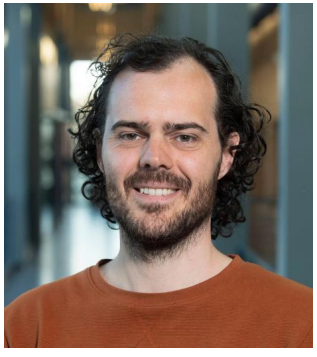
Shielded Reinforcement Learning for Hybrid Systems

Christian Schilling


joint work with Asger Horn Brorholt, Peter Gjøl Jensen,
Kim Guldstrand Larsen, and Florian Lorber

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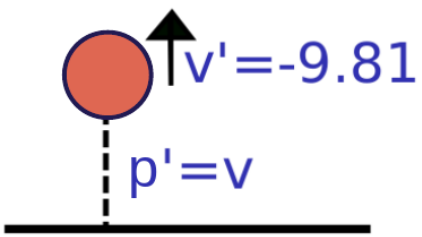
AALBORG UNIVERSITET

Overview

Overview

Control of physical systems

- Physical systems have complex dynamics
  - Continuous evolution
  - Discrete events
  - Stochastic uncertainty



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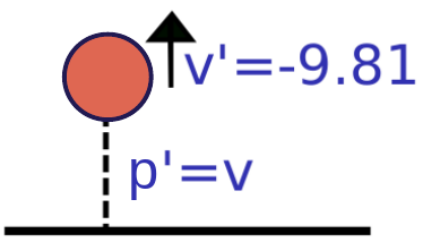

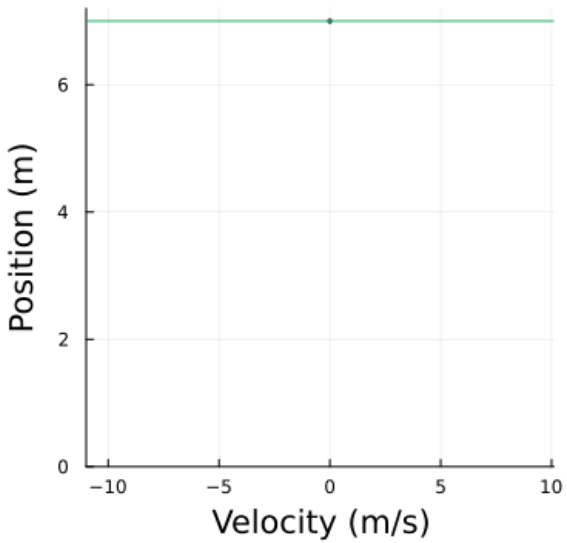

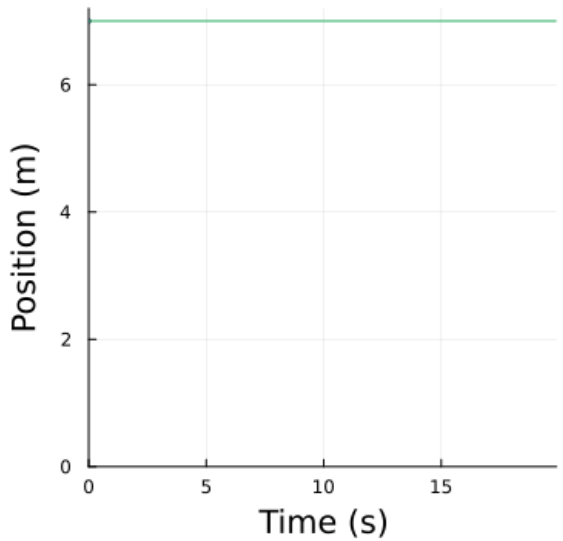

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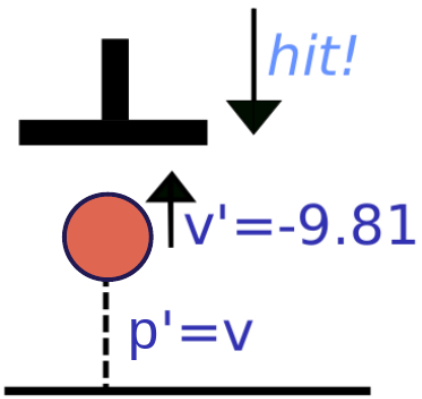

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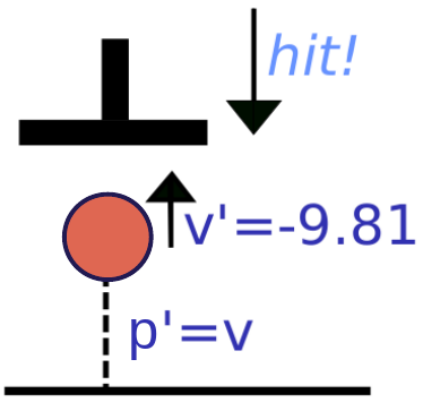
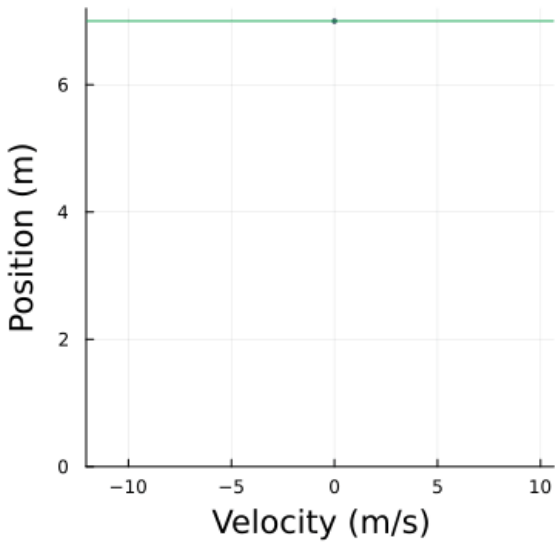
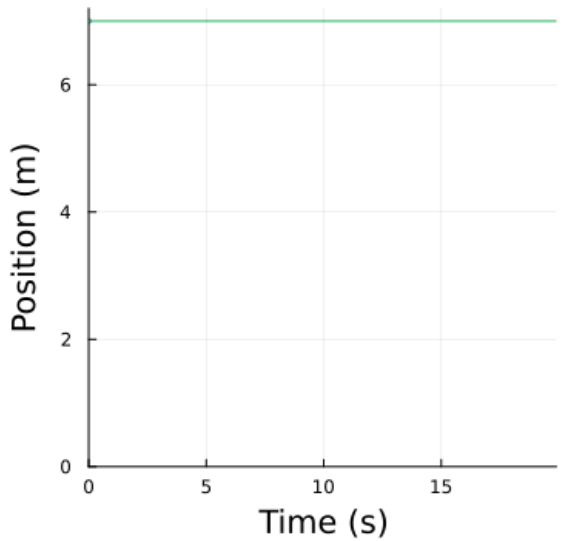
- **We want to control these systems subject to some optimality criterion, e.g., minimize number of hits**

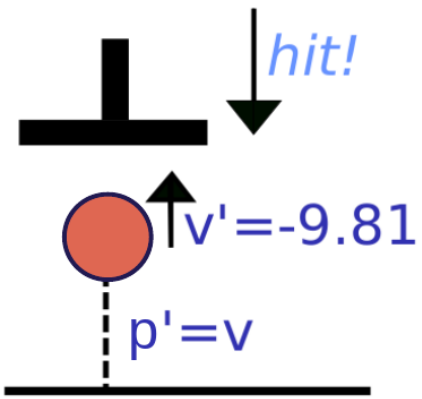
Control of physical systems







Control of physical systems



- Physical systems have complex dynamics
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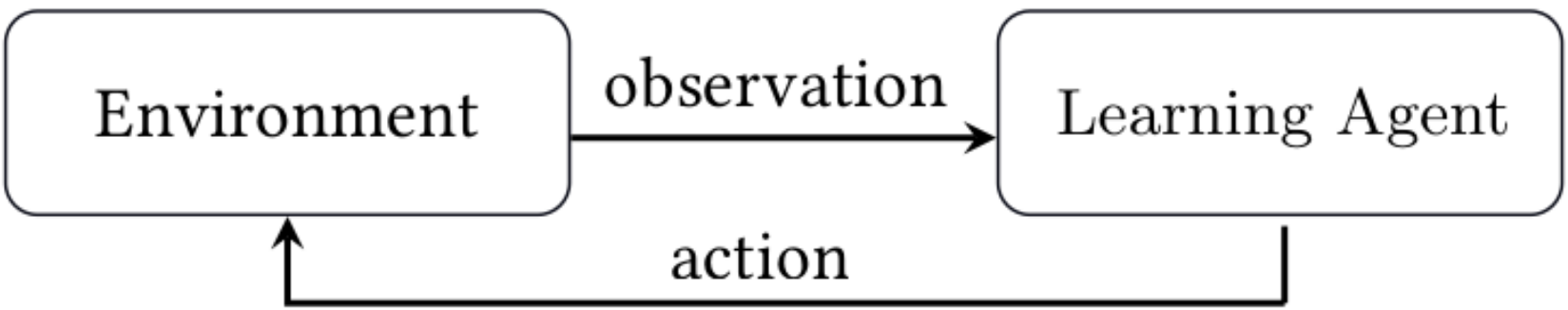
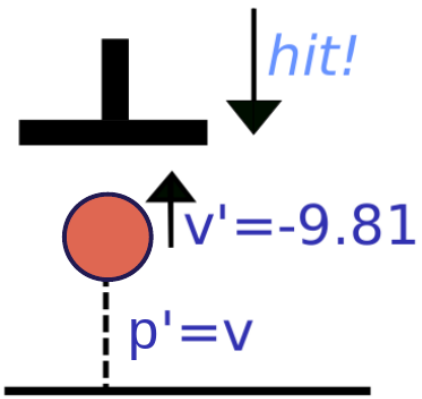
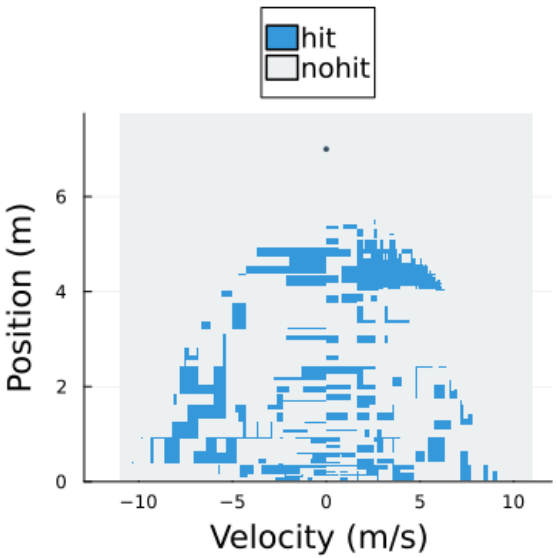
- **We can reinforcement-learn a controller, e.g., with Uppaal Stratego**

