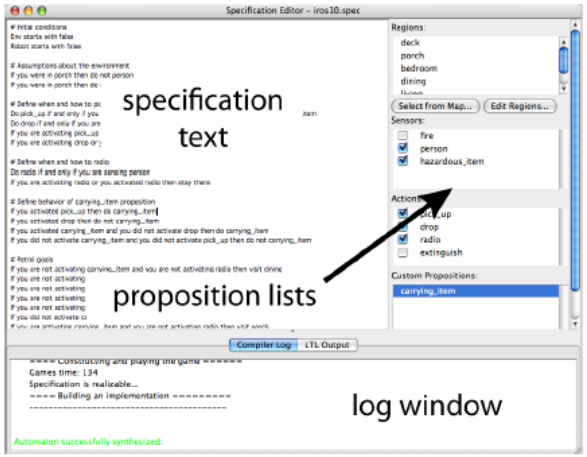

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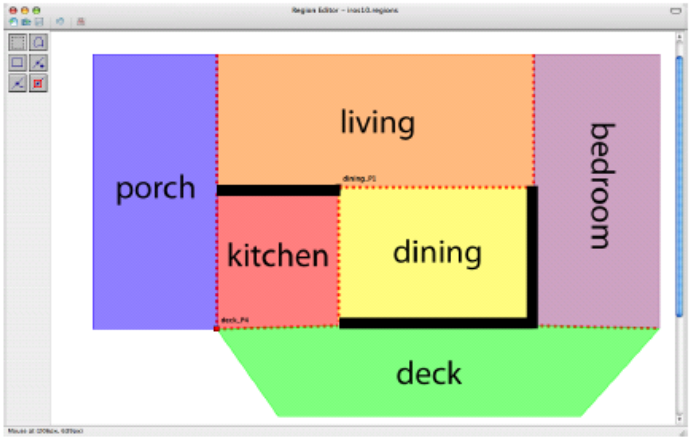

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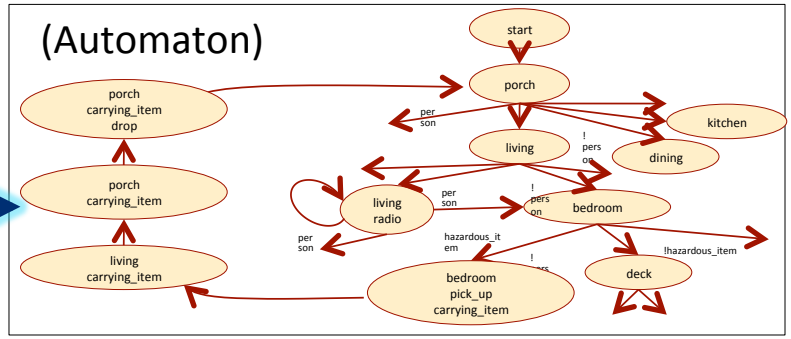

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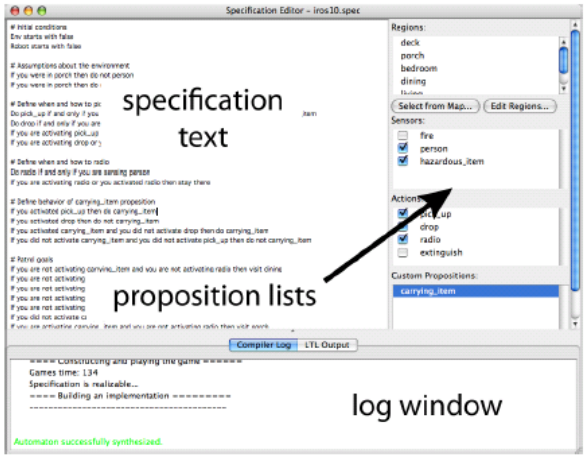

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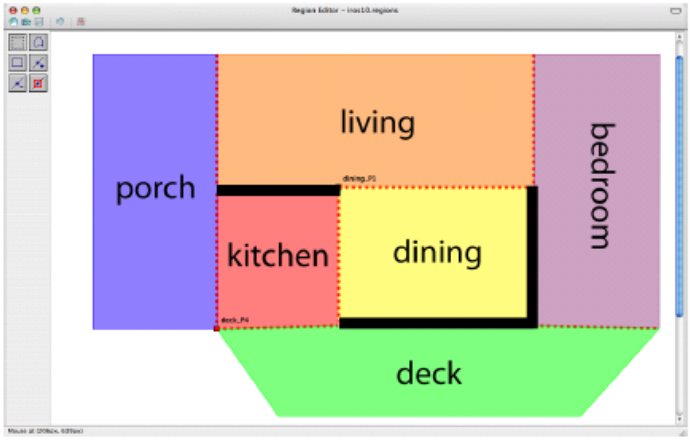

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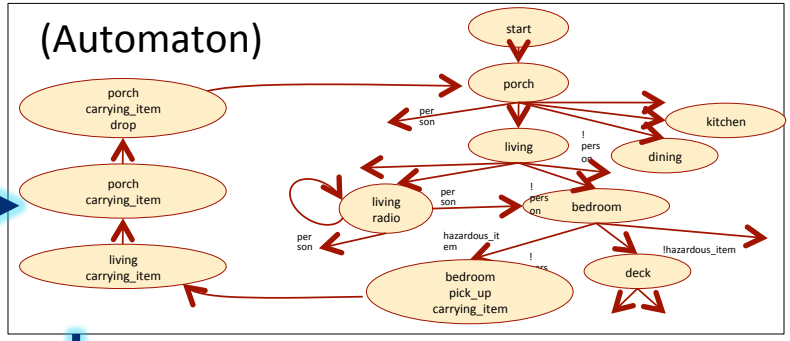
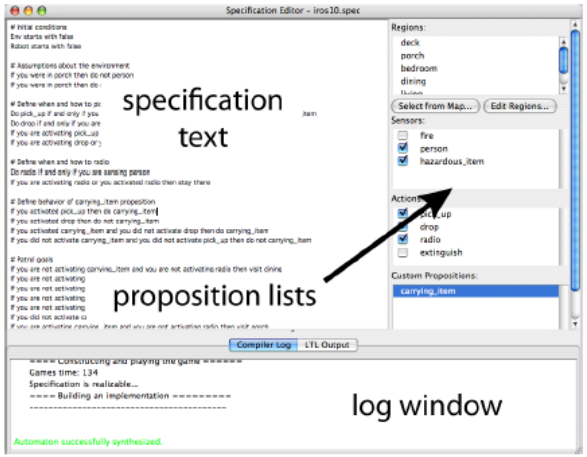


Hybrid Controller

LTLMoP Overview



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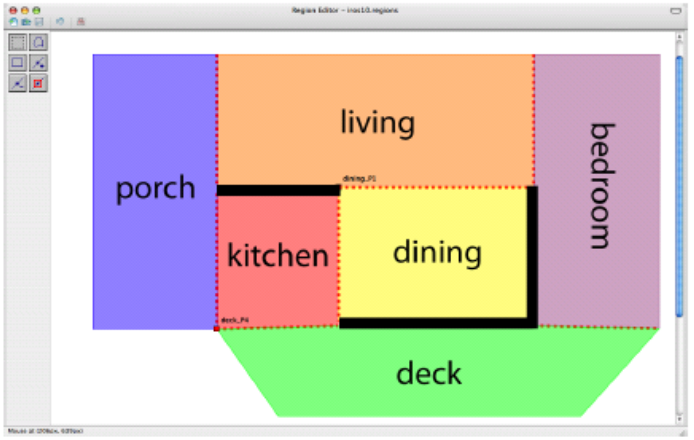

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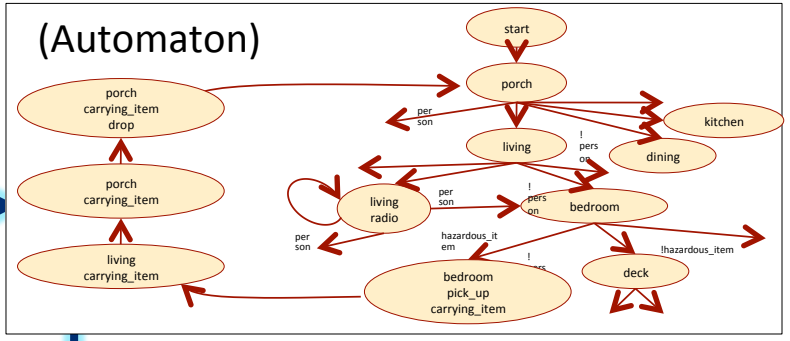

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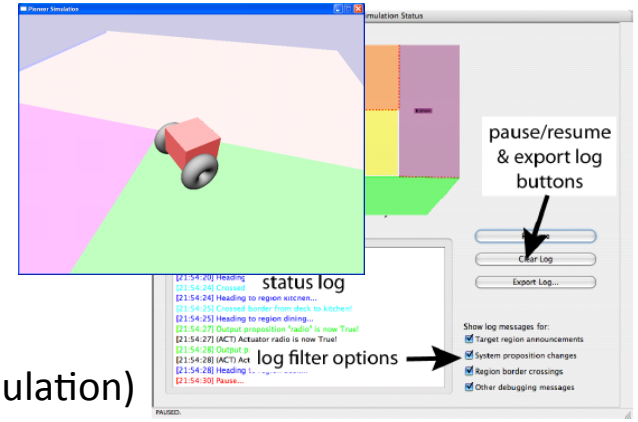

(Simulation)

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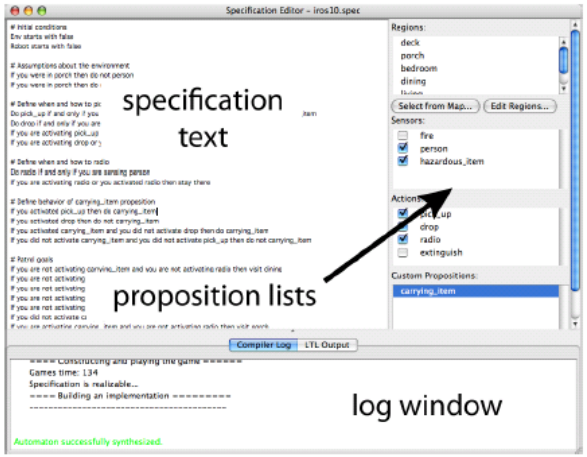

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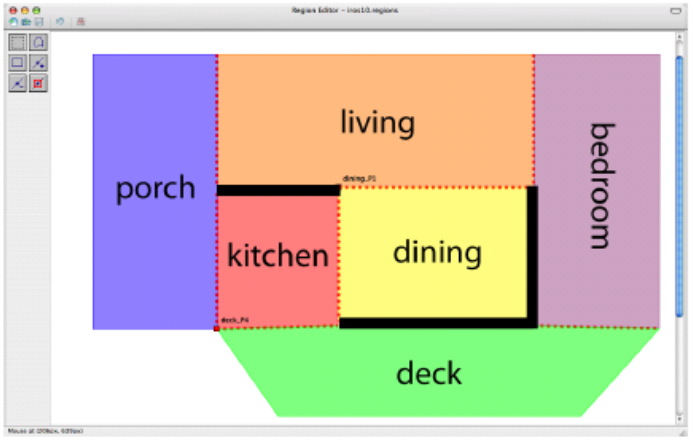

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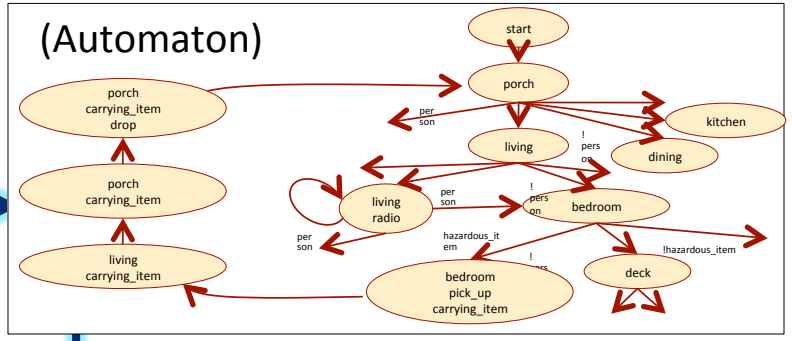

