Layered controller synthesis for dynamic multi-agent systems

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October 9 2023

Introduction

Dynamic multi-agent system's verification

Our objectives

- A running example

https://perso.eleves.ens-rennes.fr/people/Emily.Clement/Videos/example_episodes/ex_0.mp4

	Timed Automata	Reinforcement Learning
Model	Abstract representation (acceleration)	
Waekness	Time of execution	Combinatorial or Continuous aspects

- Our assumptions
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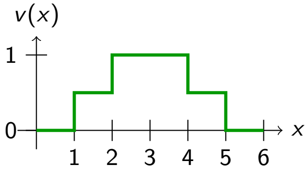
  - **Speed:** 

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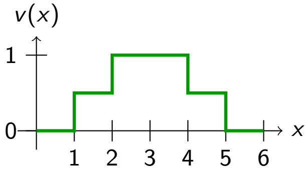
  - ▷ **Speed:** 

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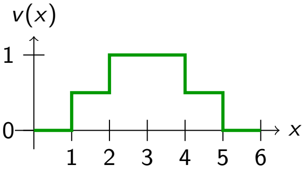
  - **Speed:** 

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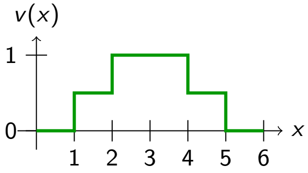

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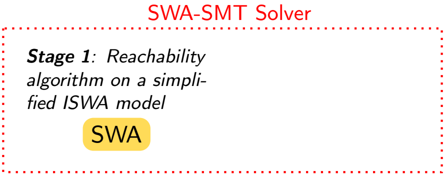

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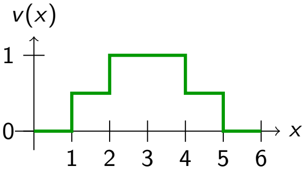

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SWA-SMT Solver

Stage 1: *Reachability algorithm on a simplified ISWA model*

SWA

Stage 2: *Refine the model of the speed*

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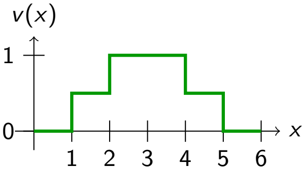
  - **Speed:** 

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SWA

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SMT

RL training

Generate *a dataset for random initial positions*

Dataset

Stage 3: *Train an RL algorithm with our dasaset*

RL

SWA-SMT solver

SWA solver

Stage 1: Reachability algorithm on system of ISWA

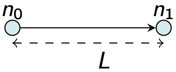
SWA

***Stage 2**: Model the accelleration and deceleration*

SMT

Model for a car traffic

- A point in $\mathbb{R}^2$: a node 

- A section $s_{[n_0, n_1], L}$ of the road: 

Model for a car traffic

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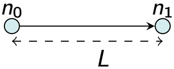

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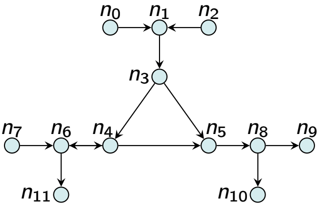


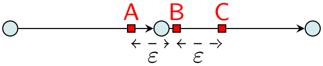
$p_0 : n_0 \rightarrow n_1 \rightarrow n_3 \rightarrow n_4 \rightarrow n_6 \rightarrow n_{11}$

$p_1 : n_2 \rightarrow n_1 \rightarrow n_3 \rightarrow n_5 \rightarrow n_8 \rightarrow n_{10}$

$p_2 : n_7 \rightarrow n_6 \rightarrow n_4 \rightarrow n_5 \rightarrow n_8 \rightarrow n_9$

Rules to model collision avoidance

- #1: security distance when driving in the same direction and between neighbouring sections



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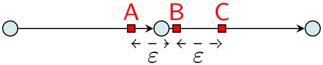

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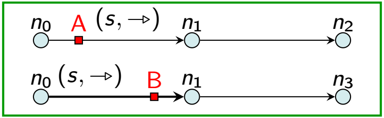

✓

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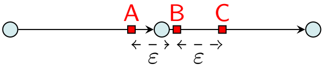

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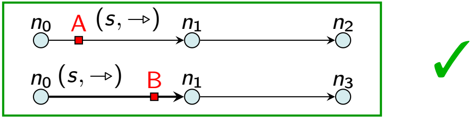

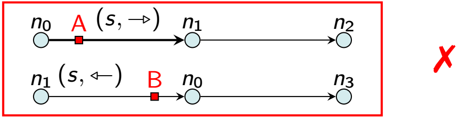

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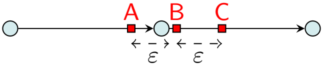

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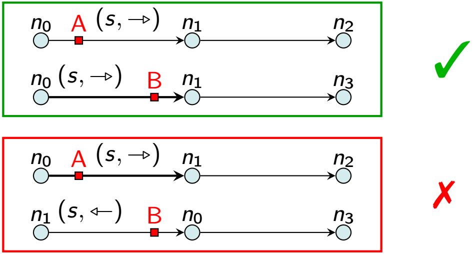

- #3: No Overtaking between cars

What type of Timed Automata to use to model this?

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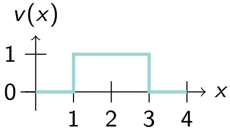

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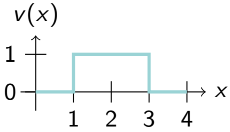
  - ▷ **Stopwatch Timed Automata**: 

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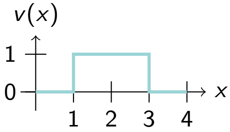
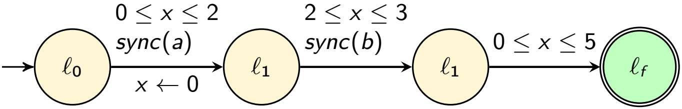
  - **Stopwatch Timed Automata**: 

  - **Synchronised action**: Compute distance between each cars.
  - **FiFo channels**: A car cannot overtake another car.