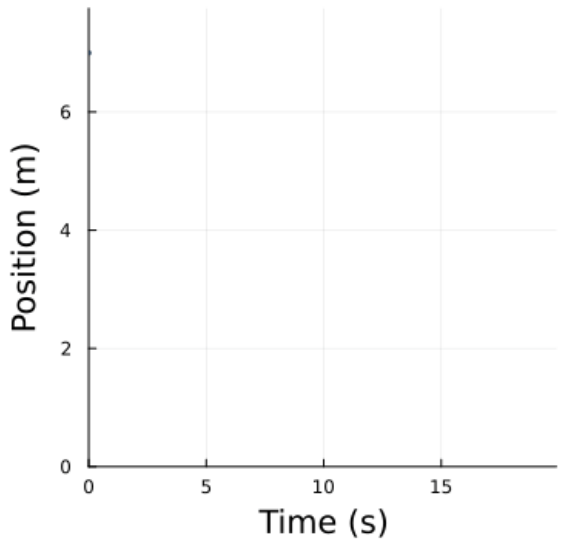
Reinforcement learning



Control of physical systems

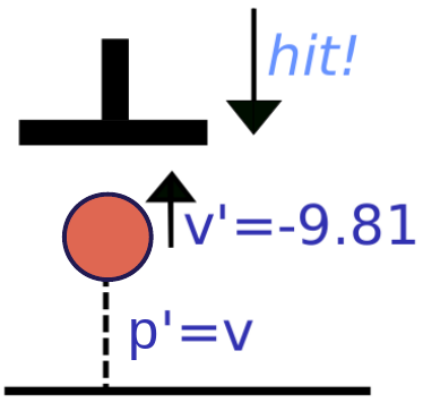






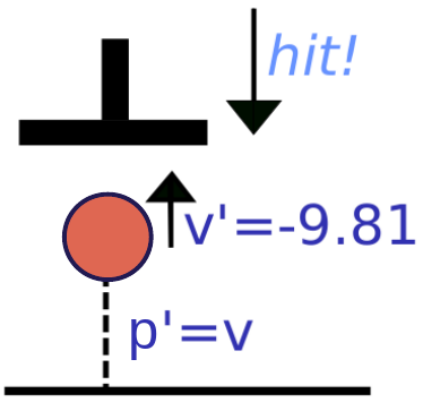
Trained for 12,000 episodes

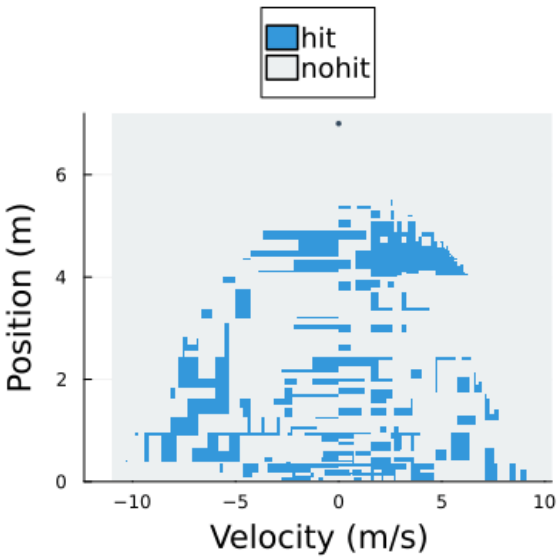
Control of physical systems

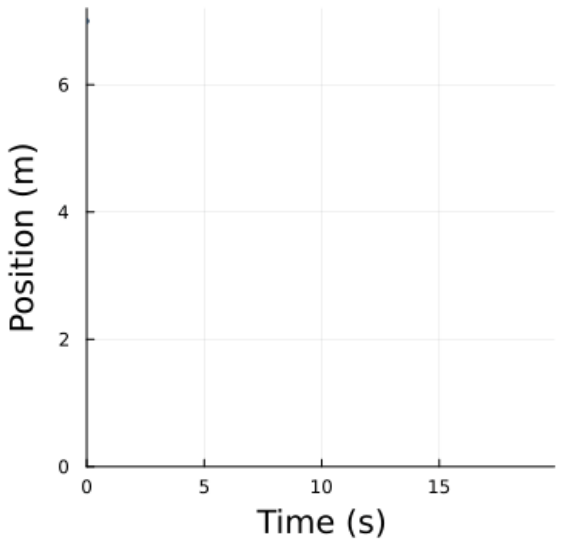


- Physical systems have complex dynamics
  - Continuous evolution
  - Discrete events
  - Stochastic uncertainty
- We want to control these systems subject to some optimality criterion,
  e.g., minimize number of hits
- We can reinforcement-learn a controller,
  e.g., with Uppaal Stratego
- **We also have safety constraints,**
  e.g., $p = 0 \implies |v| > 1$