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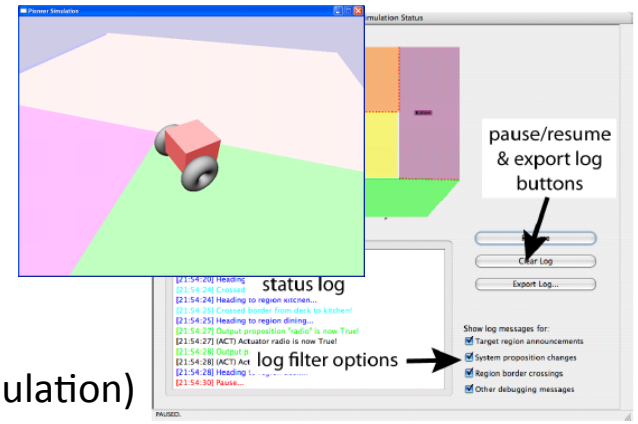

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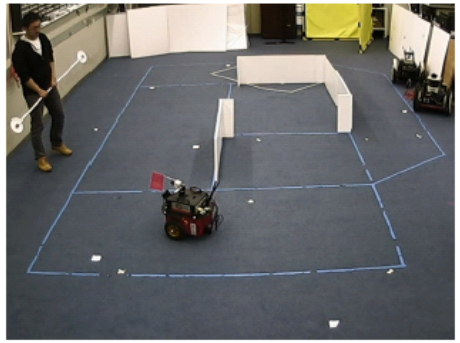

(Physical Robot)

EXAMPLE: FIRE-FIGHTING SCENARIO

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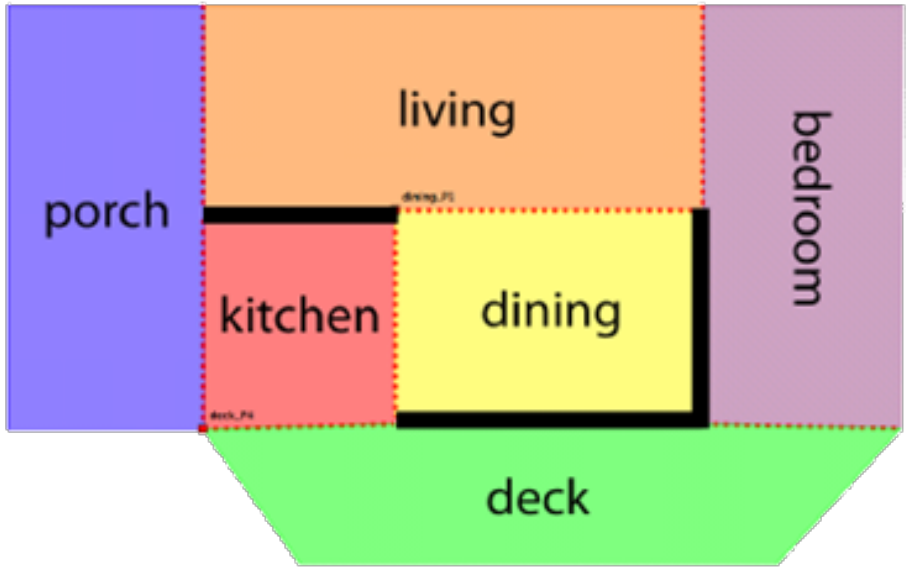

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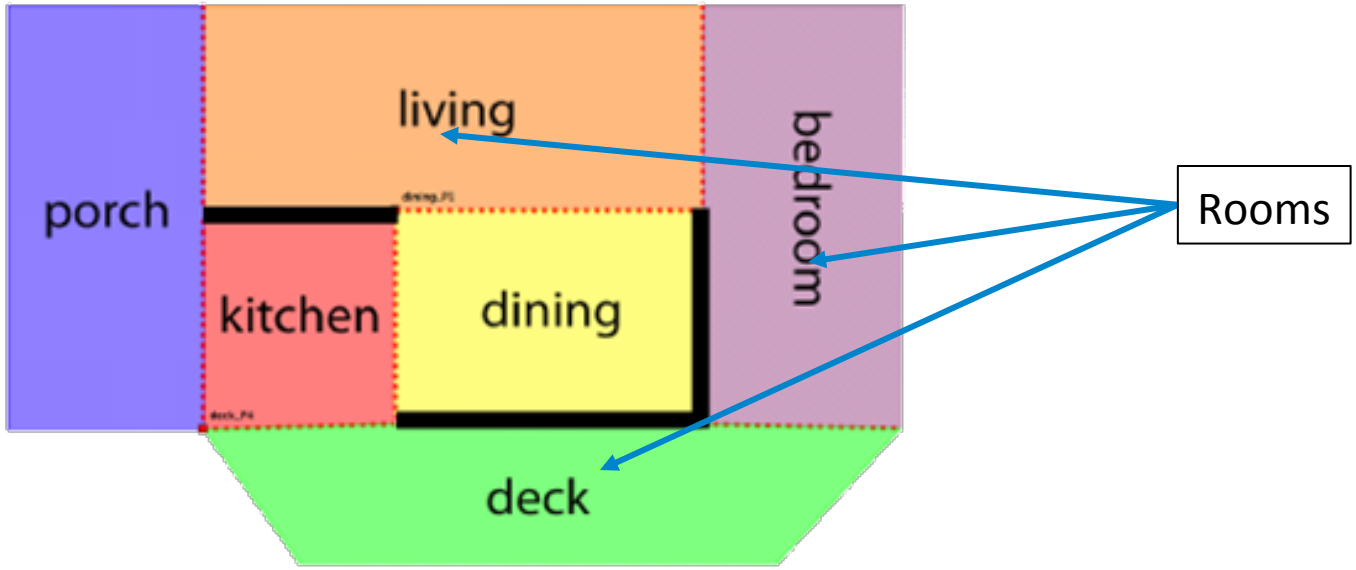
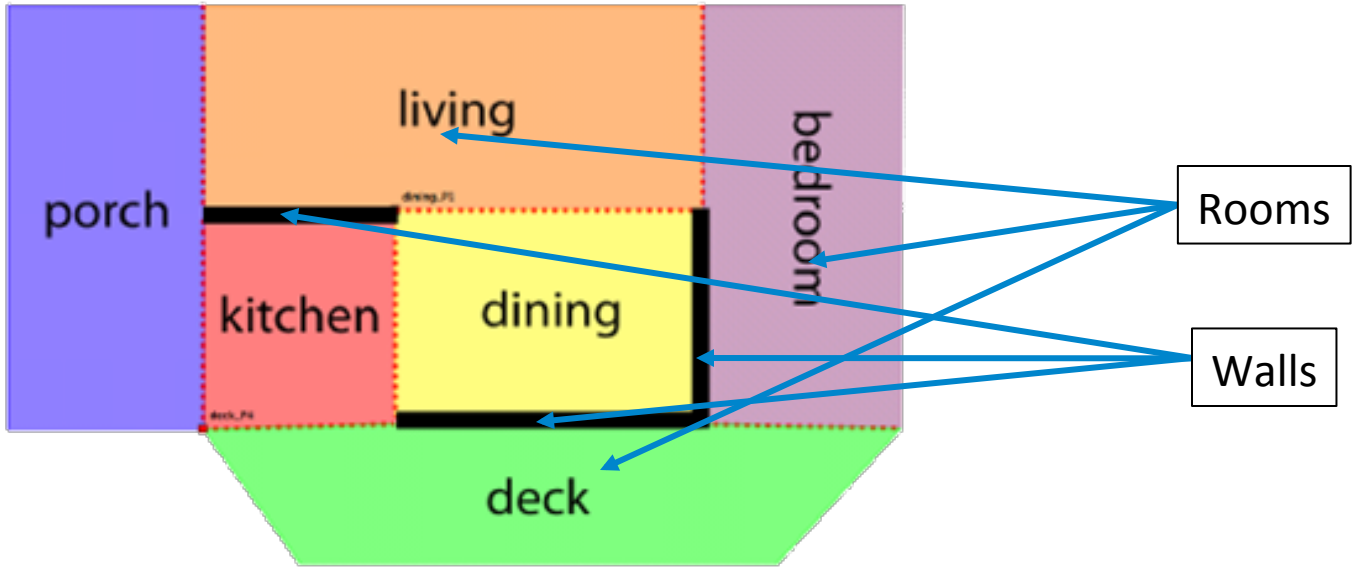


Regions:

- **porch, deck, etc.**

FIRE-FIGHTING SCENARIO



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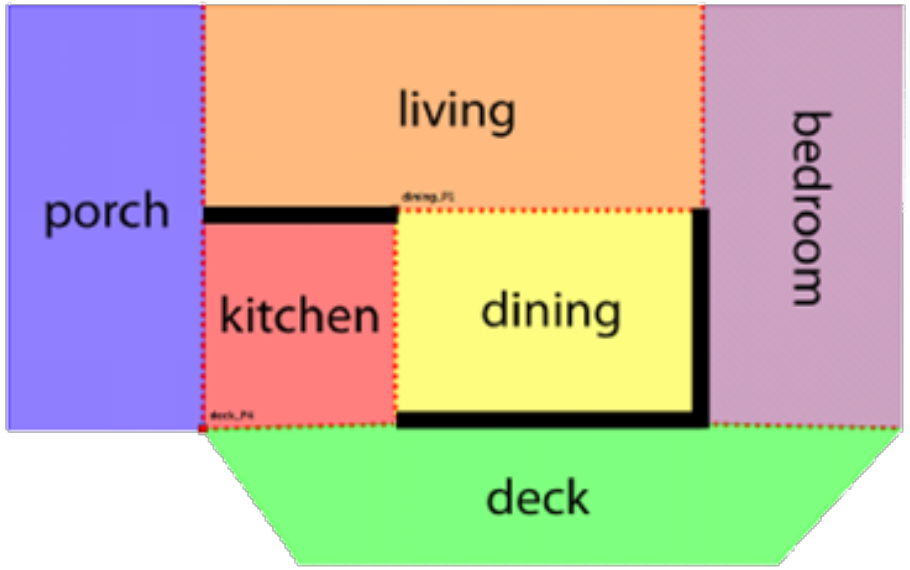

Regions:

- porch, deck, etc.

Robot actions:

- pick_up
- drop
- radio
- carrying_item

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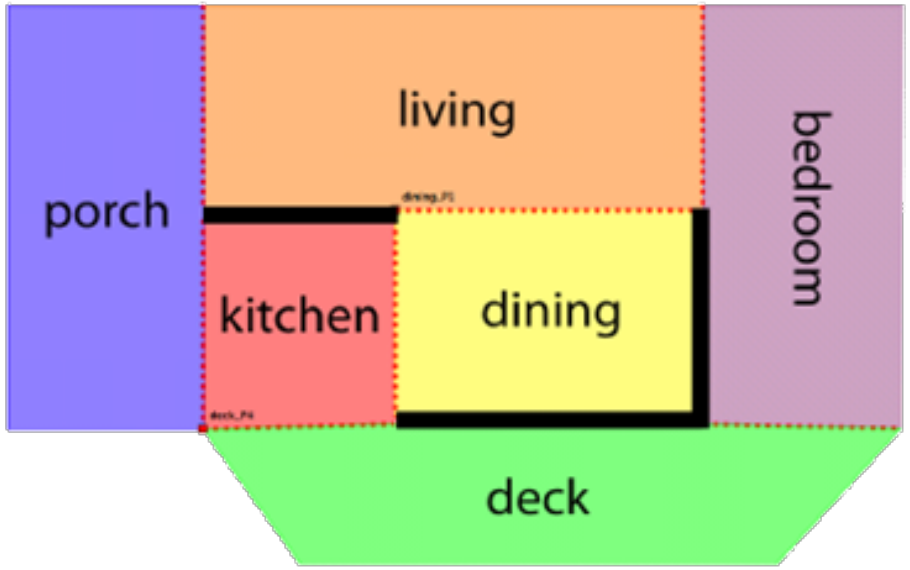

Regions:

- porch, deck, etc.