- A classic timed automaton



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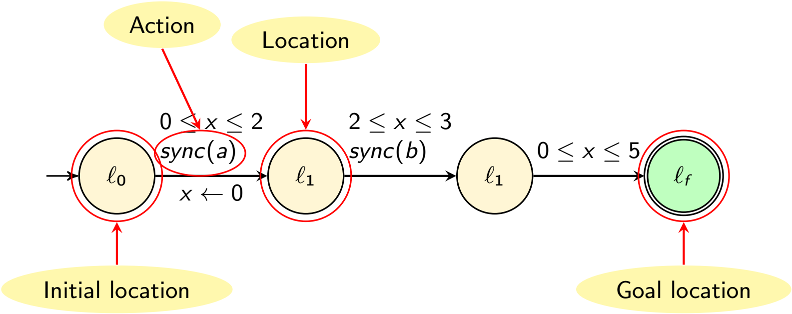

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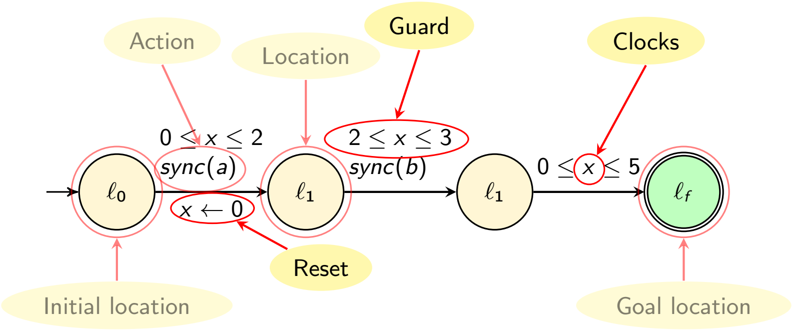

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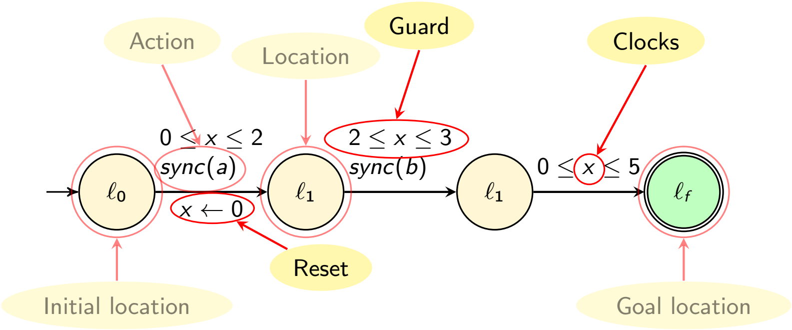

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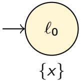
  - ▷ Stopwatch  : clock x is stopped in location ℓ_0.

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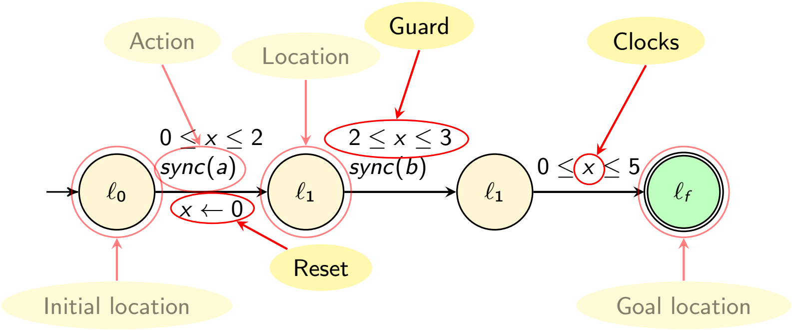

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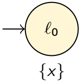
  - ▷ Stopwatch 

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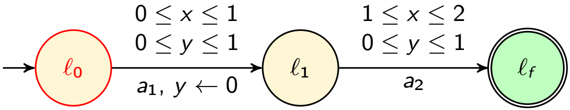
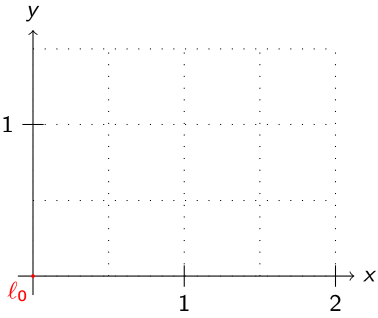
  - ▷ Channels: FiFo queue of symbols (actions) to be pushed/read

A run of a timed automaton

- A run of a two-clock Timed Automaton





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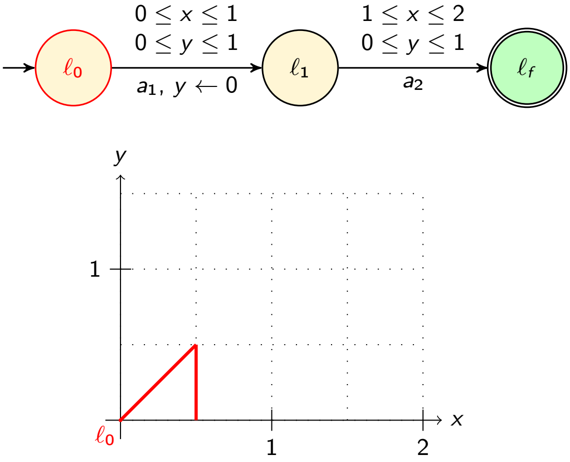