Control of physical systems



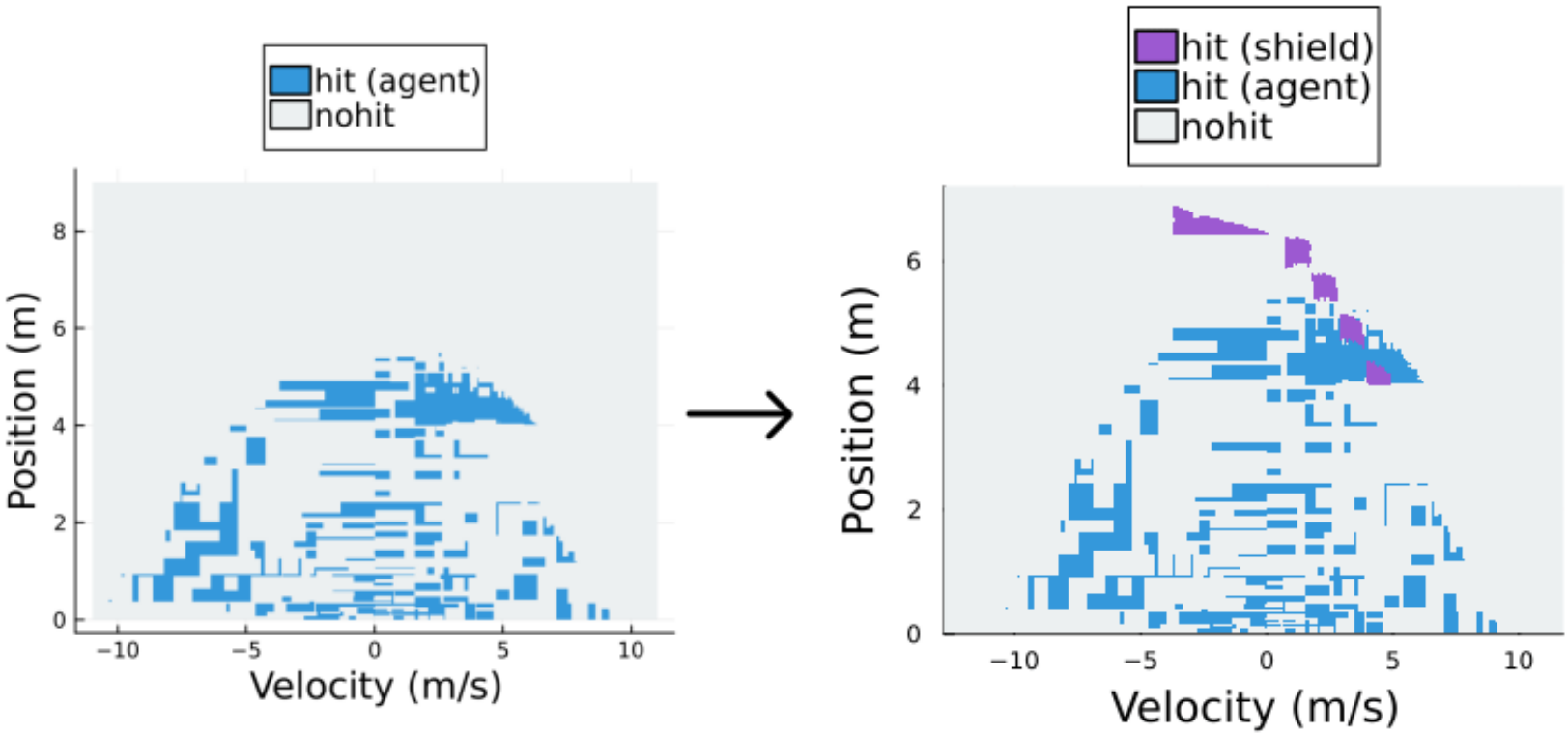




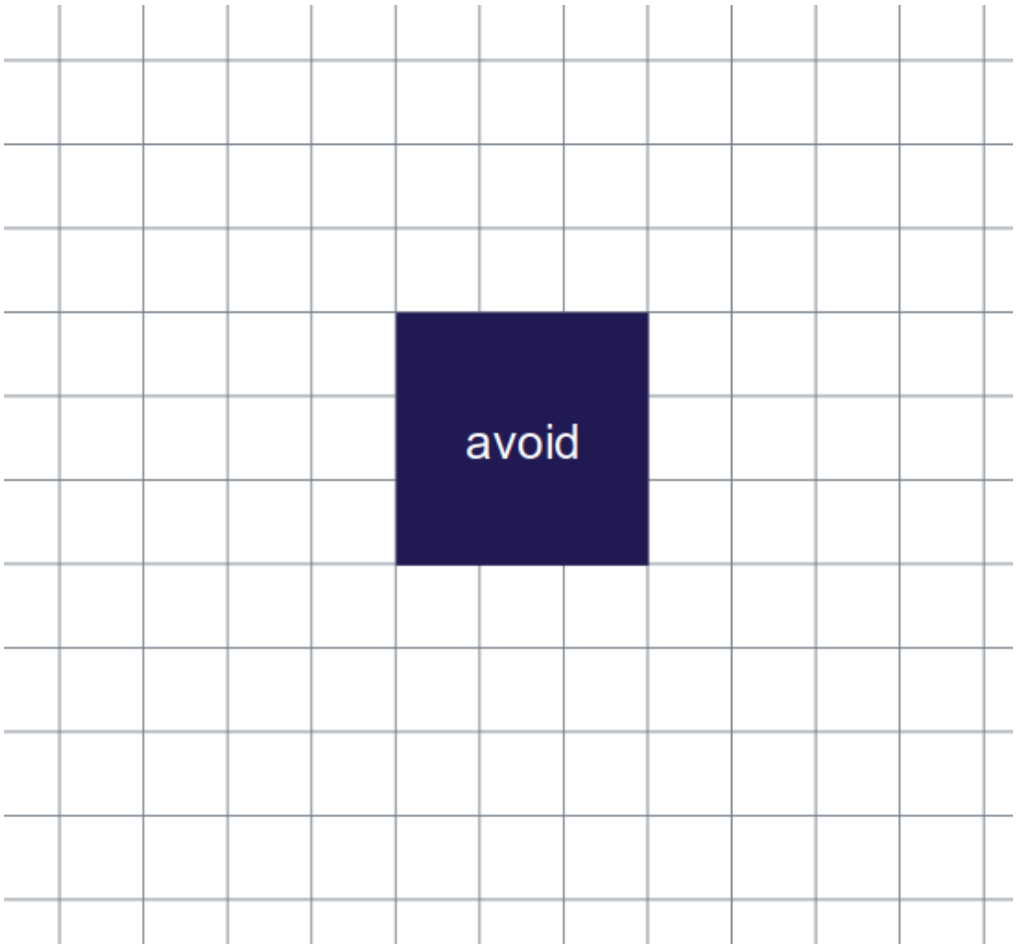
2 % of executions unsafe

Overview

Shielding

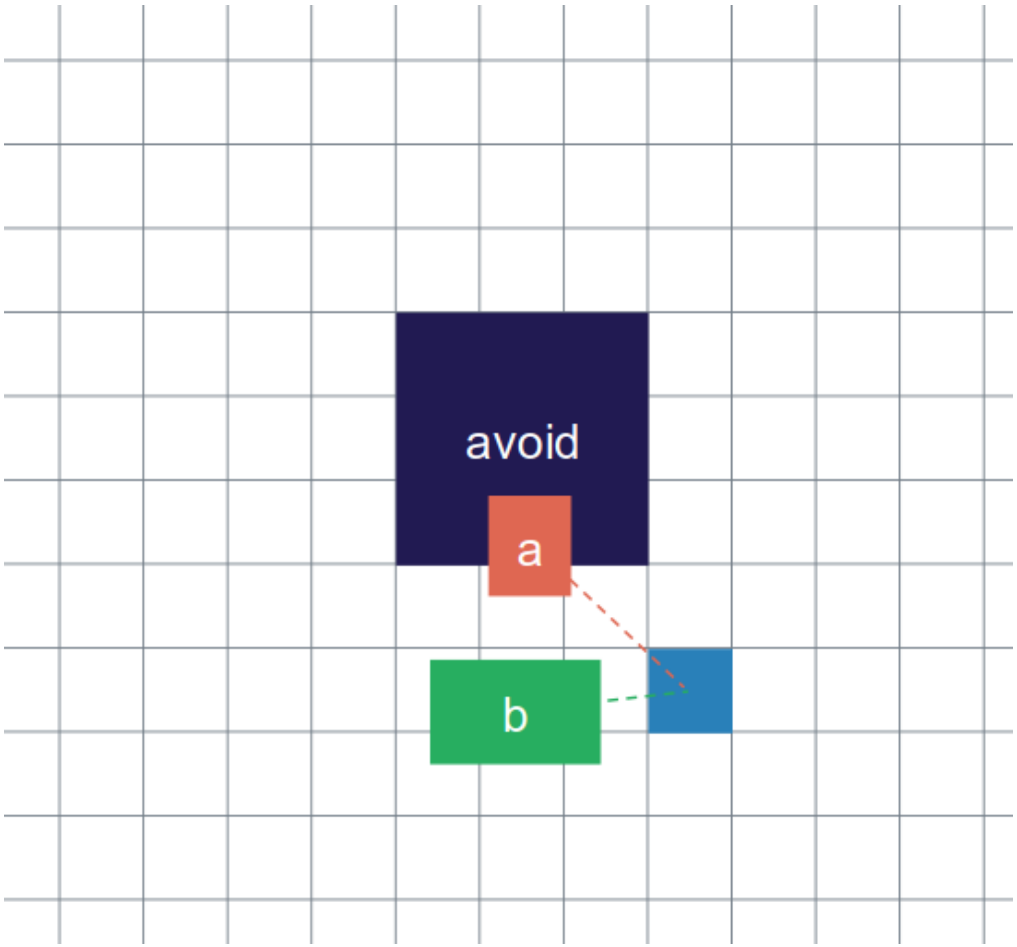

hit (agent)
nohit
Position (m)
Velocity (m/s)
hit (shield)
hit (agent)
nohit
Position (m)
Velocity (m/s)

State-space partitioning and two-player game



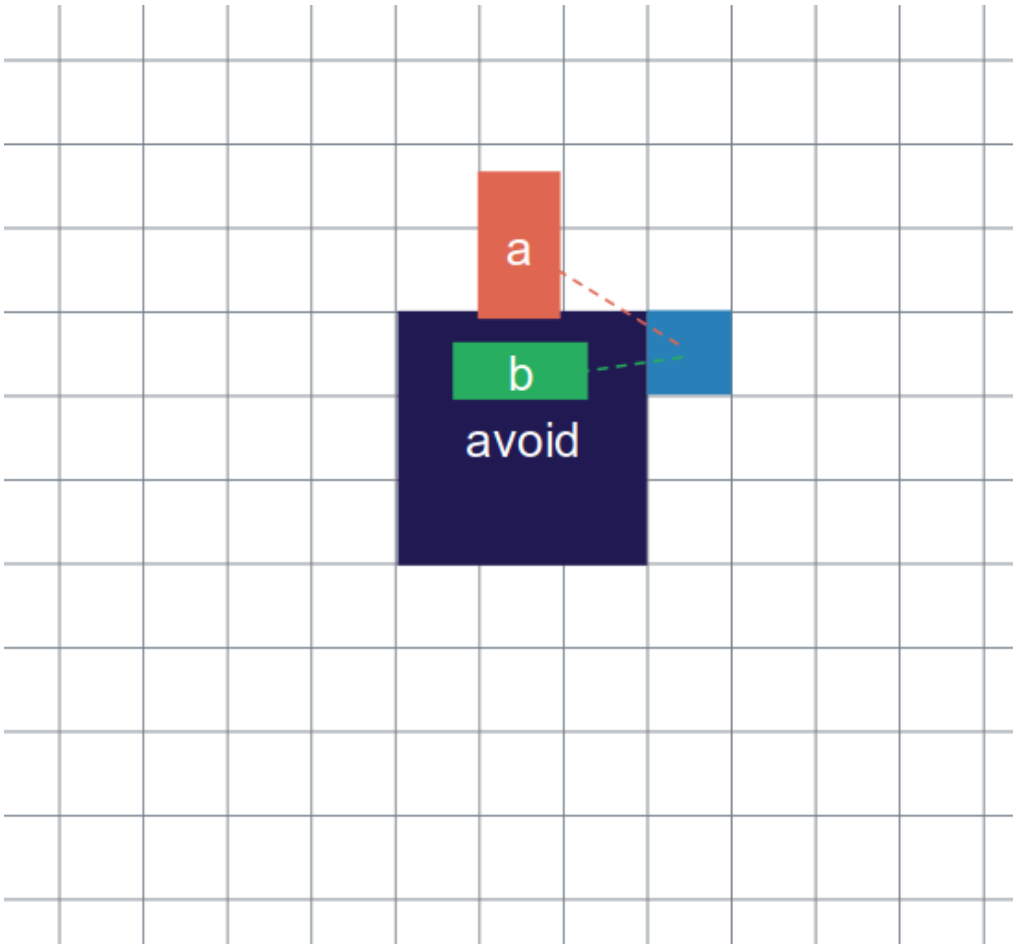
- For each block, compute the successor states under each action

State-space partitioning and two-player game



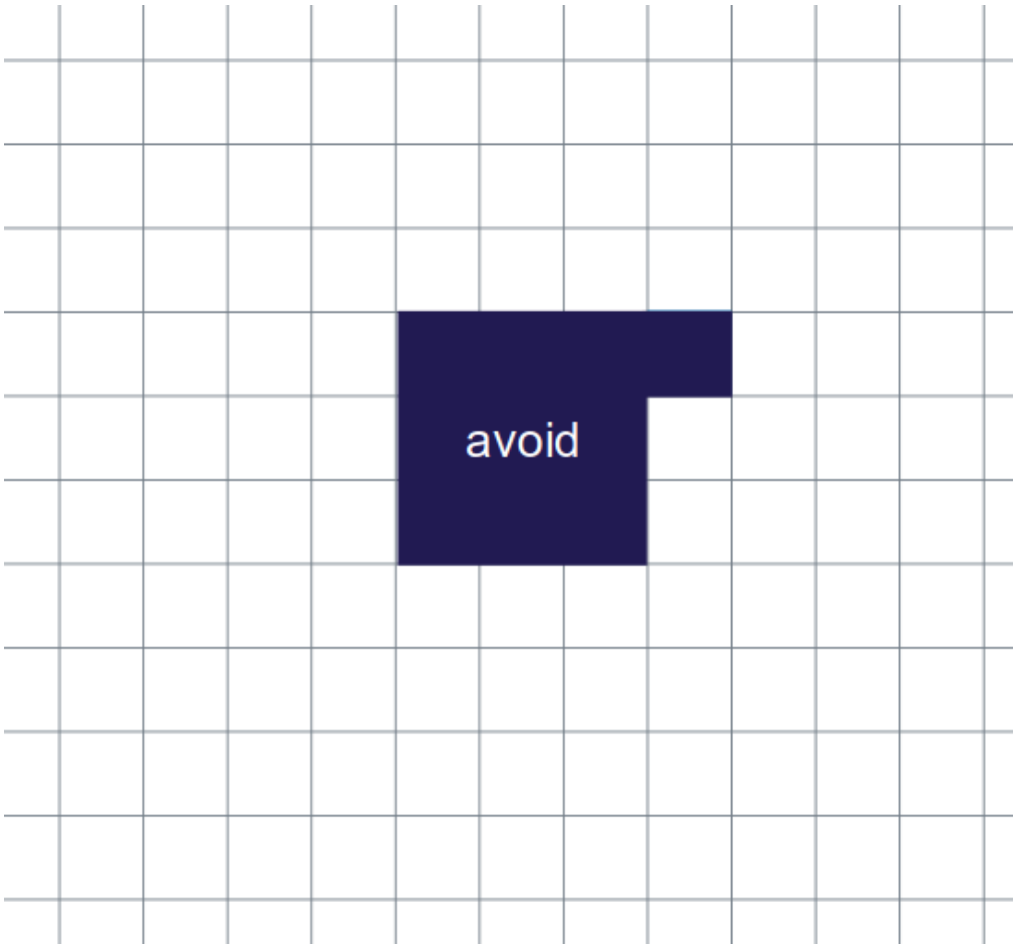
- For each block, compute the successor states under each action
- Eliminate actions that reach the avoid set