Robot actions:

- pick_up
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Sensors:

- hazardous_item
- person

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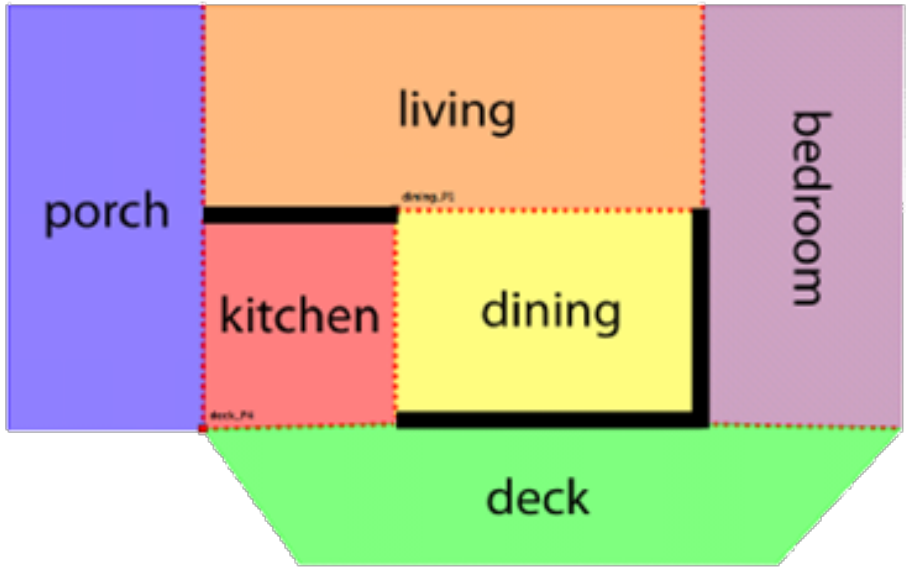

Regions:

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System Propositions

Sensors:

- hazardous_item
- person

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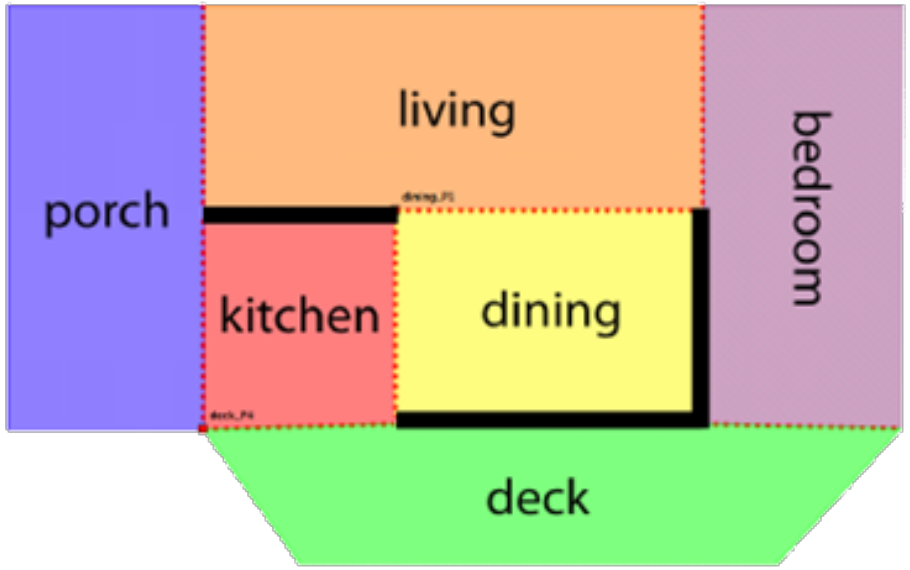

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Sensors:

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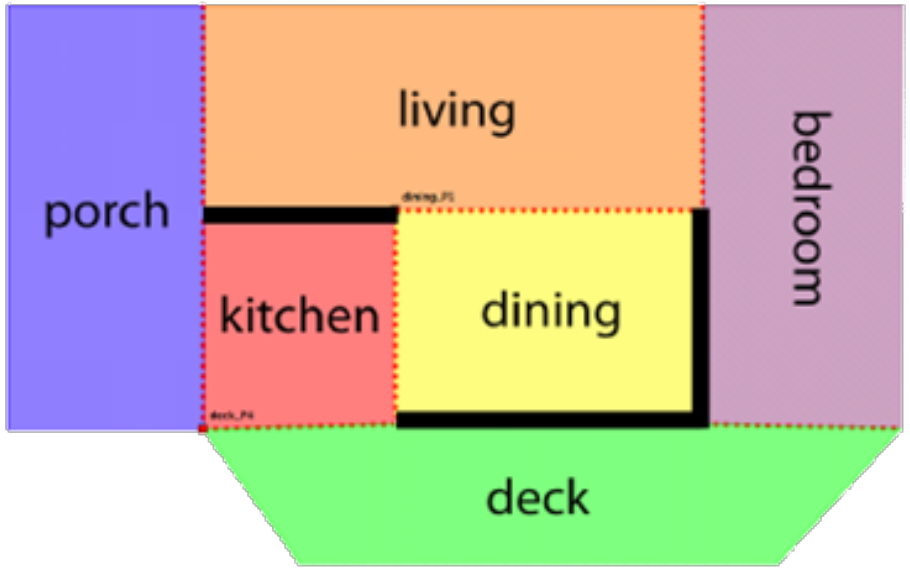
Environment Propositions

FIRE-FIGHTING SCENARIO



Regions:

- porch, deck, etc.

Robot actions:

- pick_up
- drop
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- carrying_item

Sensors:

- hazardous_item
- person

Env starts with false
Robot starts with false
Robot starts in **porch**

If you were in **porch** then
do not **hazardous_item**

Do **pick_up** if and only if you are sensing **hazardous_item** and you are not activating **carrying_item**

If you did not activate **carrying_item** then always not **porch**

Do **radio** if and only if you are sensing **person**

If you are activating **radio** or you were activating **radio** then stay there

If you are not activating **carrying_item** and you are not activating **radio** then visit **dining**

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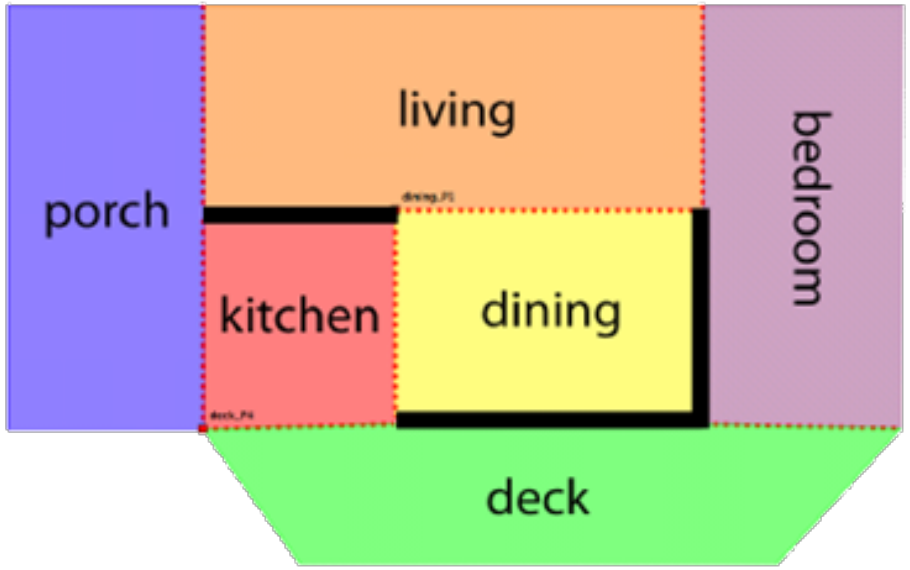

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- pick_up
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Sensors:

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Robot starts in **porch**

Initial Conditions

If you were in **porch** then do not **hazardous_item**

Do **pick_up** if and only if you are sensing **hazardous_item** and you are not activating **carrying_item**

If you did not activate **carrying_item** then always not **porch**

Do **radio** if and only if you are sensing **person**

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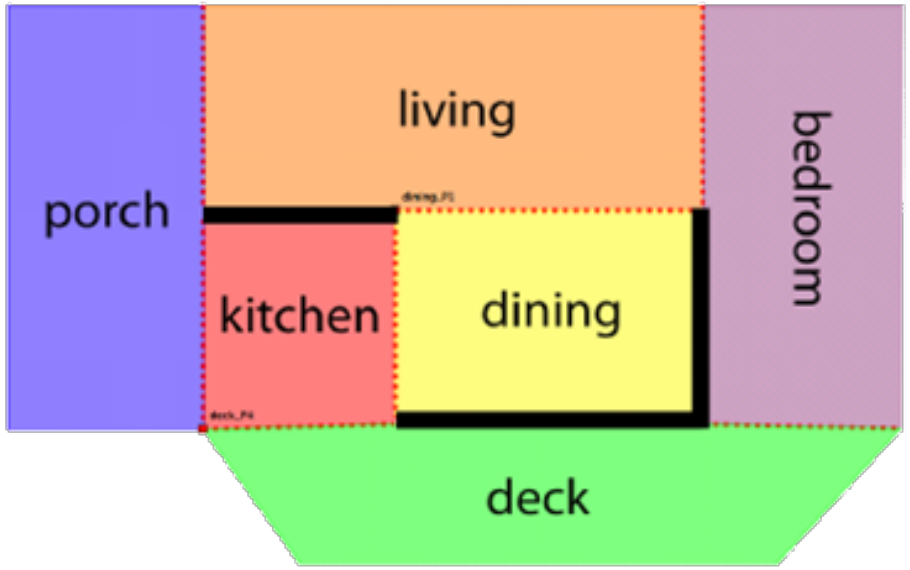

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If you were in **porch** then do not **hazardous_item** } Environment Safety

Do **pick_up** if and only if you are sensing **hazardous_item** and you are not activating **carrying_item**

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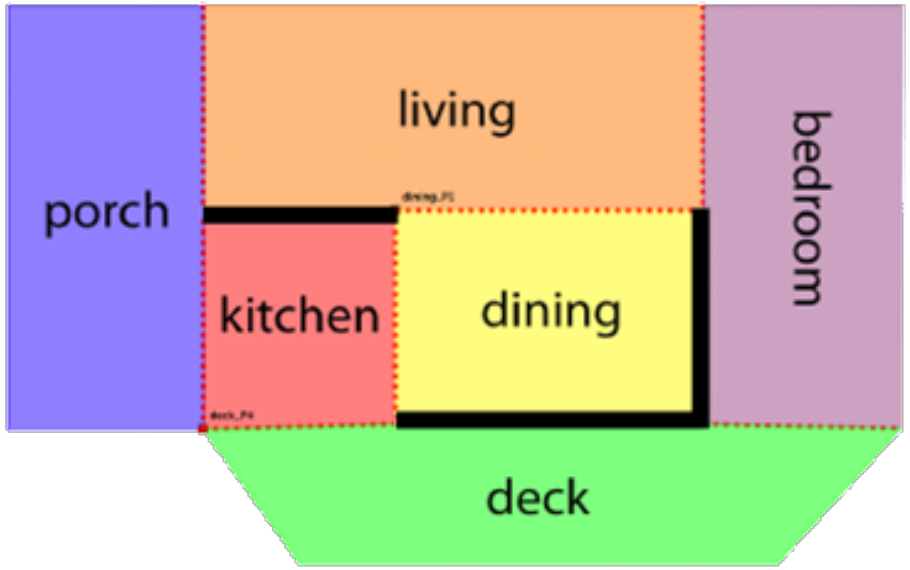

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Regions:

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Robot actions:

- **pick_up**
- **drop**
- **radio**
- **carrying_item**

Sensors:

- **hazardous_item**
- **person**

System Safety

Do **pick_up** if and only if you are sensing **hazardous_item** and you are not activating **carrying_item**