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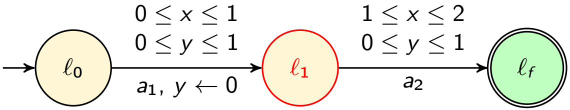

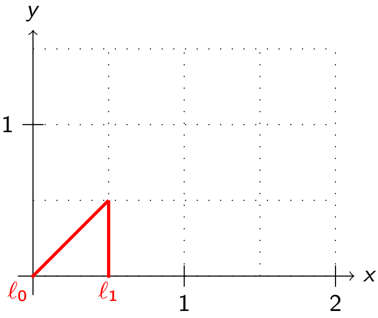

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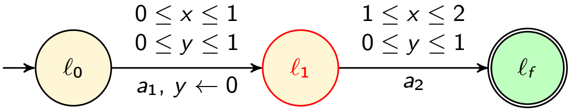

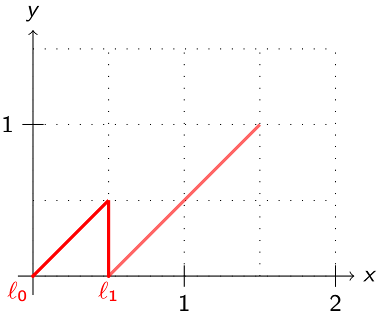

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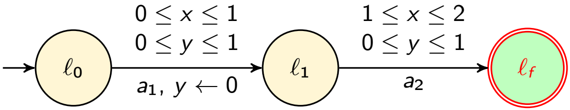

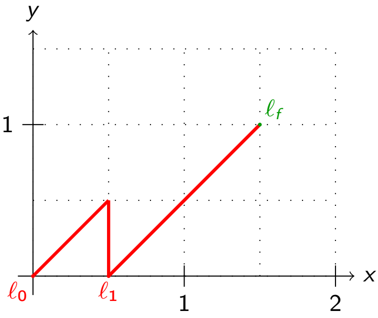

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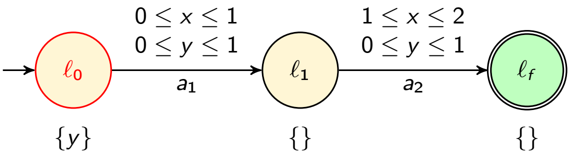

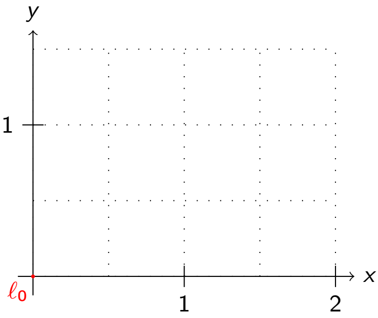

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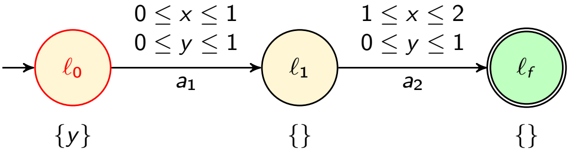

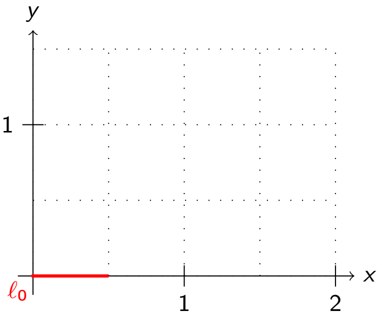

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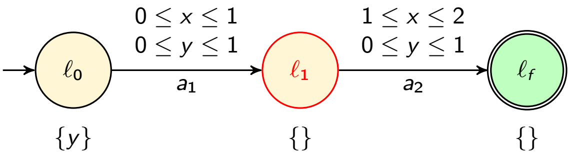

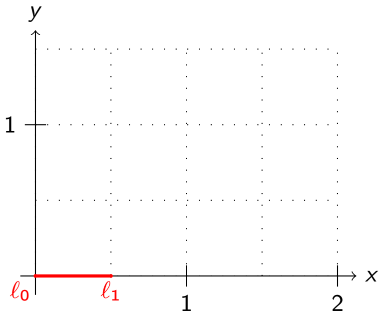

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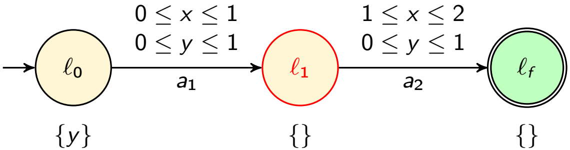

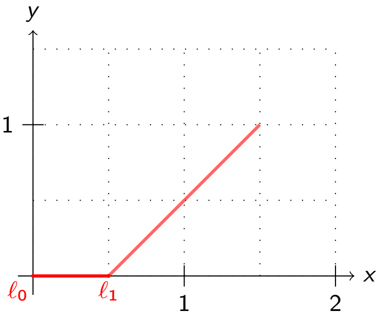

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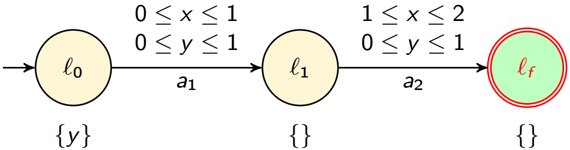
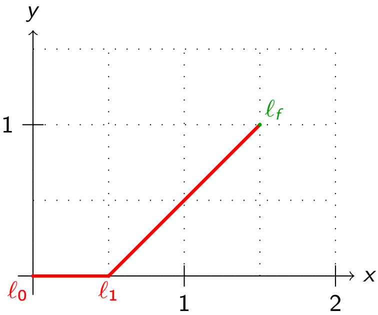
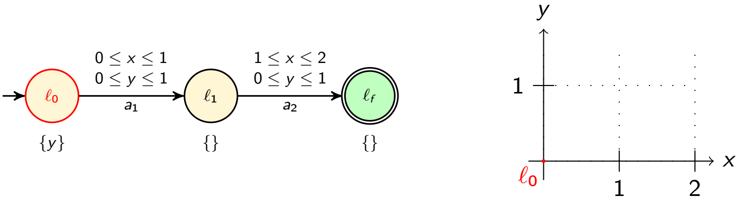