State-space partitioning and two-player game



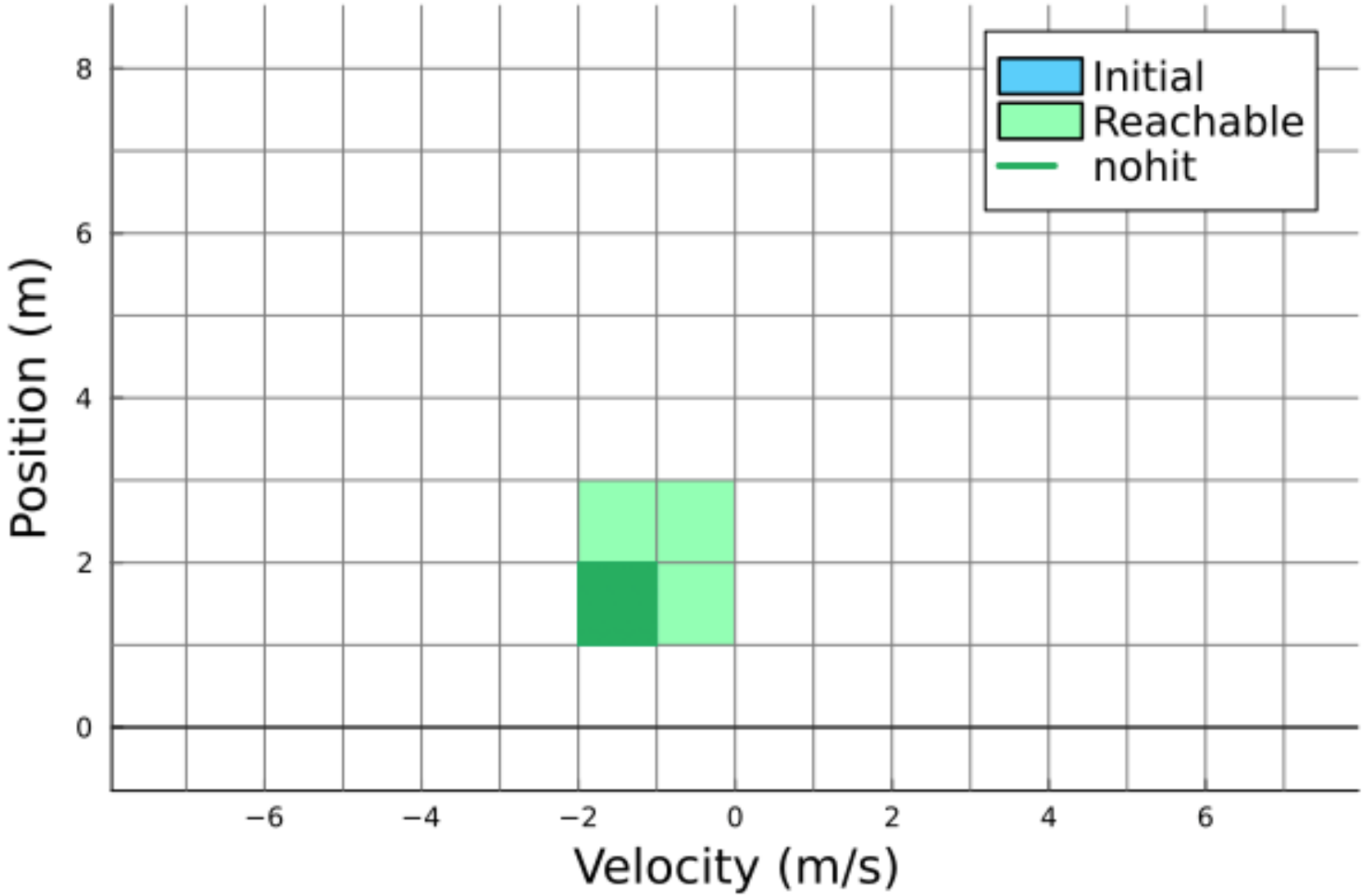
- For each block, compute the successor states under each action
- Eliminate actions that reach the avoid set
- If no action is safe,

State-space partitioning and two-player game

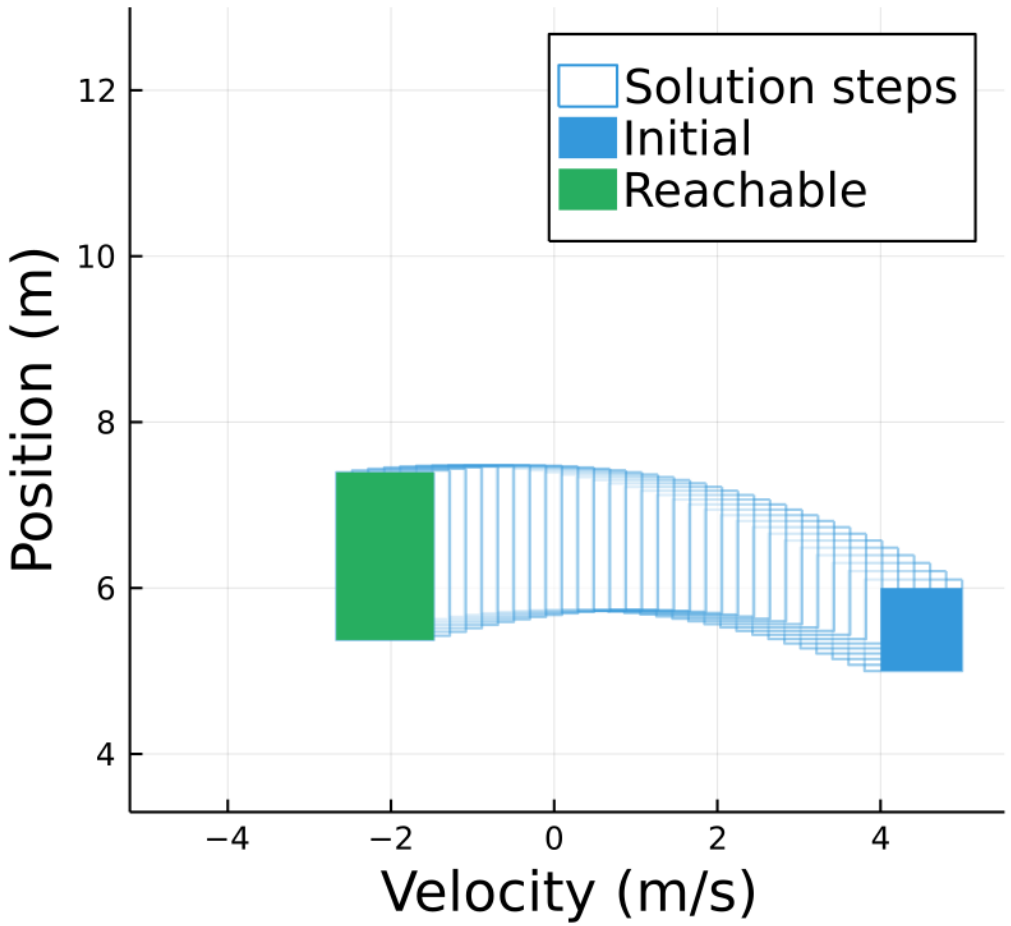


- For each block, compute the successor states under each action
- Eliminate actions that reach the avoid set
- If no action is safe, add the block to the avoid set

How to compute reachable blocks for complex systems?