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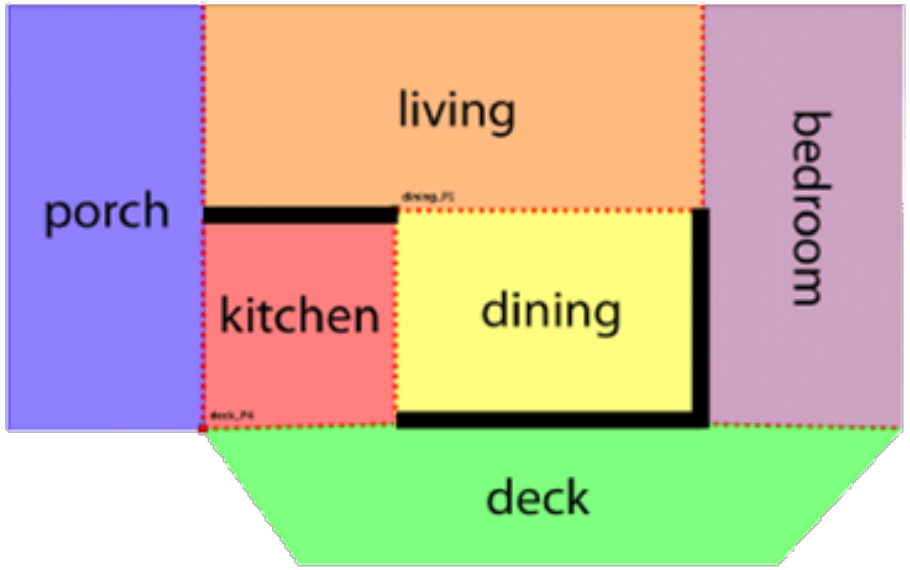

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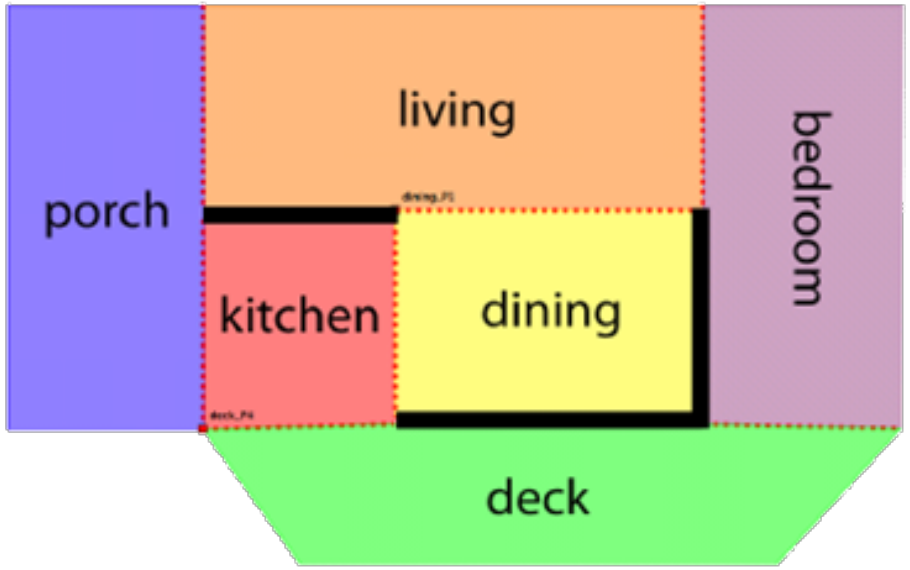
System Liveness

If you are not activating **carrying_item** and you are not activating **radio** then visit **dining**

FIRE-FIGHTING SCENARIO



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Problem: Unsynthesizable Specifications

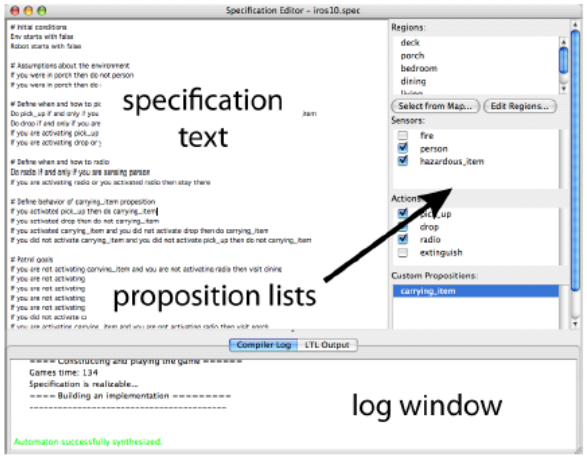
- Unsatisfiable:
  System requirements cannot be fulfilled in **any** environment

- Unrealizable:
  System requirements cannot be fulfilled in **some** admissible environment

Goals:

- Identify the cause of failure in the LTL specification
- Map it back to structured English

LTLMoP Overview



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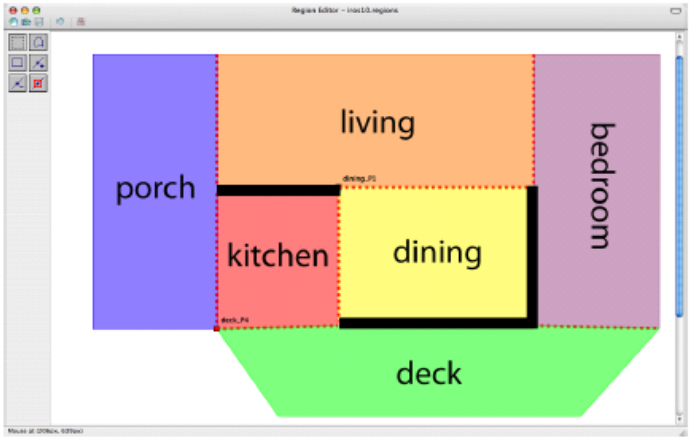

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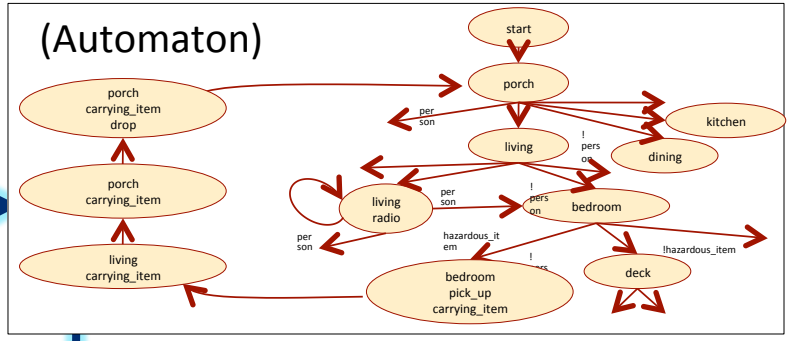
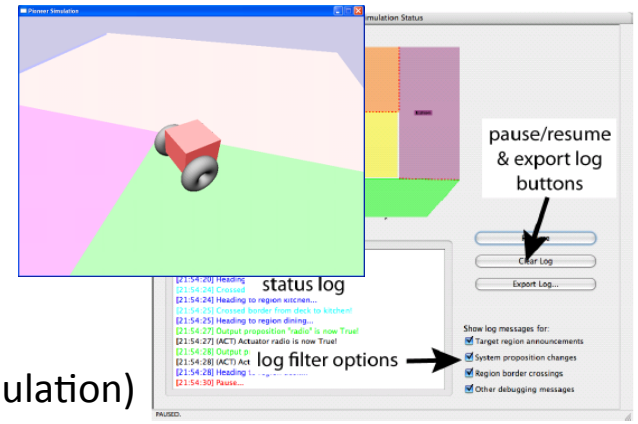


Hybrid Controller



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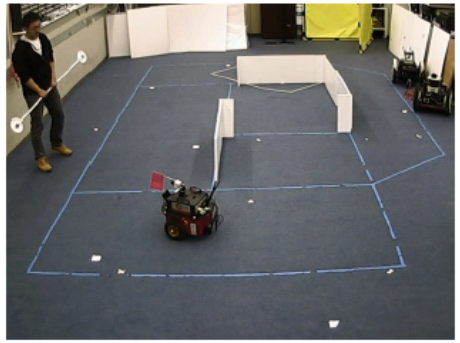

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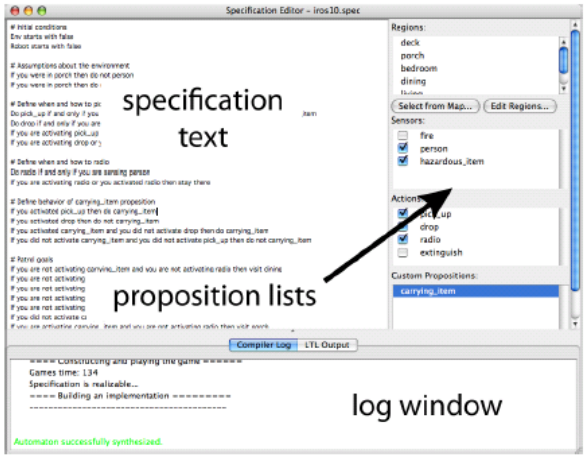
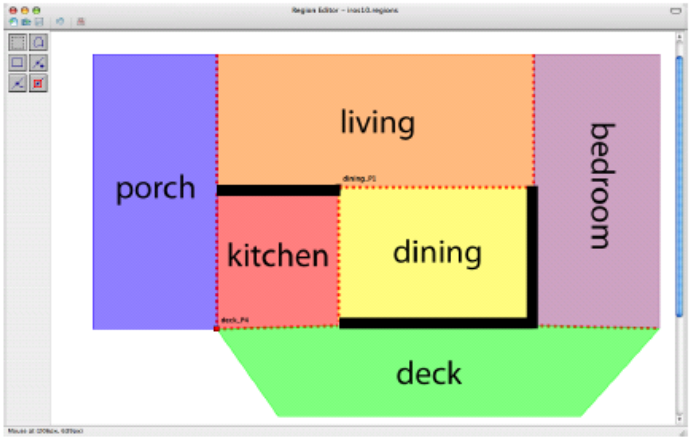


(Specification Editor)

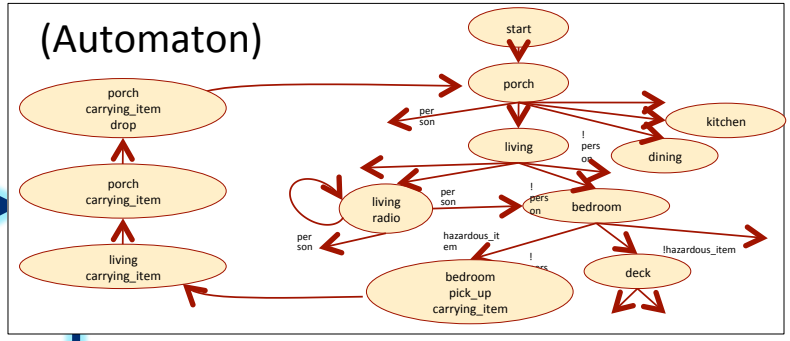
Robot Capability Definitions (Sensors/Actions)



(Region Editor)