Initialized Stopwatch Timed Automata with bounded channels

- Example of a two-clocks Stopwatch Timed Automata



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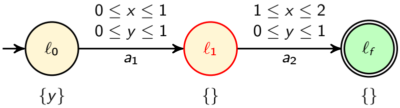

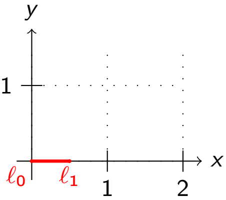

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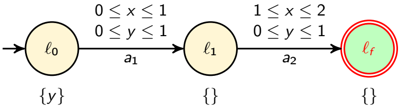

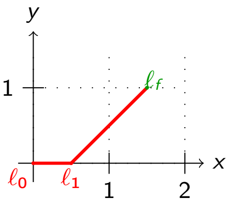

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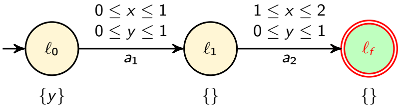

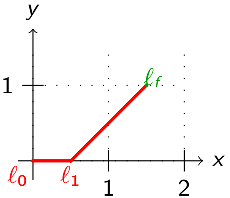

  - ▷ Reachability is Undecidable in general cases.

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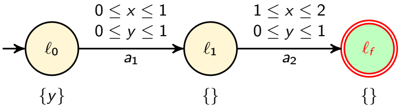
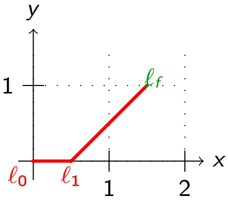
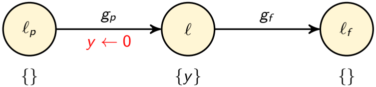




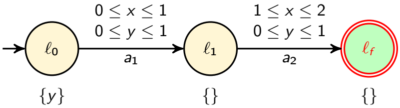
  - ▷ Reachability is Undecidable in general cases.

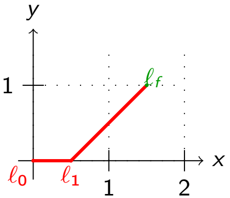
- Initialized Stopwatch Timed Automata
  - ▷ Reset the stopped clock in the previous or following transition:



  - ▷ **Reachability** becomes Decidable for this fragment of SWA.

- Example of a two-clocks Stopwatch Timed Automata





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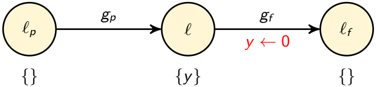

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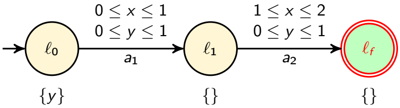

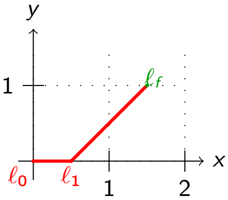

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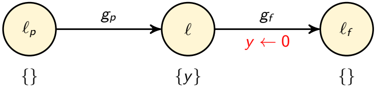
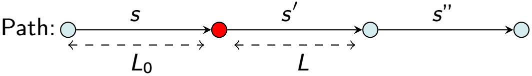


  - **Reachability** becomes Decidable for this fragment of SWA.

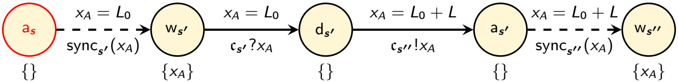
- Bounded channels
  - Channels: FiFo queue of symbols (actions) to be pushed/read

Model the car progress

- Car A progress along its paths



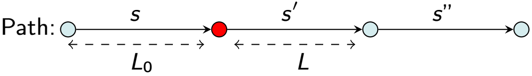
- Car A Timed automaton:



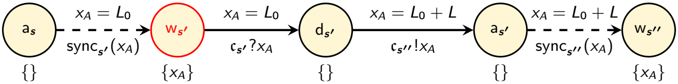
  - **Clock** x_A: distance travelled along its paths
  - **Stopwatches** $\{x_A\}$: the car A stops instantly.
  - **Channels** $\mathfrak{c}_{s'}!x_A/\mathfrak{c}_{s'}?x_A$: respect the order of cars in a section $s \Rightarrow$ no over-taking.
  - **Intersection**: use classical synchronized action to activate *intersection automata*

Model the car progress

- Car *A* progress along its paths



- Car *A* Timed automaton:



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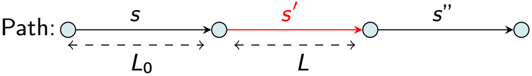
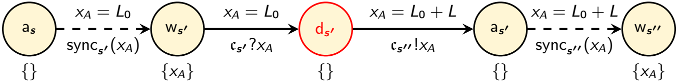
- Car A progress along its paths



- Car A Timed automaton:



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Model the car progress

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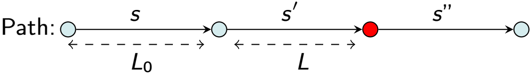