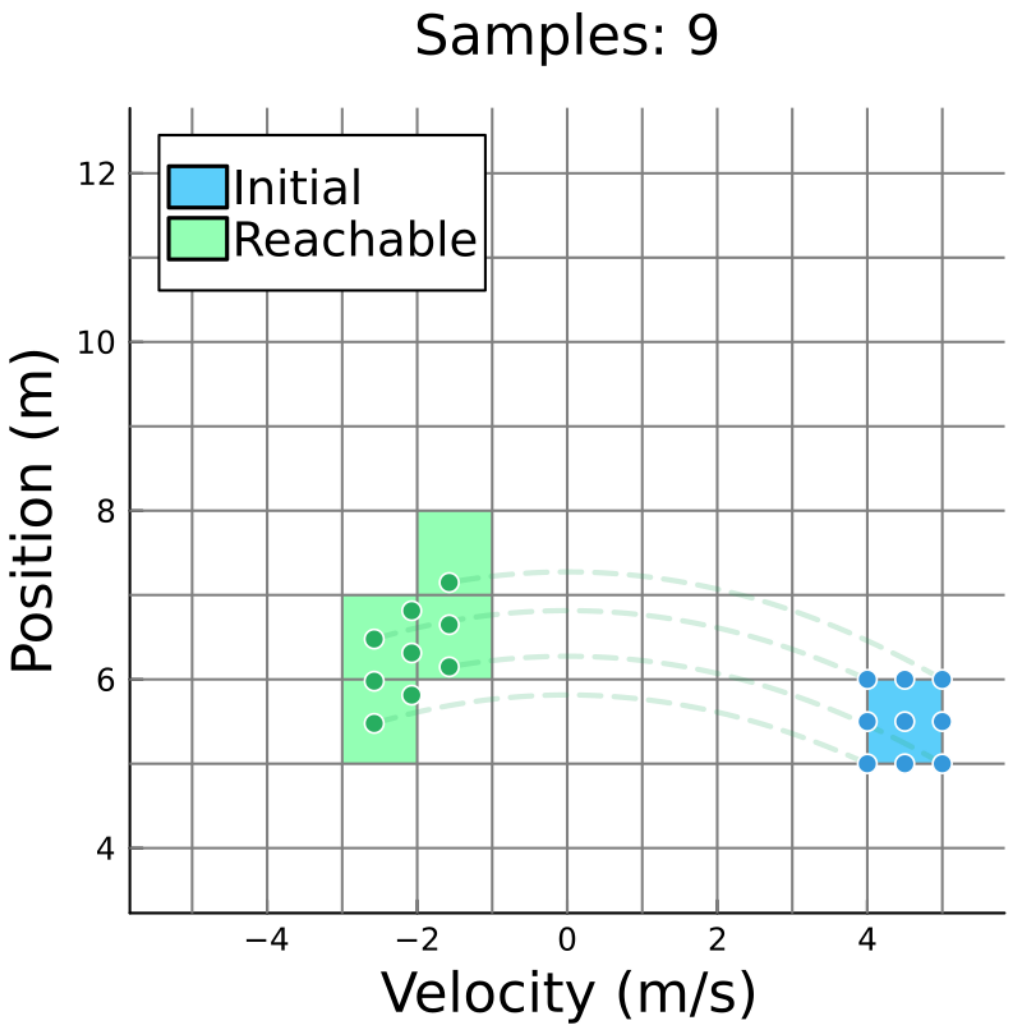


Computation via reachability method (here: JuliaReach)



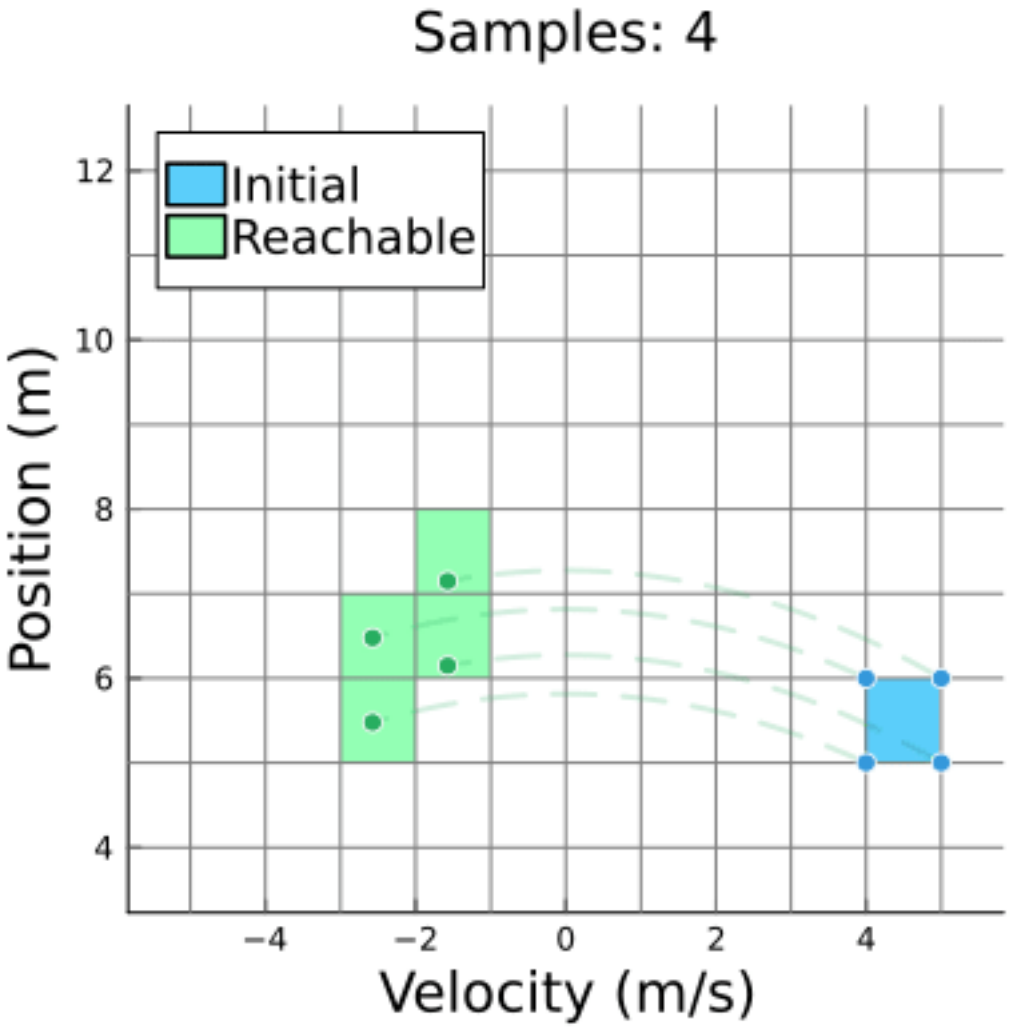
- Sound result
- Expensive

Computation via simulation-based method



- Cheap
- May miss behavior
- Accuracy improves with more samples

Computation via simulation-based method



- Cheap
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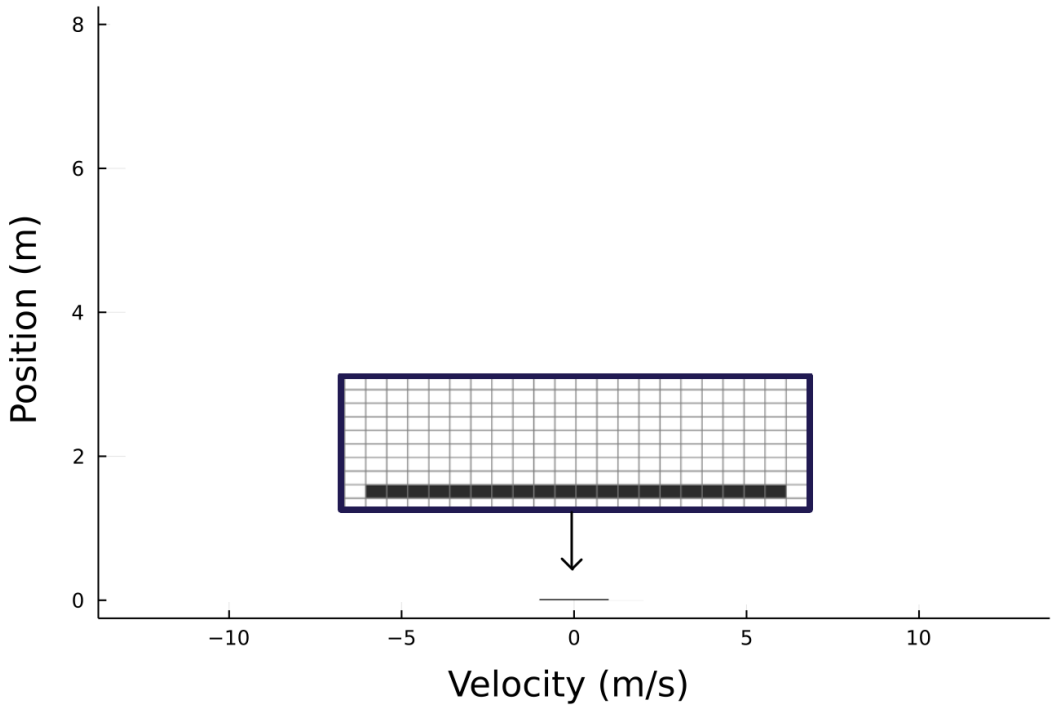
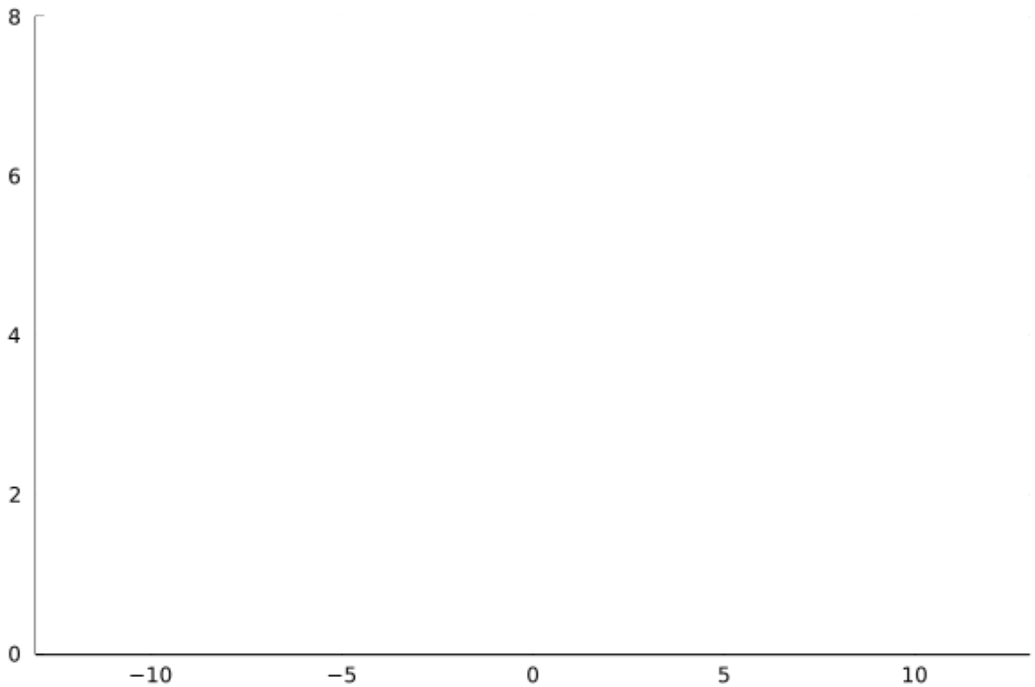
Synthesis algorithm in action