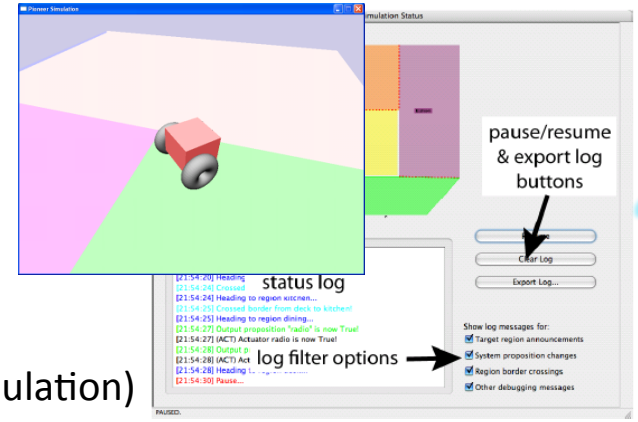
Structured English-to-LTL Parser

Synthesis

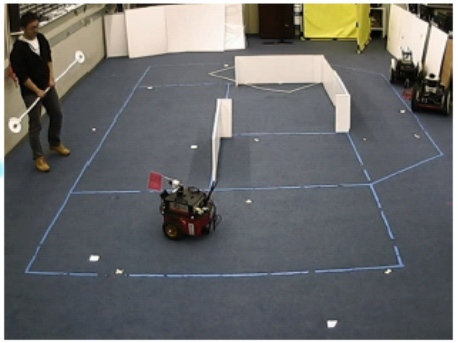


Layer of Analysis for Specifications

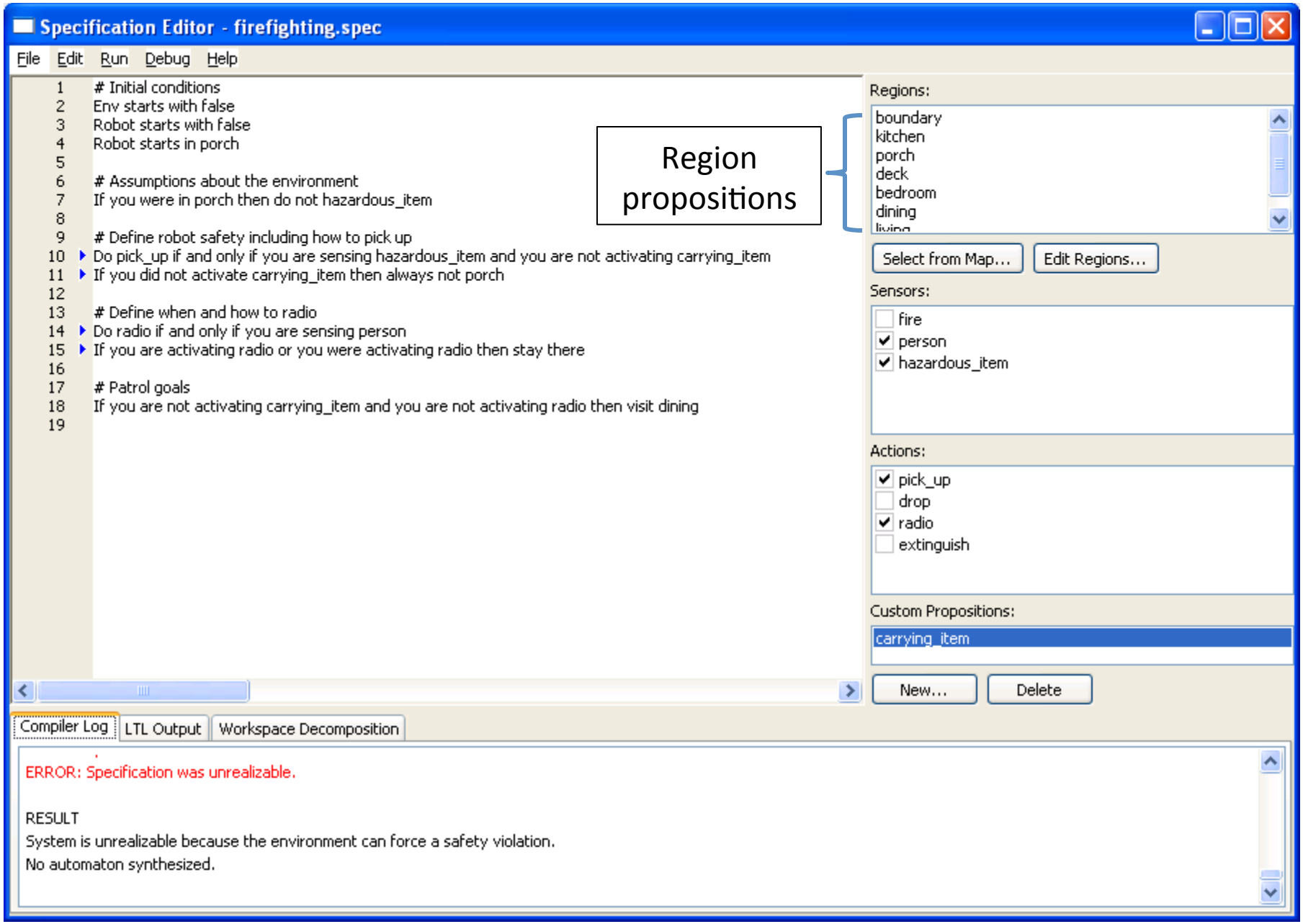
Hybrid Controller



(Simulation)



(Physical Robot)