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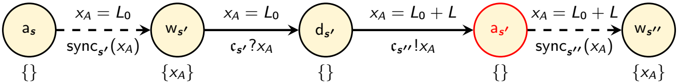

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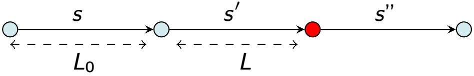
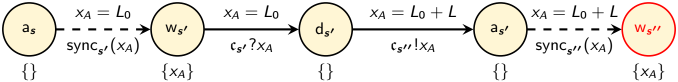
Model the car progress

- Car A progress along its paths

Path: 

- Car A Timed automaton:



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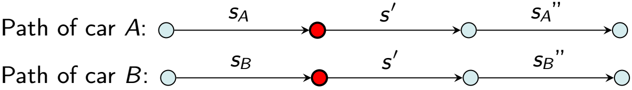
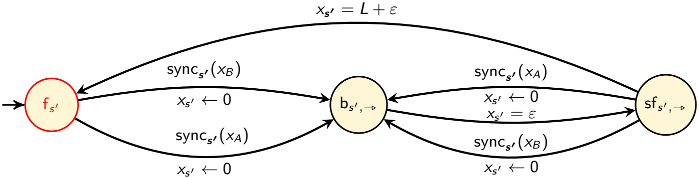
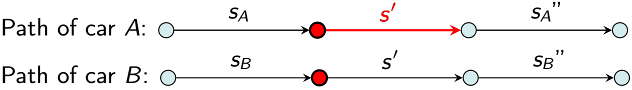


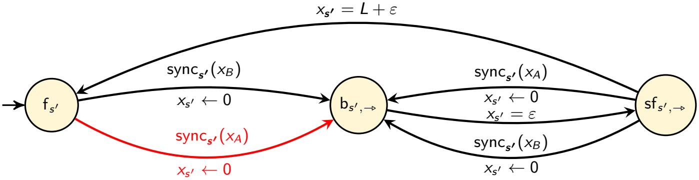
- Intersection automaton



Model distance between cars: intersection



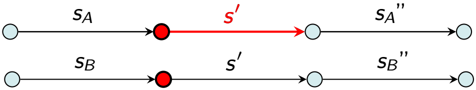
- Intersection automaton



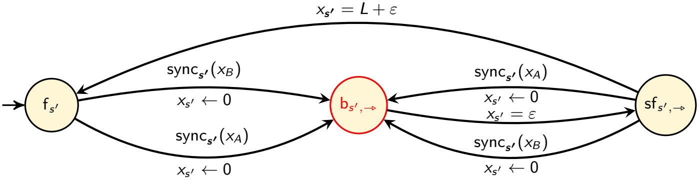
Model distance between cars: intersection

Path of car A:

Path of car B:



- Intersection automaton



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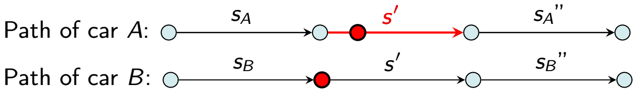
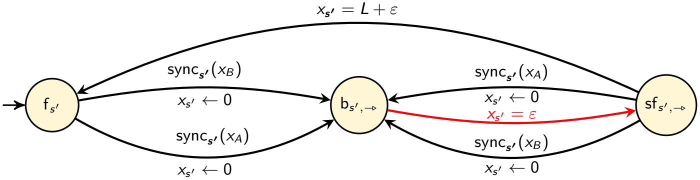
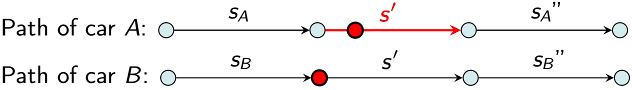


- Intersection automaton





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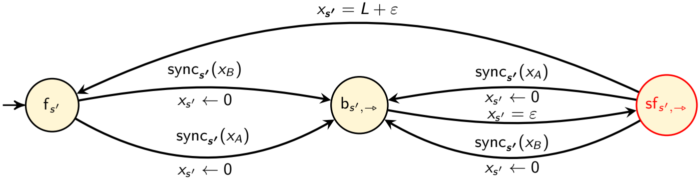

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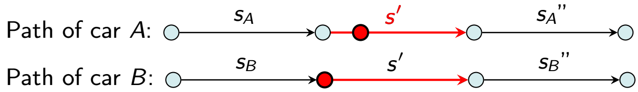

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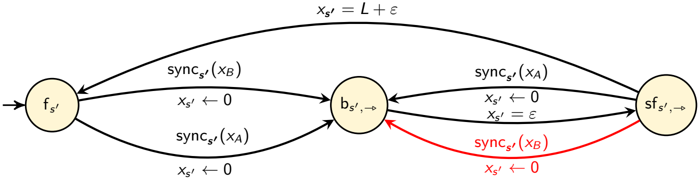

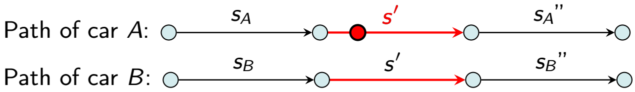

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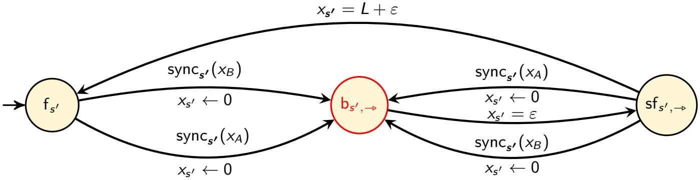