- 16 samples per block
- Grid size 0.02
- Synthesis: 134 sec

Synthesis algorithm in action



- 16 samples per block
- Grid size 0.02
- Synthesis: 134 sec

Overview

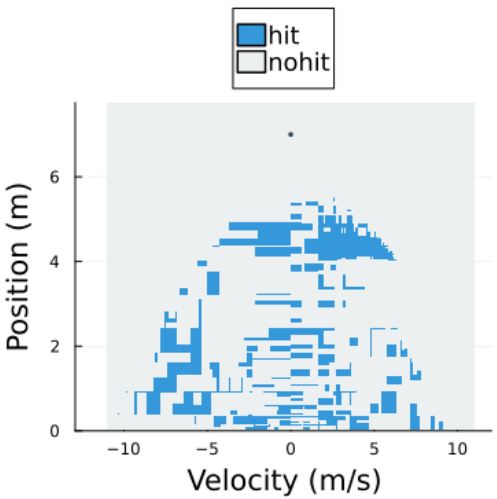
Scalability

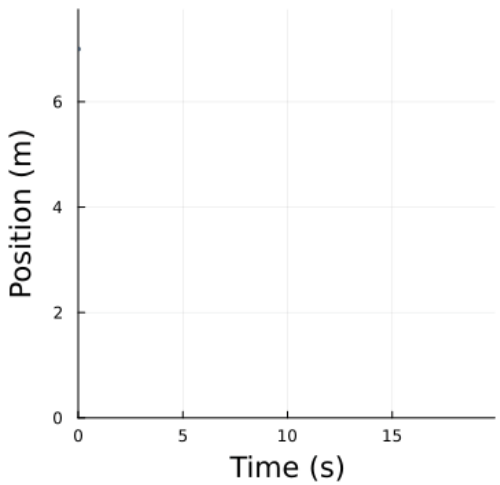
Grid size	Samples	Time
0.02	4	2m 14s
0.02	8	4m 02s
0.02	16	11m 03s
0.01	4	19m 00s
0.01	8	27m 21s
0.01	16	56m 32s

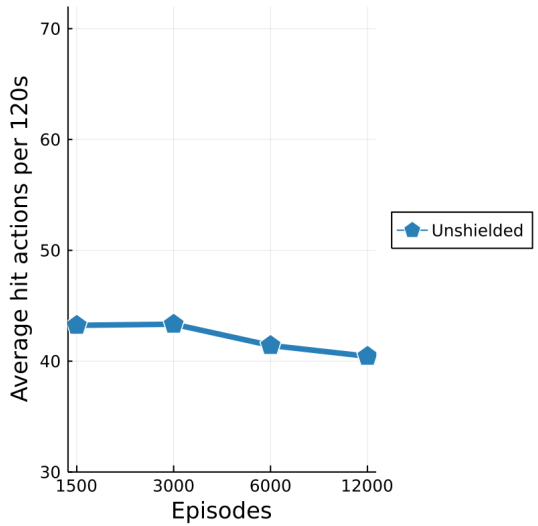
Grid size	Time
0.01	41h 05m

- Statistically safe ($\geq 99.99\,\%$ with confidence $99\,\%$)

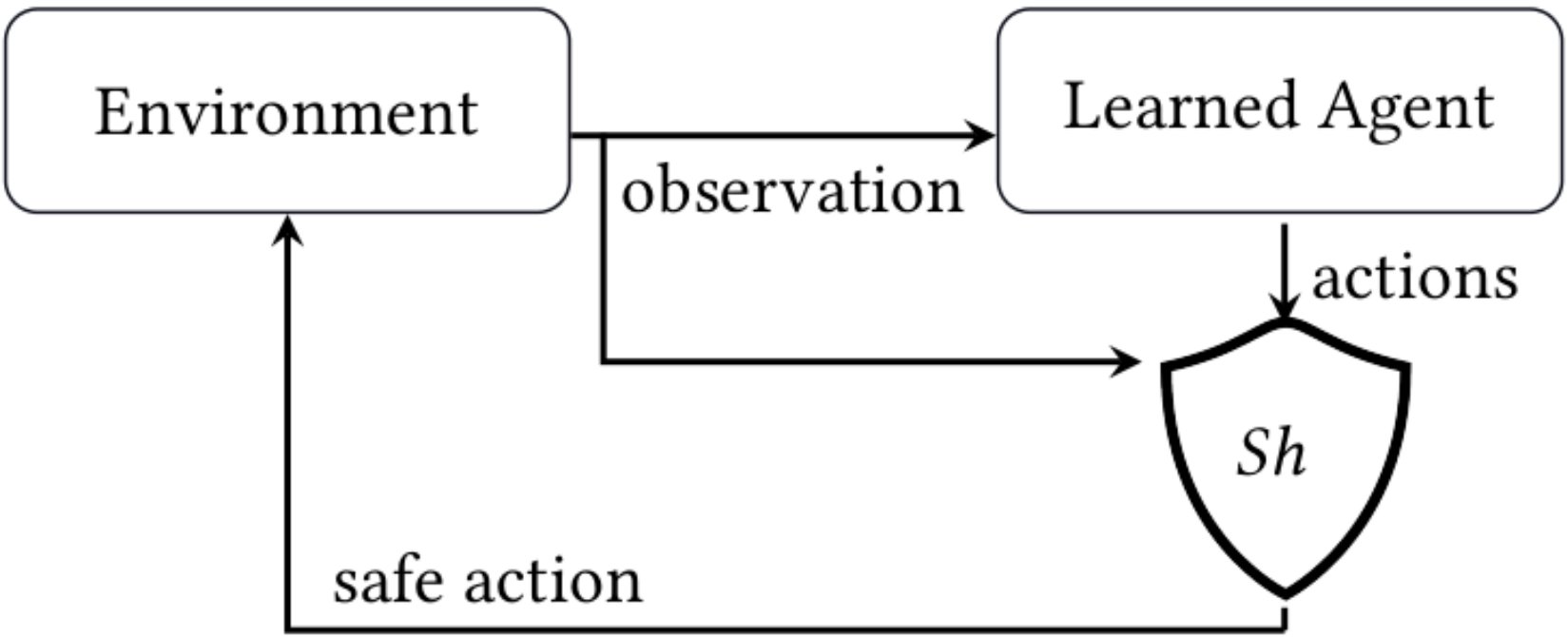
Unshielded agent







Post-shielded agent



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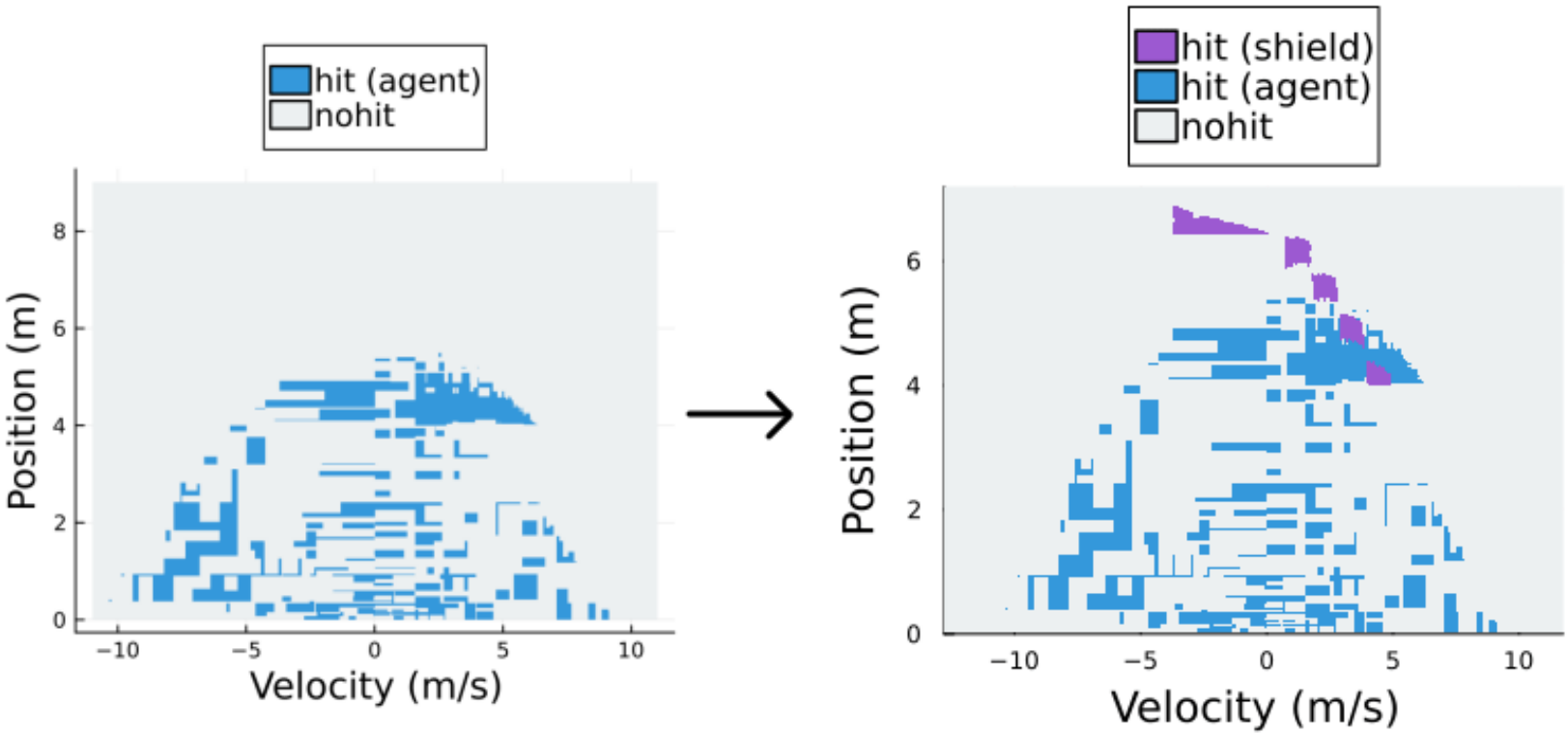