Specification Editor - firefighting.spec
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17 # Patrol goals
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Select from Map...
Edit Regions...
Sensors:
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drop
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extinguish
Custom Propositions:
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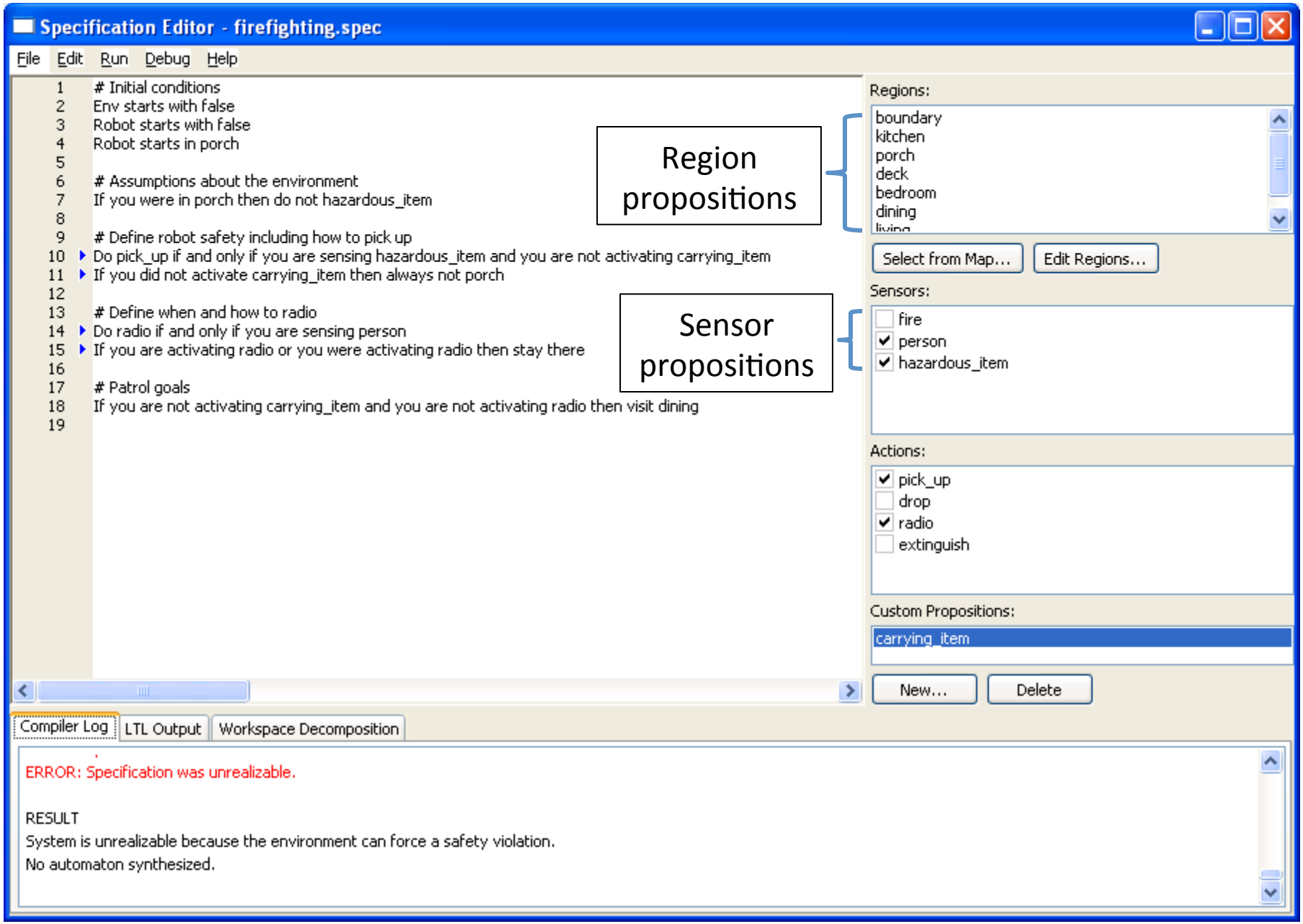
New...
Delete
Compiler Log
LTL Output
Workspace Decomposition
ERROR: Specification was unrealizable.
RESULT
System is unrealizable because the environment can force a safety violation.
No automaton synthesized.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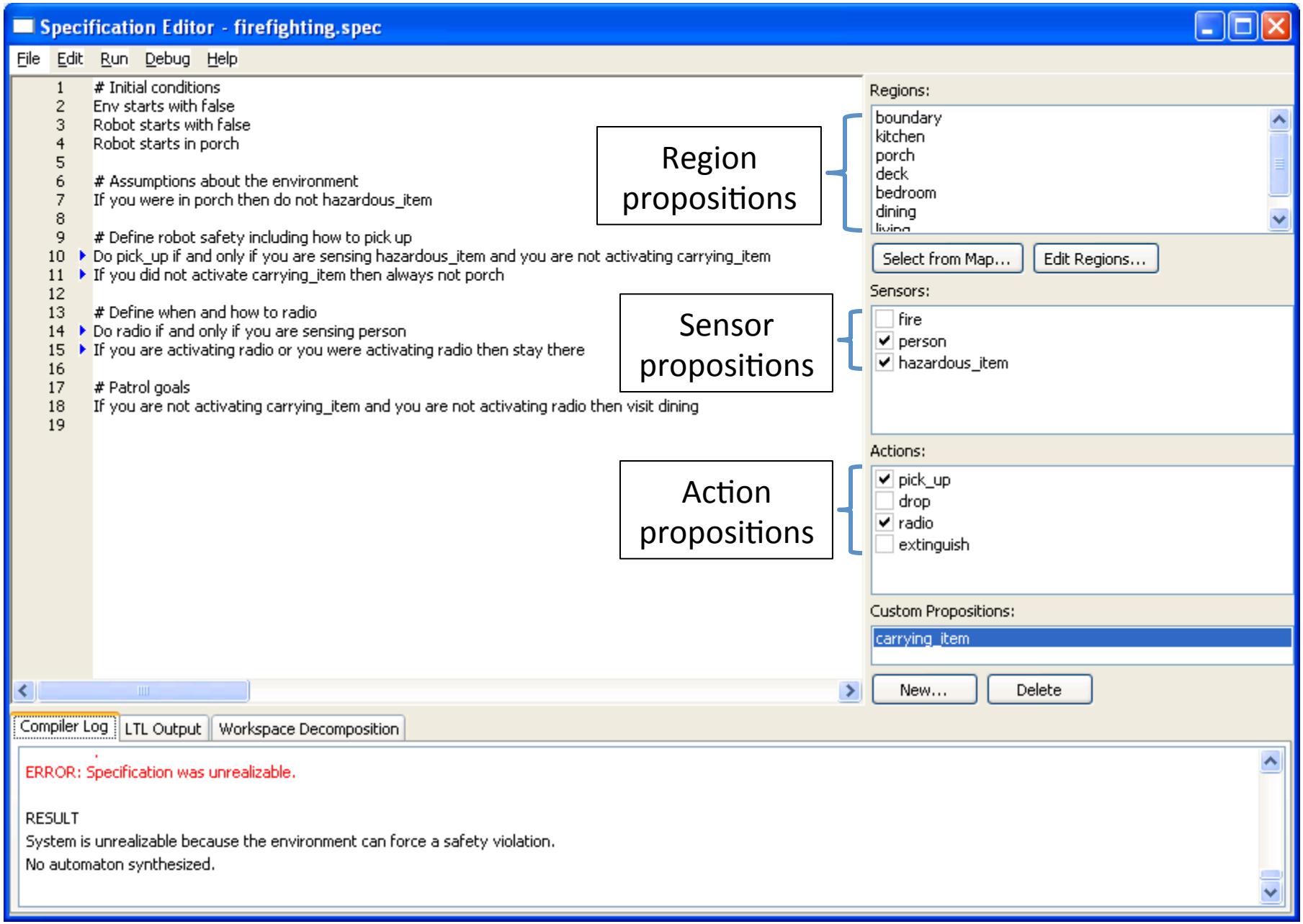
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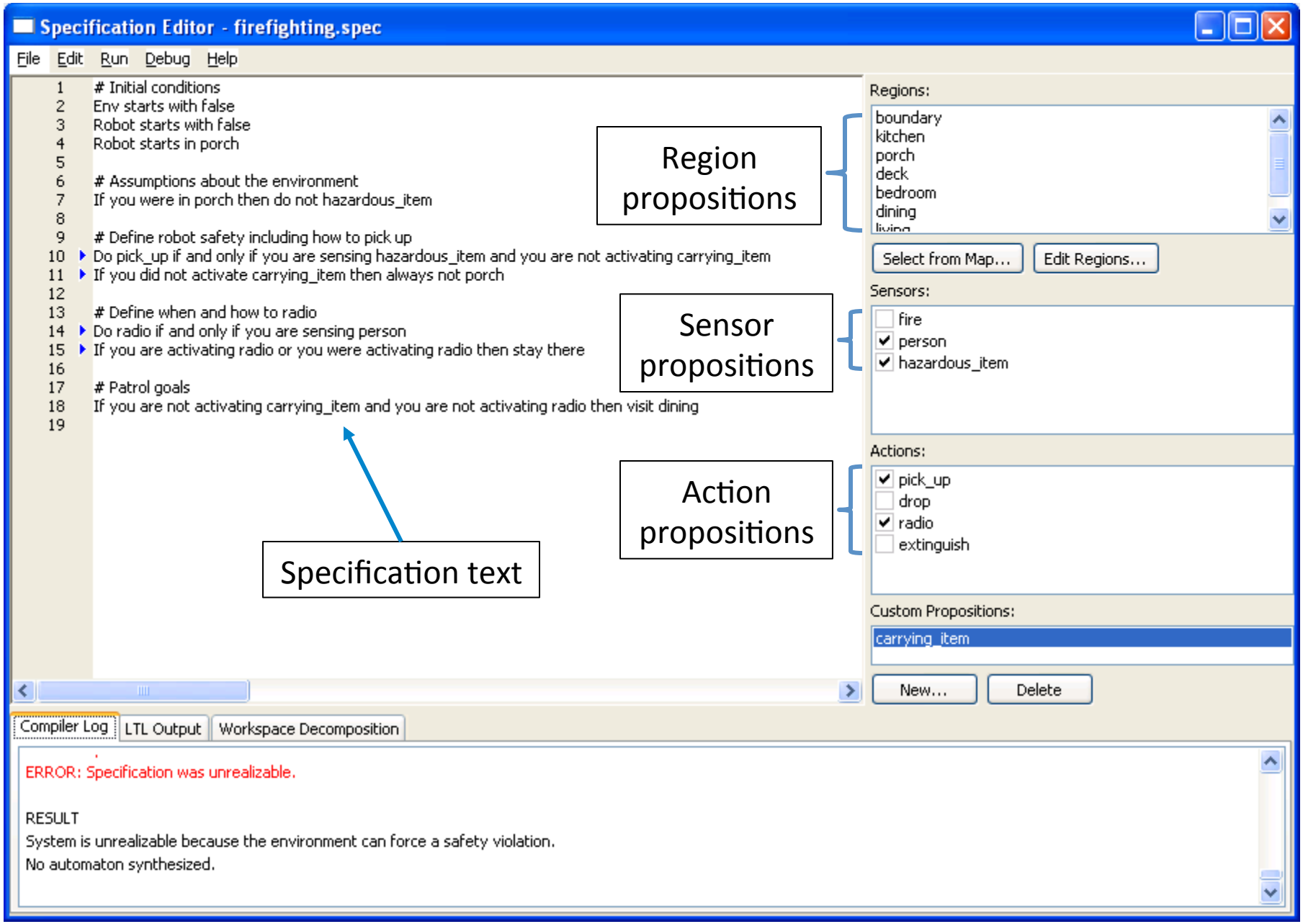
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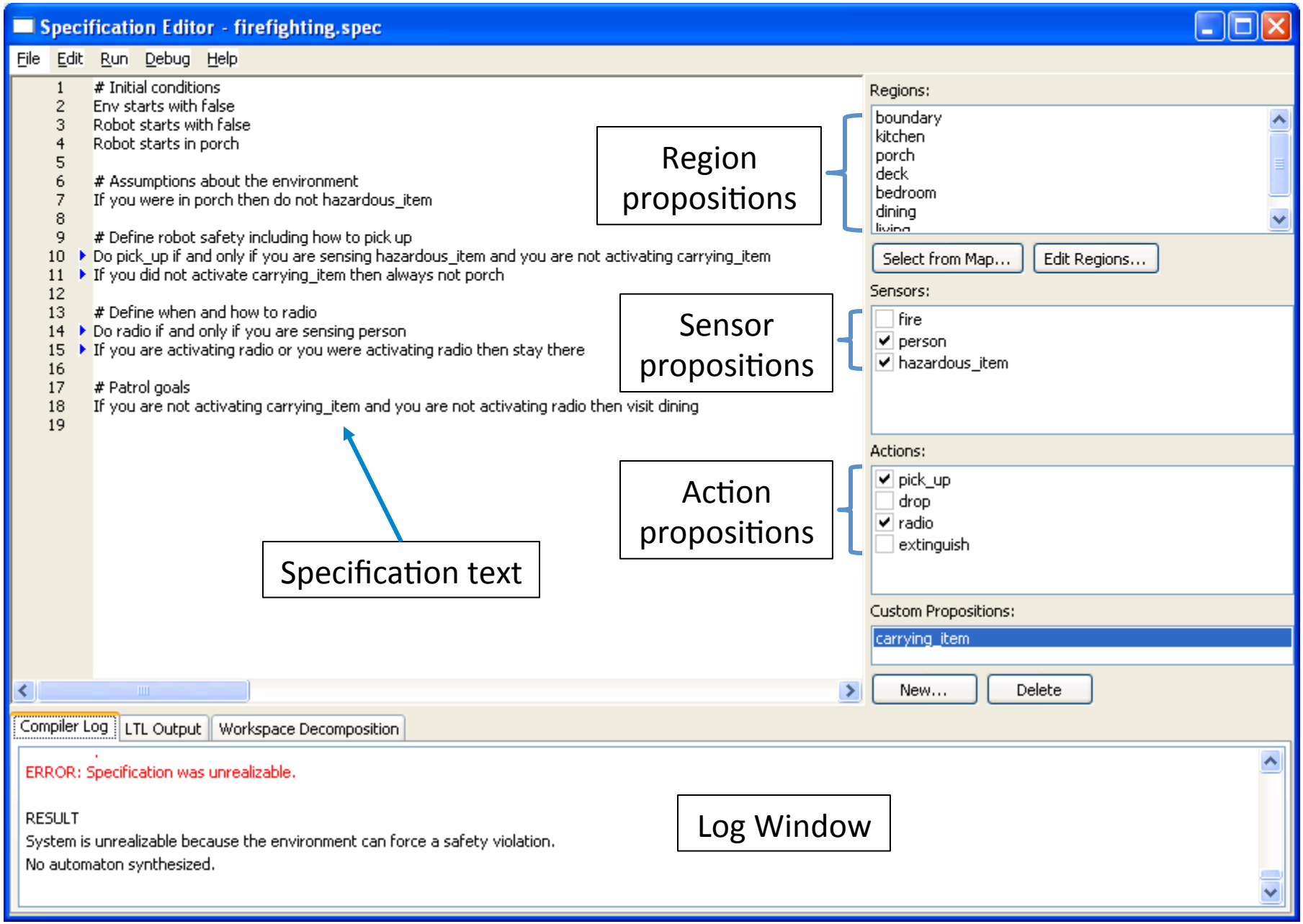