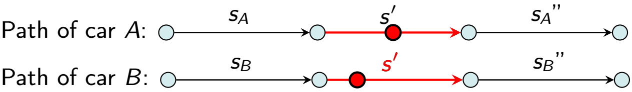

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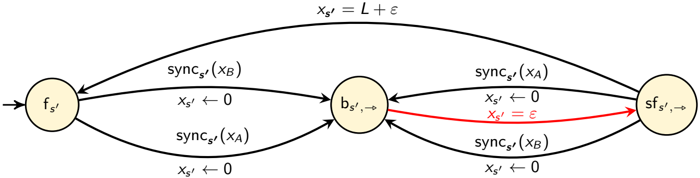

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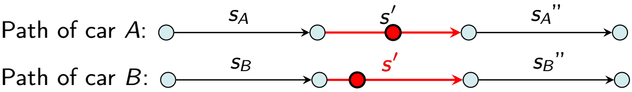

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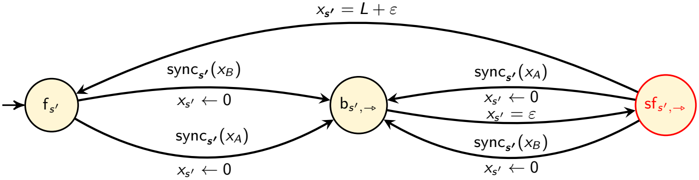

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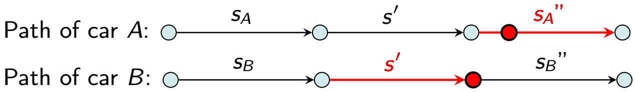

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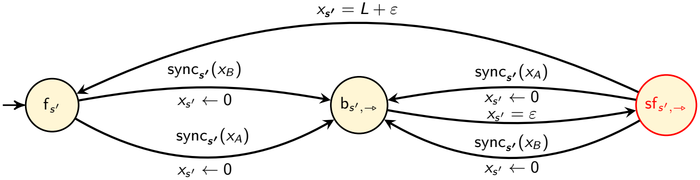

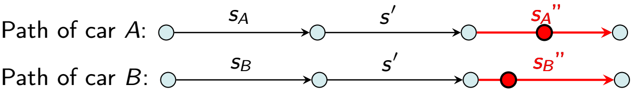

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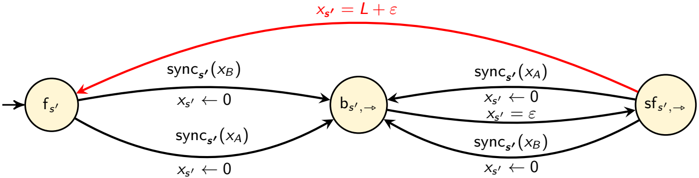

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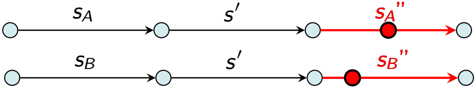

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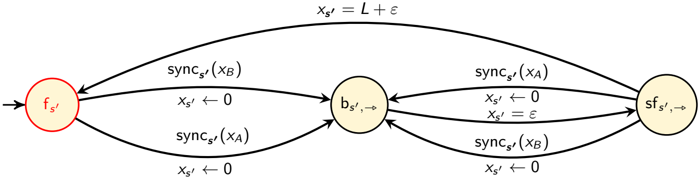
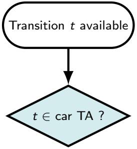


Our Algorithm: a DFS with an optimised succ function



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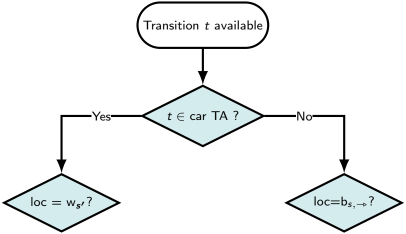

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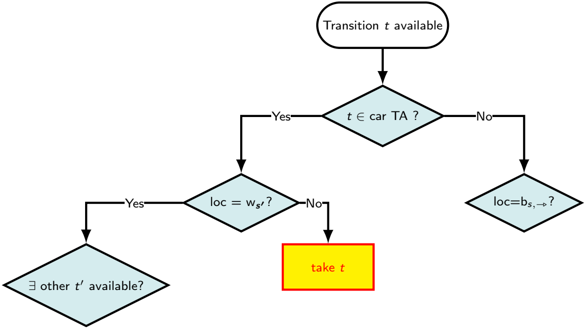

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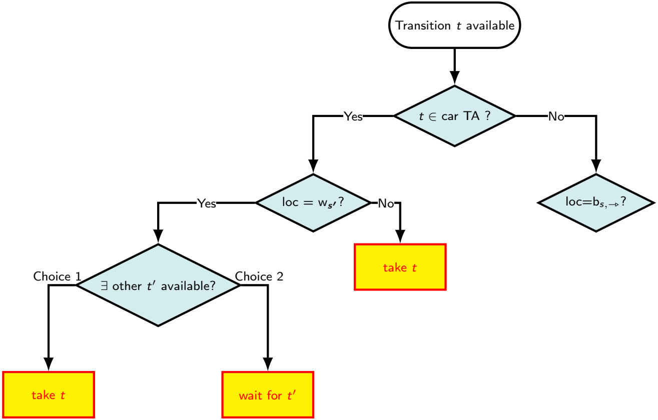