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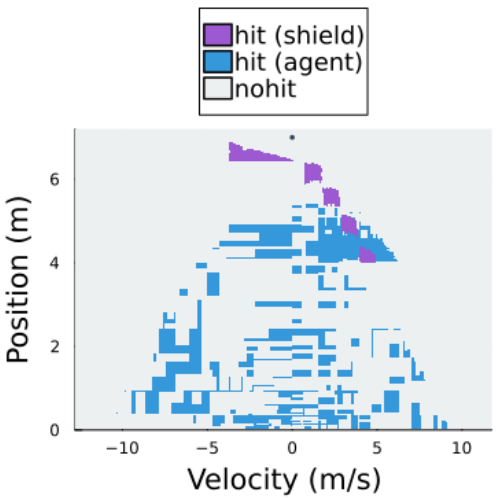
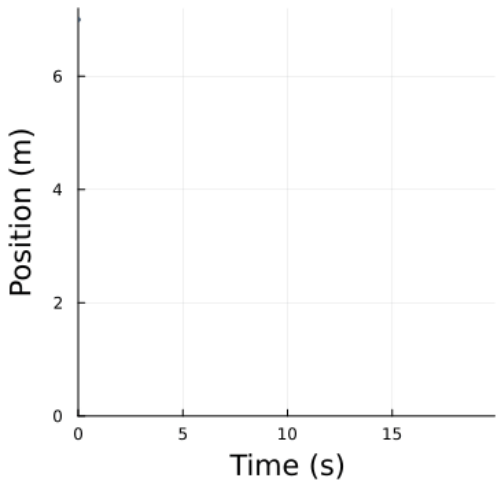
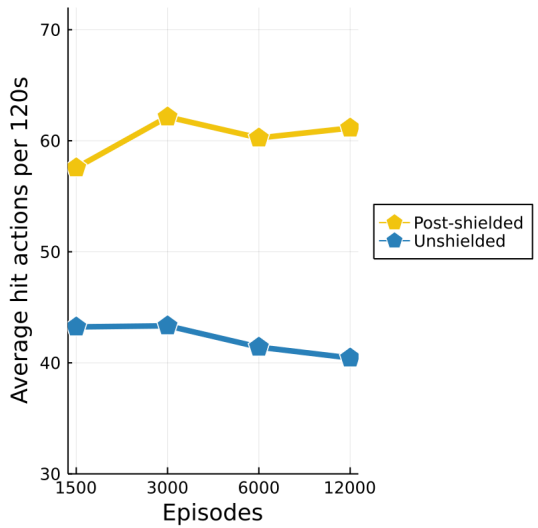
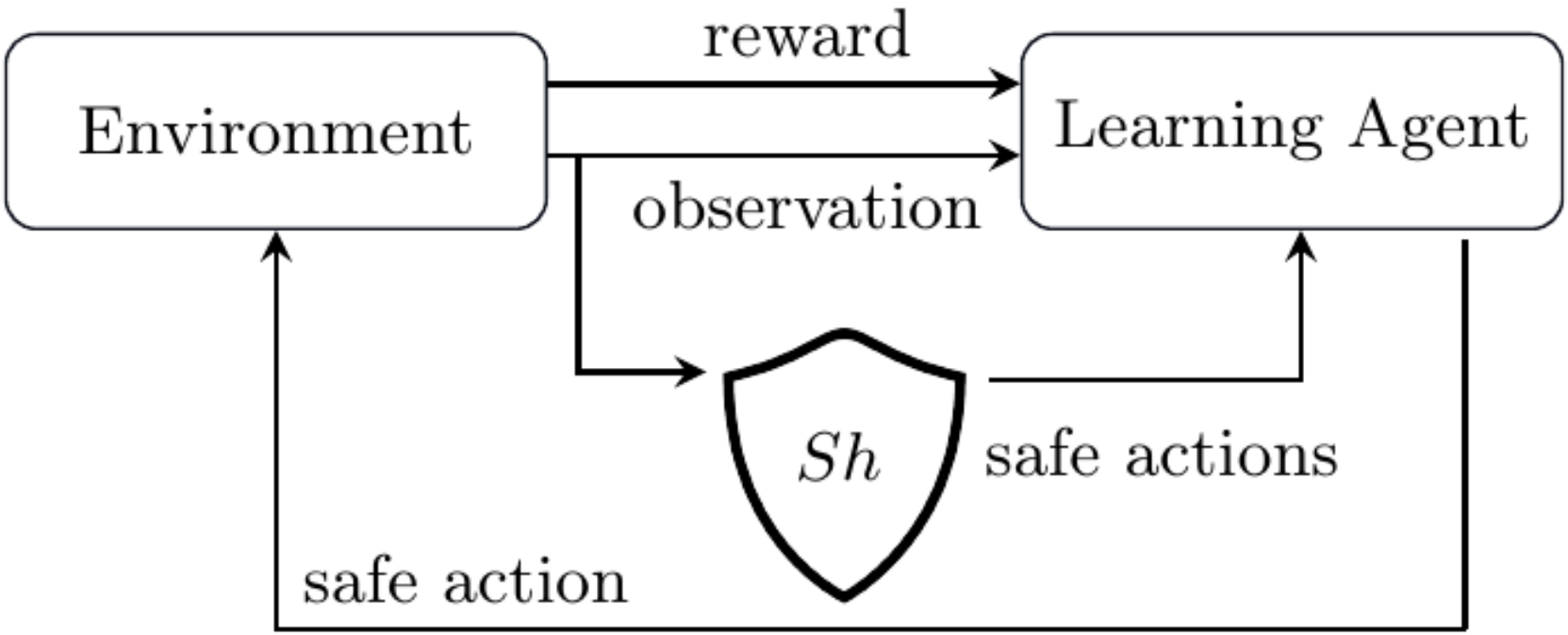