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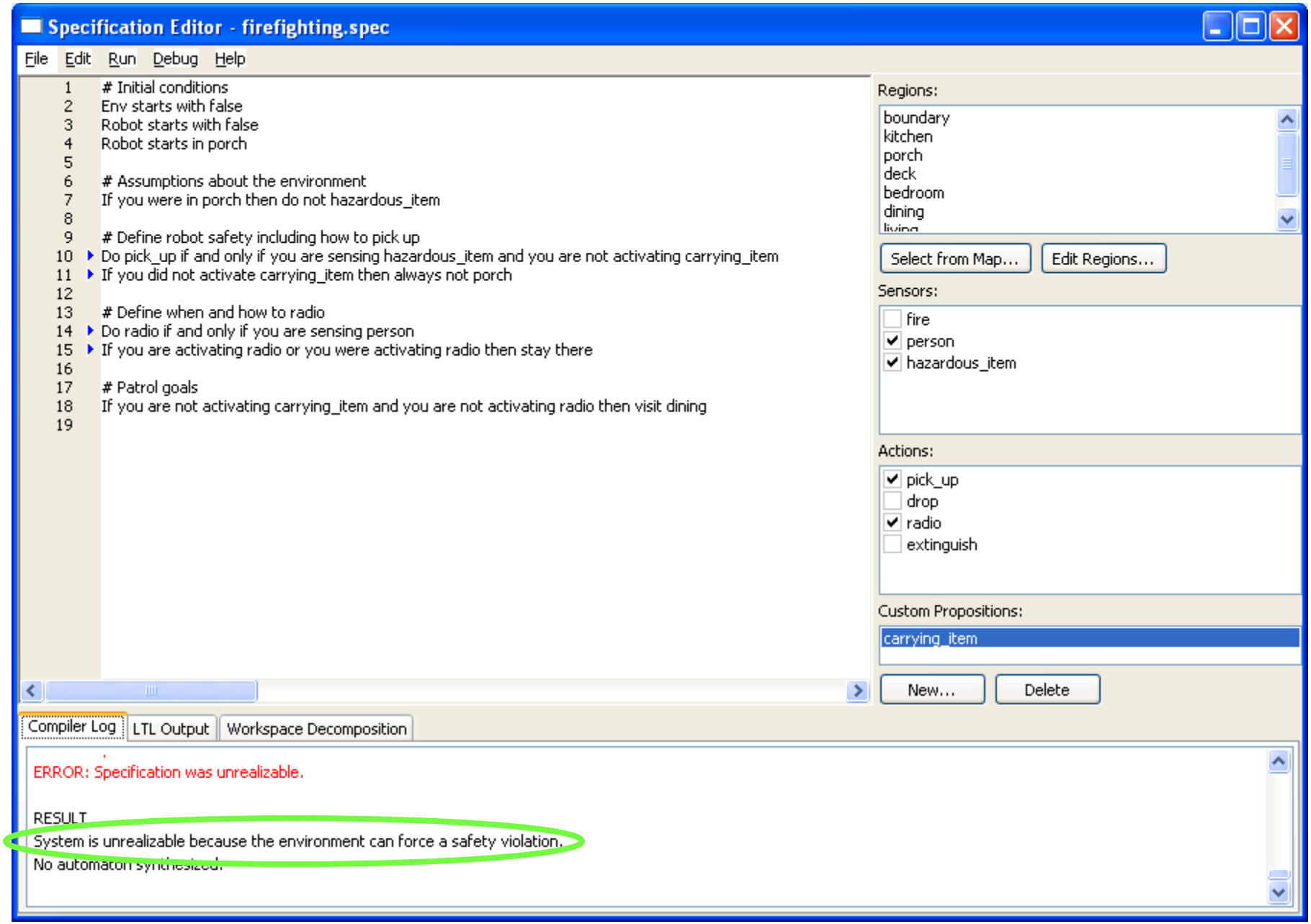
Log Window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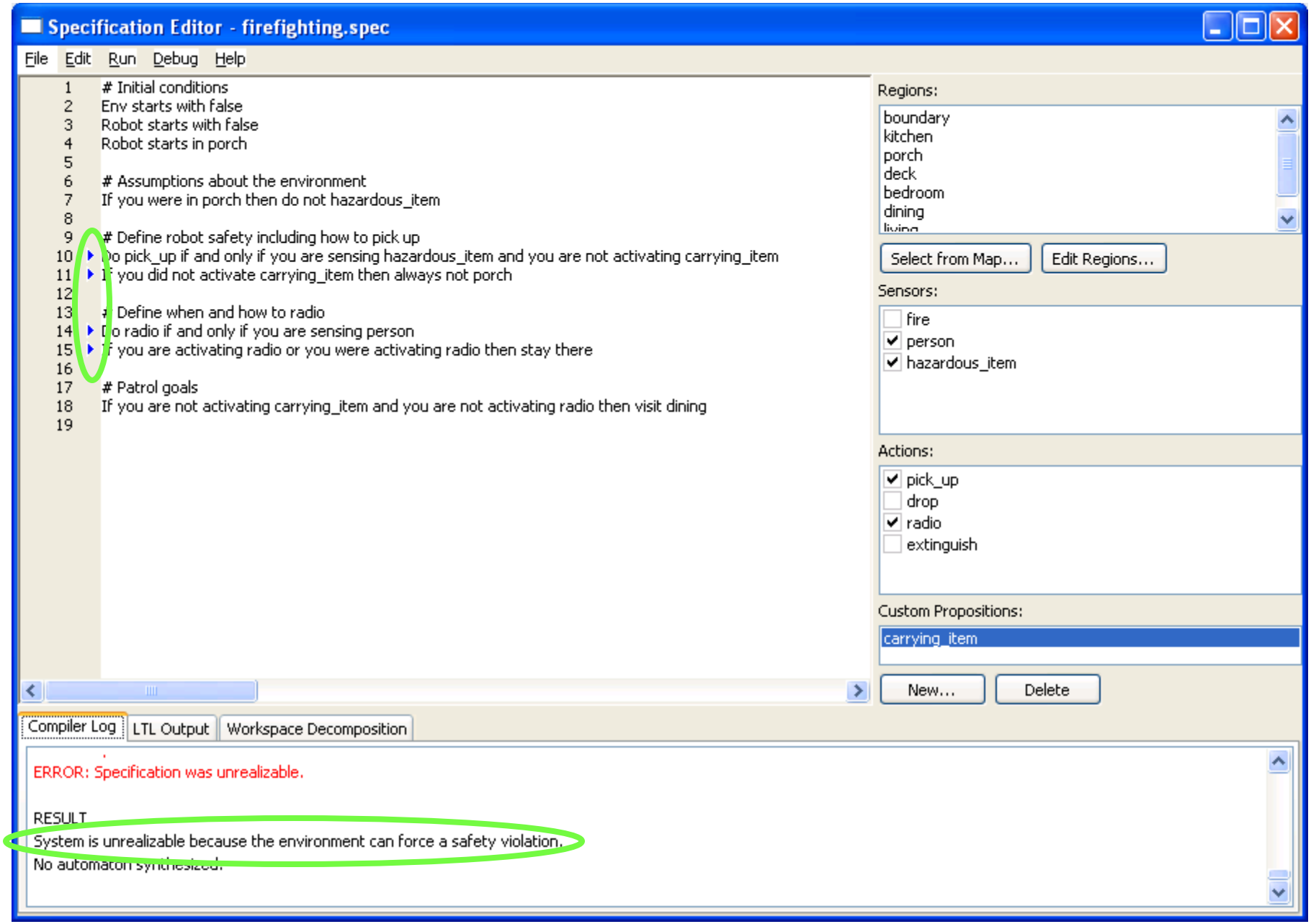
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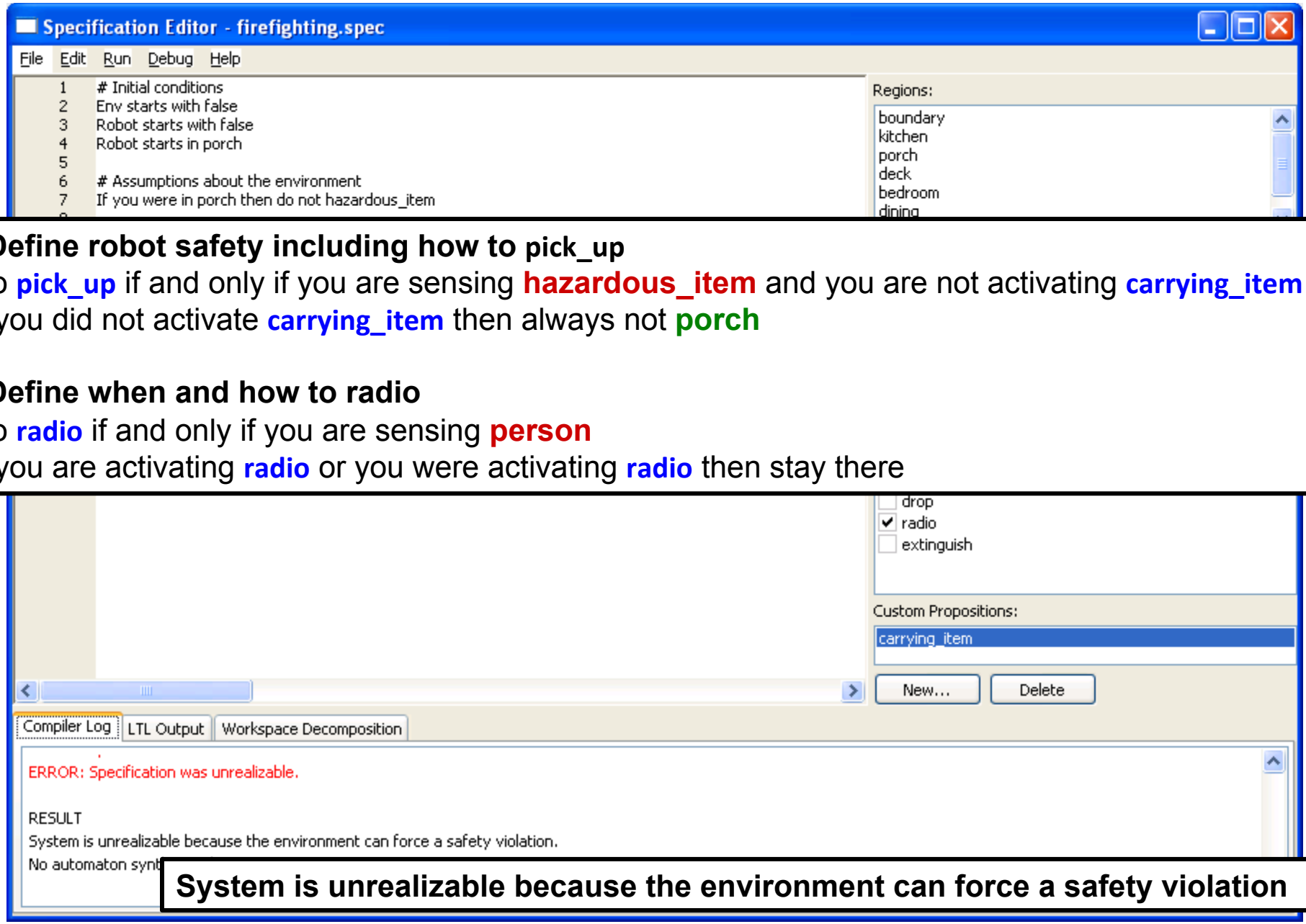
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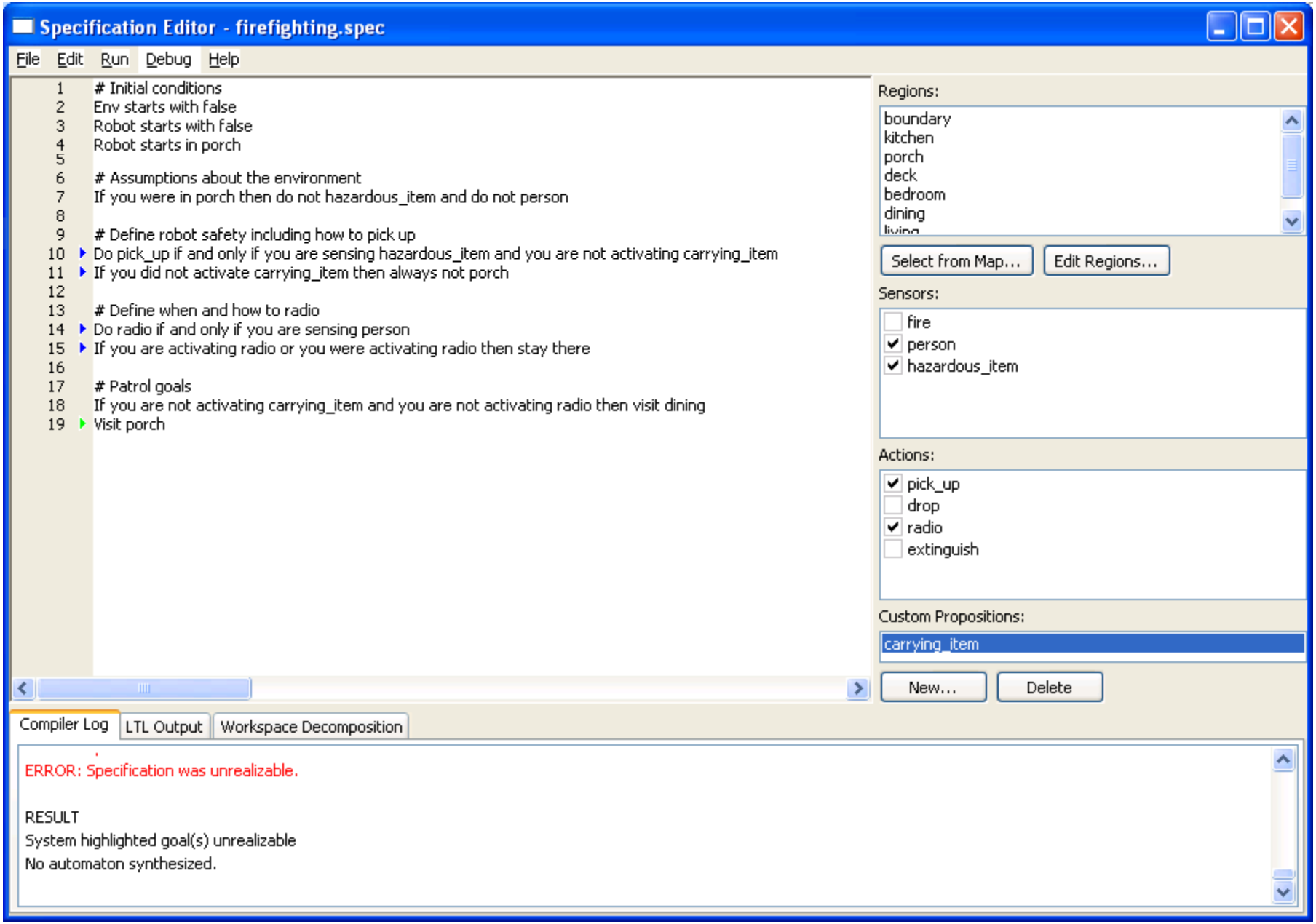
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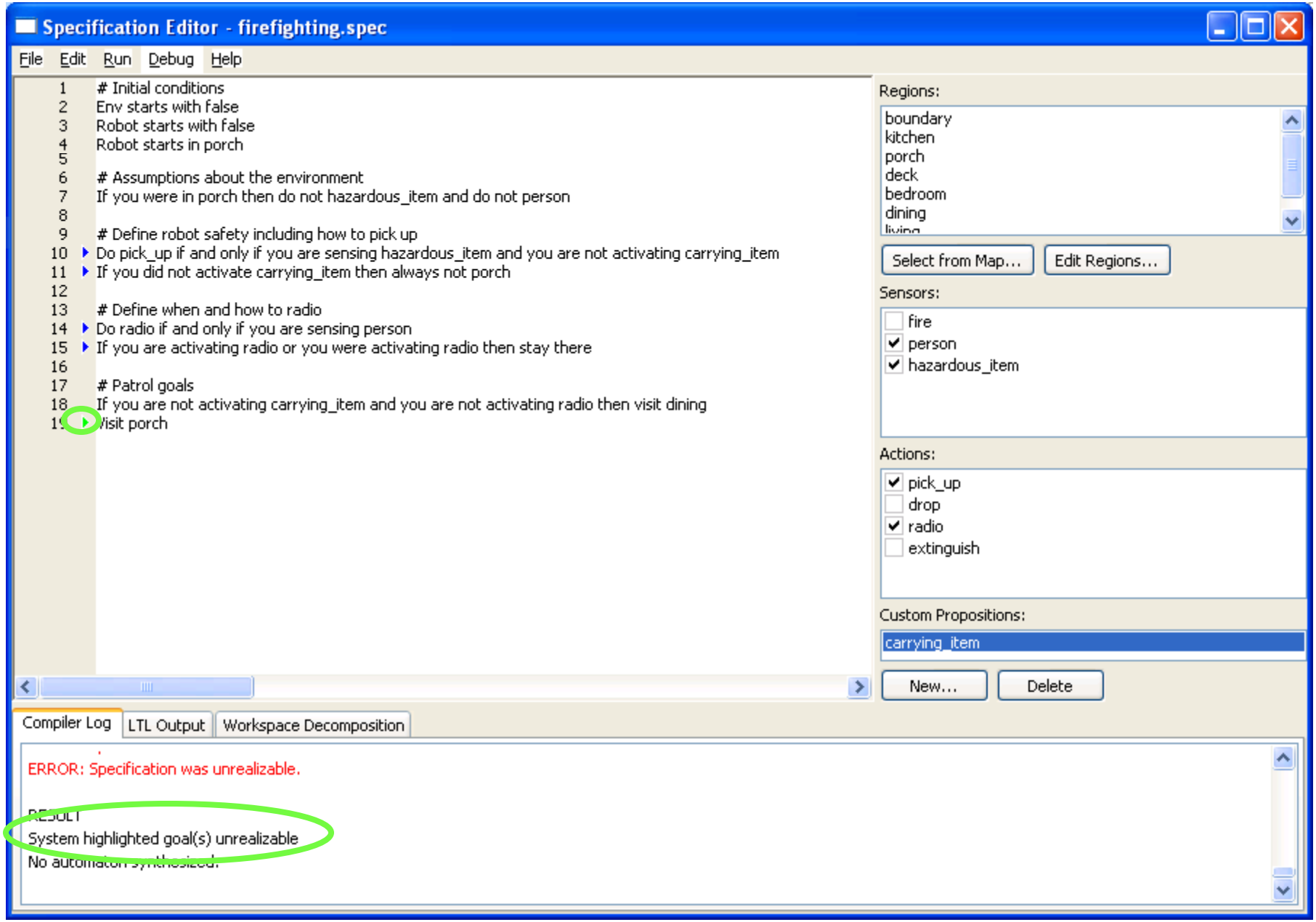
ERROR: Specification was unrealizable.
RESULT
System highlighted goal(s) unrealizable
No automaton synthesized.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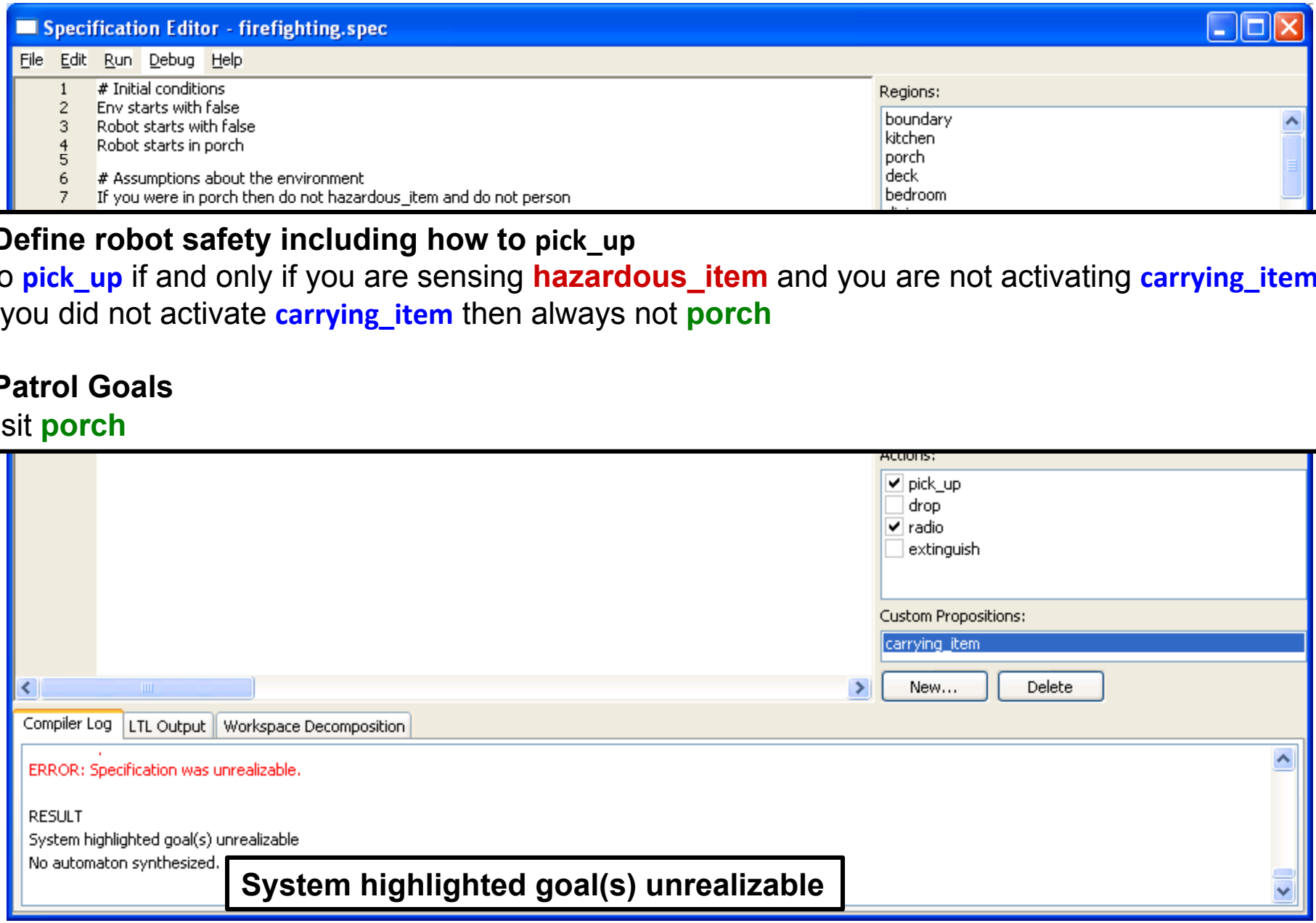
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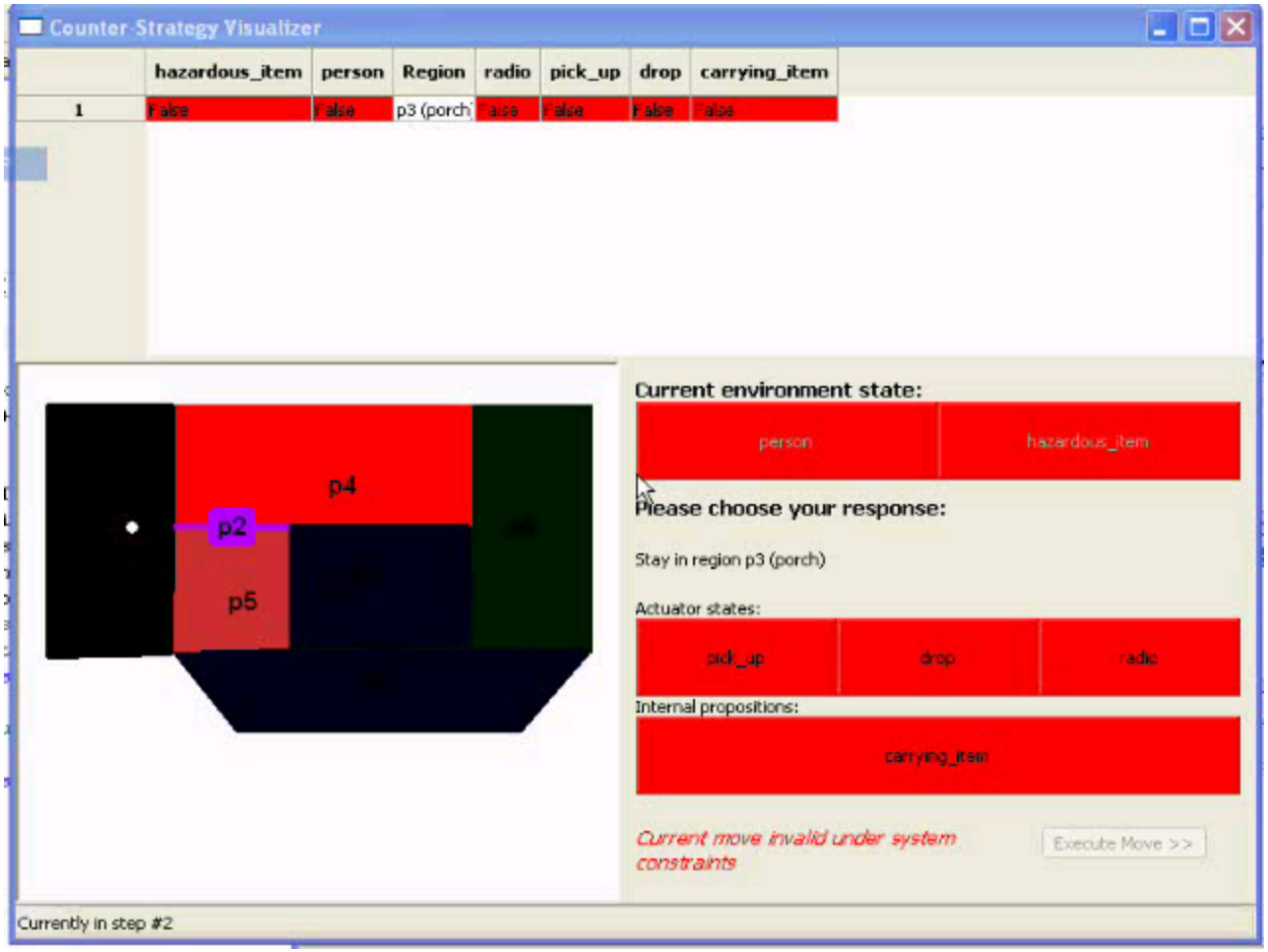
RESULT
System highlighted goal(s) unrealizable
No automaton synthesized.
System highlighted goal(s) unrealizable