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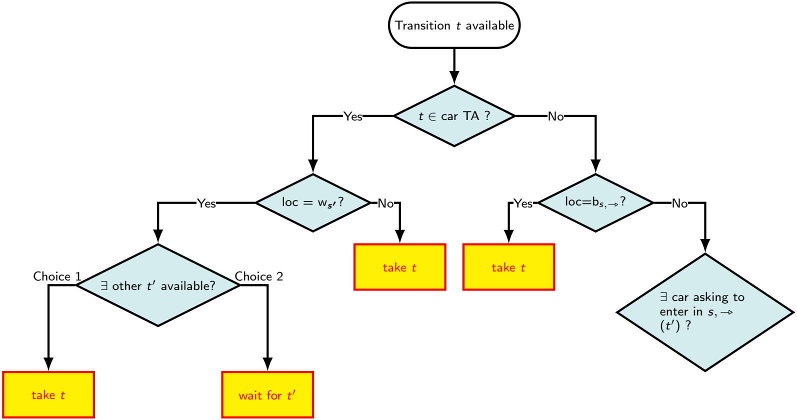

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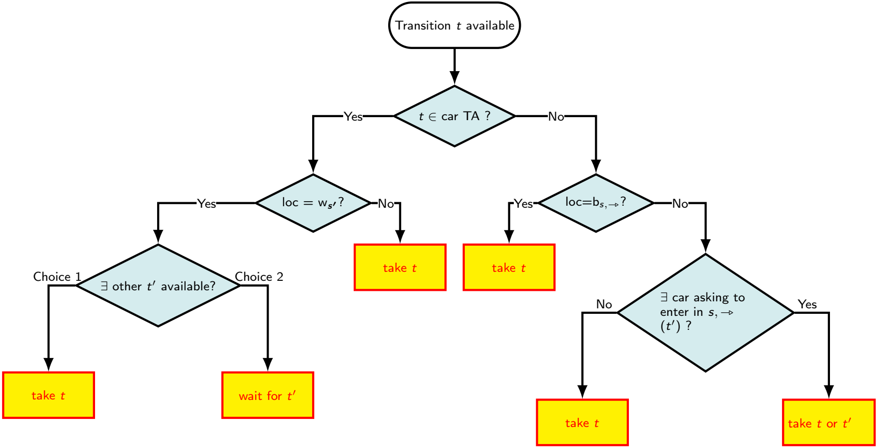

SWA-SMT solver

SMT solver

Stage 1: Reachability algorithm on system of ISWA

SWA

***Stage 2**: Model the accelleration and deceleration*

SMT

Why use of SMT solver?

DFS algorithm

Stage 1: *Reachability algorithm on a simplified ISWA model*

SWA

Solved: combinatorial aspect of the problem. Results: Important events and their relative order

Drawback: A very abstract model of speed

SMT Solver

Stage 2: *Refine the model of the speed*

SMT

RL training

Generate *a dataset for random initial positions*

Dataset

Stage 3: *Train an RL algorithm with our dasaset*

RL

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SMT Solver

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SMT

RL training

Generate *a dataset for random initial positions*

Dataset

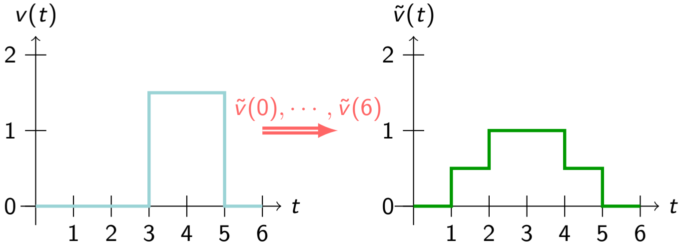
Stage 3: *Train an RL algorithm with our dasaset*

RL

- SMT solver
  - The **continuous** aspect of the problem
  - Introduce a more **realistic** model of speed

- A constant piecewise affine function
  - A more realistic model that takes into account the **dynamic of the system**
  - **Different** car speeds
  - **Bounds** on deceleration and acceleration

$$
\begin{array}{lcl}
v_i(t) & \Rightarrow & \tilde{v}_i(0), \cdots, \tilde{v}_i(k-1) \\
x(t) & \Rightarrow & \tilde{x}_i(k) = \sum_{l=0}^{k-1} \tilde{v}_i(l)
\end{array}
$$



- New positions/speeds
  - $\tilde{x}_i(k) = \sum_{l=0}^{k-1} \tilde{v}_i(l)$
  - $\tilde{v}_i(0), \cdots, \tilde{v}_i(k-1)$

How to preserve security distance ?

- New positions/speeds
  - $\tilde{x}_i(k) = \sum_{l=0}^{k-1} \tilde{v}_i(l)$
  - $\tilde{v}_i(0), \cdots, \tilde{v}_i(k-1)$

- Example of SMT solver's inequalities

For each step k :

  - $\tilde{v}_i(k) - d_{\max} \leq \tilde{v}_i(k+1) \leq \tilde{v}_i(k) + a_{\max}$

- New positions/speeds
  - ▷ $\tilde{x}_i(k) = \sum_{l=0}^{k-1} \tilde{v}_i(l)$
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- Example of SMT solver's inequalities

For each step k :

- ▷ $\tilde{v}_i(k) - d_{\max} \leq \tilde{v}_i(k+1) \leq \tilde{v}_i(k) + a_{\max}$
- ▷ $0 \leq \tilde{v}_i(k) \leq v_{\max}$

RL training

Generate *a dataset for random initial positions*

Dataset

Stage 3*: Train an RL algorithm with our dasaset*

RL

Why use of SMT solver?