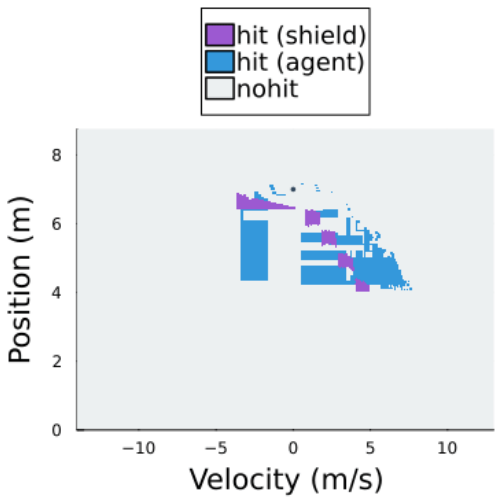


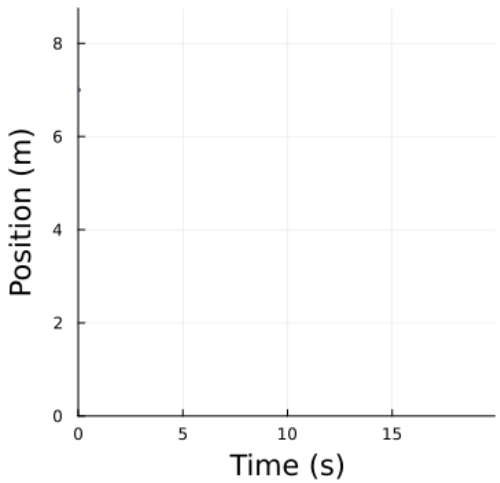


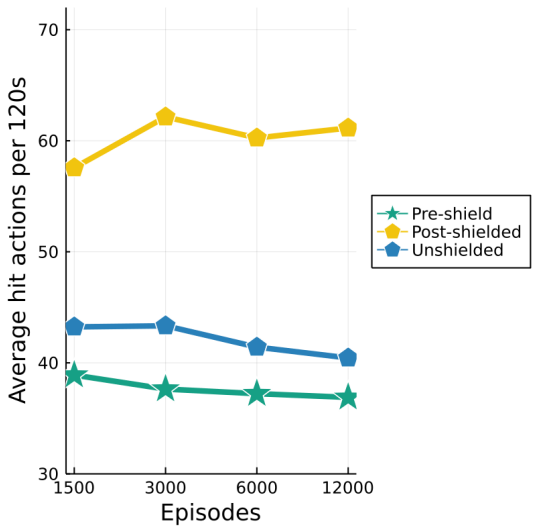
Pre-shielded agent



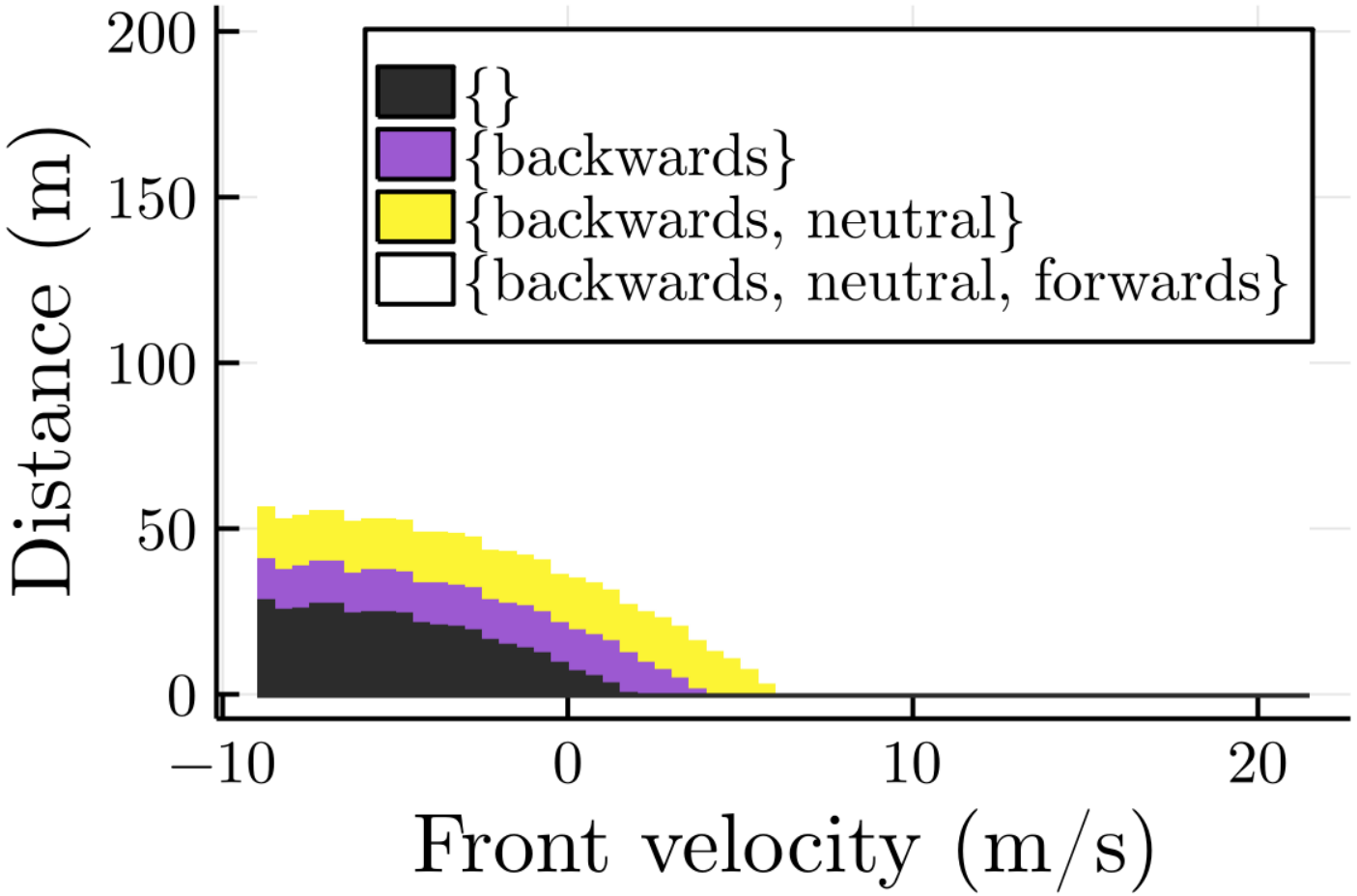
Pre-shielded agent





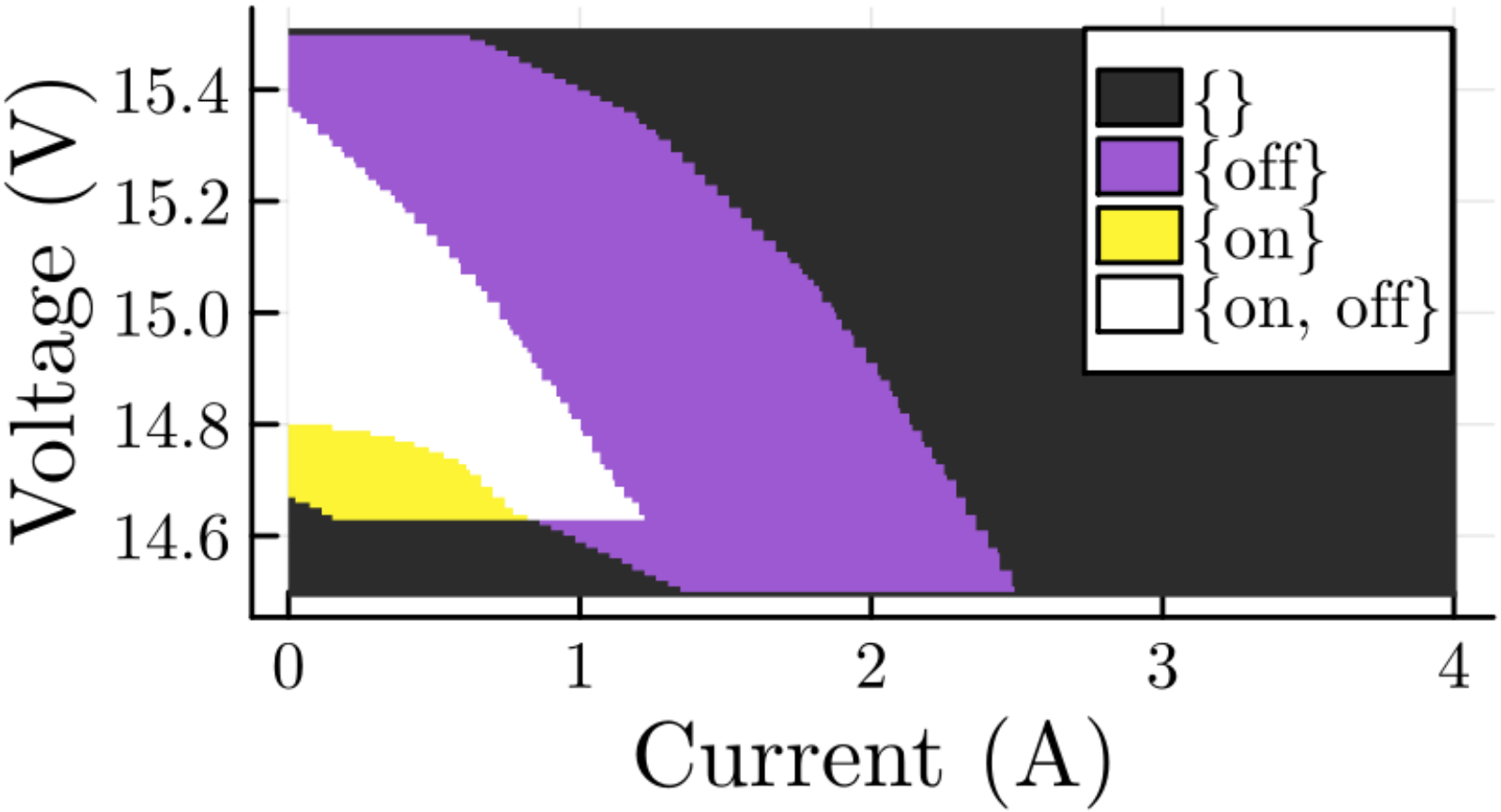


Cruise control (car behind another car)



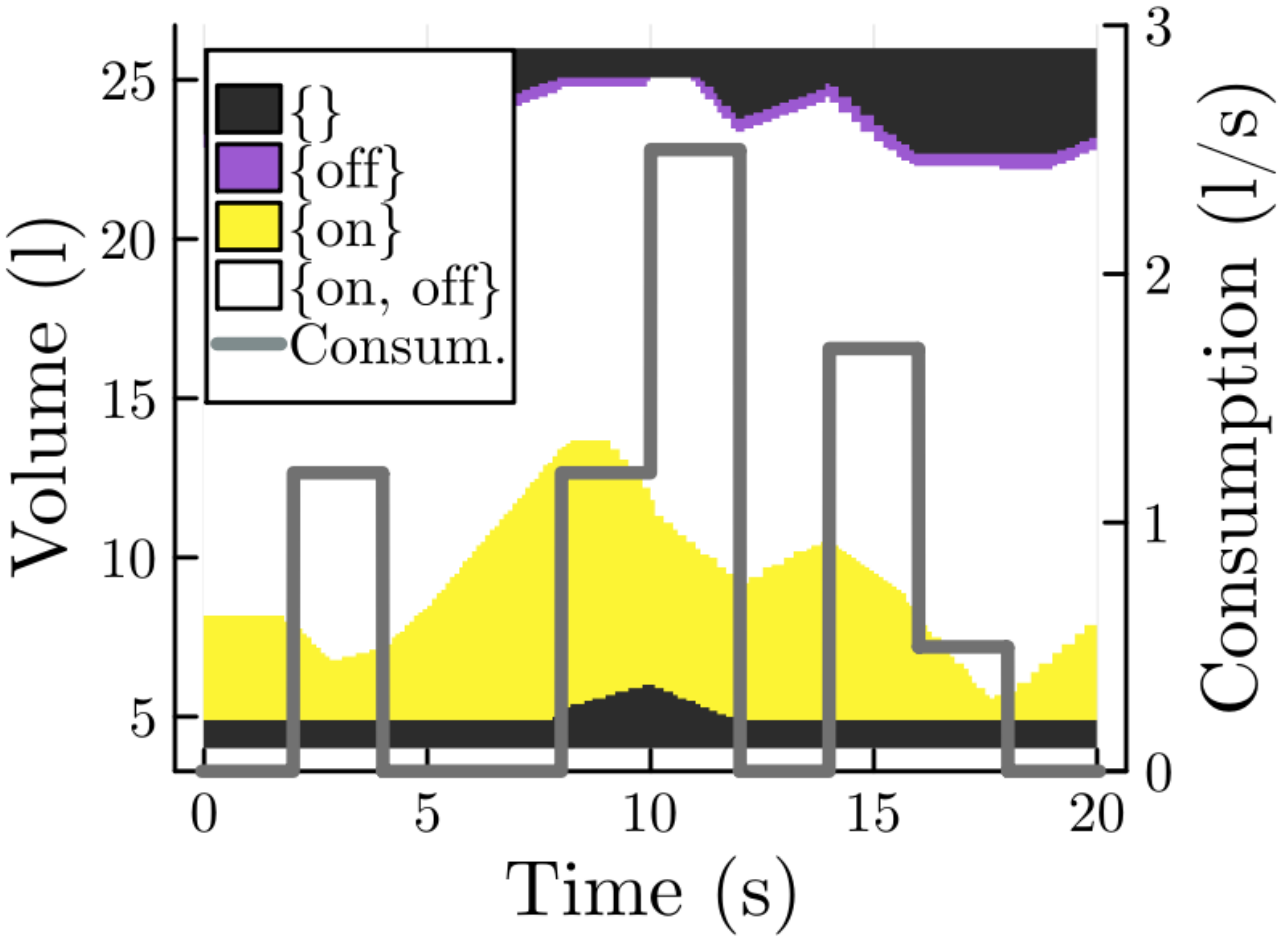
Synthesis time: 36 min

DC-to-DC boost converter



Synthesis time: 1 h 19 min

Oil pump (here: strategy when pump is *on*)



Synthesis time: 5 h 23 min

Overview

Conclusion

- Shield synthesis for complex (continuous + discrete + stochastic) systems
- Key idea: replace undecidable step (reachability) by simulation
- No soundness guarantee, but statistically safe

Future work

- Multiple steps for more permissive shield
- Dynamic partitioning
- Combine with symbolic approach