Other Tools for Analysis

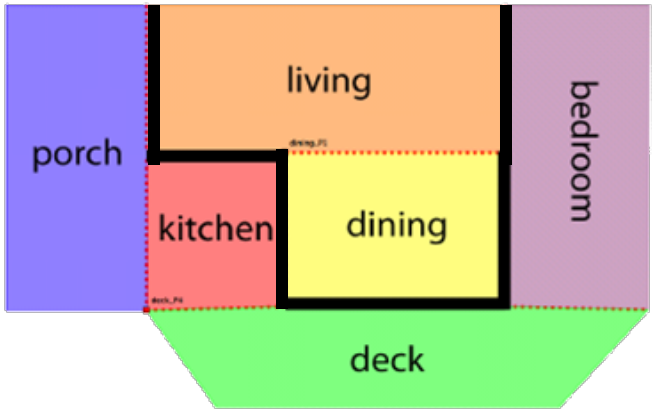
- Interactive game to help explain unrealizability
  - Let the user interact with an environment constructed to thwart the system.
  - Similar to RATSY[1], augmented with domain-specific interface.



[1] R.Bloem, A. Cimatti, K. Greimel, G. Hofferek, R. Könighofer, M. Roveri, V. Schuppan, R. Seeber: ***RATSY - A New Requirements Analysis Tool with Synthesis***. CAV 2010: 425-429

CURRENT AND FUTURE WORK

- Identifying domain-specific special cases of unsatisfiability
  - e.g. disconnected topology



- Further narrowing down the cause of unsynthesizability
  - Unsatisfiable/unrealizable cores

- Suggesting changes to the specification that would allow synthesis
  - Add environment assumptions
  - Weaken system requirements

[1] R.Bloem, A. Cimatti, K. Greimel, G. Hofferek, R. Könighofer, M. Roveri, V. Schuppan, R. Seeber: ***RATSY - A New Requirements Analysis Tool with Synthesis***. CAV 2010: 425-429

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REMINDER: Tool Demo Session
3:00-6:00pm

LTLMoP: https://github.com/LTLMoP
(GPL)