DFS algorithm

SMT Solver

RL training

***Stage 1**: Reachability algorithm on a simplified ISWA model*

SWA

Solved: combinatorial aspect of the problem.
Results: Important events and their relative order

Drawback: A very abstract model of speed

***Stage 2**: Refine the model of the speed*

SMT

A more realistic model of speed
Results: traces that takes into account the dynamical aspect of the problem
Drawback: runtime execution

SWA-SMT solver

***Generate** a dataset for random initial positions*

Dataset

***Stage 3**: Train an RL algorithm with our dasaset*

RL

Drawback: our problem has both combinatorial and continuous aspects
Goal: get an intuition from dataset to avoid unsuccessful choices

Why use of SMT solver?

DFS algorithm

Stage 1: Reachability algorithm on a simplified ISWA model

SWA

Solved: combinatorial aspect of the problem.
Results: Important events and their relative order

Drawback: A very abstract model of speed

SMT Solver

Stage 2: Refine the model of the speed

SMT

A more realistic model of speed
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SWA-SMT solver

RL training

Generate a dataset for random initial positions

Dataset

Stage 3: Train an RL algorithm with our dasaset

RL

Drawback: our problem has both combinatorial and continuous aspects
Goal: get an intuition from dataset to avoid unsuccessful choices

- RL training dataset
  - Create random initial positions/speeds for cars
  - Generate traces with the SWA-SMT solver

- Markov Decision Process
  - **Deterministic running example**: deterministic transition function.

Model

- Markov Decision Process
  - **Deterministic running example**: deterministic transition function.
  - **State** s_i. For each section s, if a car c is in s: $v_{i,c}, \mathsf{pos}_{i,c}, \mathsf{id}_\mathsf{c}, 1$

- Markov Decision Process
  - **Deterministic running example**: deterministic transition function.
  - **State** s_i. For each section s, if a car c is in s: $v_{i,c}, \mathrm{pos}_{i,c}, \mathrm{id}_c, 1$
  - **Action** act_i: $(\mathrm{acc}_{i,c})_{c \in \mathbf{Cars}}$

$$\underset{i}{(\mathrm{pos}_{i,c}, v_{i,c})} \dashrightarrow \underset{i+1}{(\mathrm{pos}_{i,c} + v_i, v_{i,c} + \mathrm{acc}_{i,c})}$$

Model

- Markov Decision Process
  - **Deterministic running example**: deterministic transition function.
  - **State** s_i. For each section s, if a car c is in s: $v_{i,c}, \mathrm{pos}_{i,c}, \mathrm{id}_c, 1$
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$$\underset{i}{(\mathrm{pos}_{i,c}, v_{i,c})} \dashrightarrow \underset{i+1}{(\mathrm{pos}_{i,c} + v_i, v_{i,c} + \mathrm{acc}_{i,c})}$$

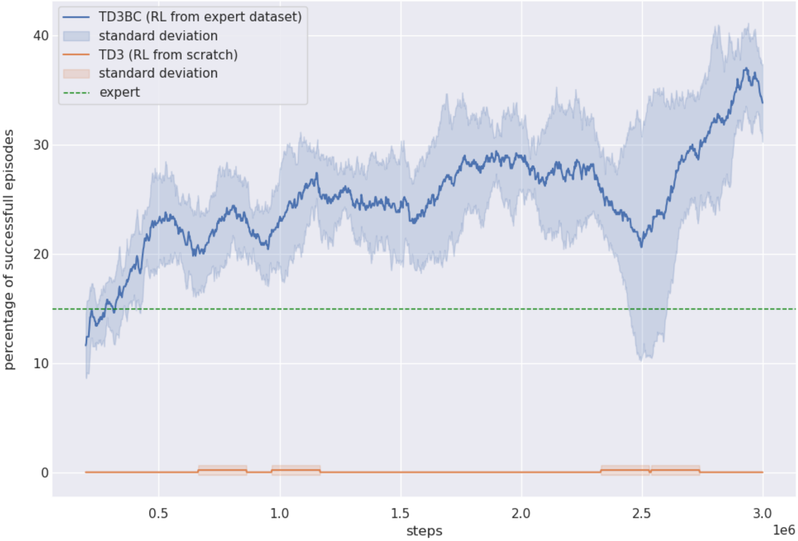
  - **Trajectories** s_i, Obs_i, act_i

- Markov Decision Process
  - **Deterministic running example**: deterministic transition function.
  - **State** s_i. For each section s, if a car c is in s: $v_{i,c}, \mathsf{pos}_{i,c}, \mathsf{id}_c, 1$
  - **Action** act_i: $(\mathsf{acc}_{i,c})_{c \in \mathsf{Cars}}$

$$\underset{i}{(\mathsf{pos}_{i,c}, v_{i,c})} \dashrightarrow \underset{i+1}{(\mathsf{pos}_{i,c} + v_i, v_{i,c} + \mathsf{acc}_{i,c})}$$

  - **Trajectories** s_i, Obs_i, act_i
  - **Reward**:
    - $+2000$ if goals are achieved
    - -100 if distance rules are not respected
    - $\nearrow$ with speed
    - $\nearrow$ with the increase of distance between cars

Results with SWA-SMT solver, post SWA-SMT solver RL and single RL training



DFS algorithm

Stage 1: *Reachability algorithm on a simplified ISWA model*

SWA

Solved: combinatorial aspect of them problem.
Results: Important events and their relative order

Drawback: A very abstract model of speed

SMT Solver

Stage 2: *Refine the model of the speed*

SMT

A more realistic model of speed
Results: traces that takes into account the dynamical aspect of the problem
Drawback: runtime execution

SWA-SMT solver

RL training

Generate *a dataset for random initial positions*

Dataset

Stage 3: *Train an RL algorithm with our dasaset*

RL

Drawback: our problem has both combinatorial and continuous aspects
Method: get an intuition from dataset to avoid unsuccessful choices
MDP model to reward short-time episode and distance between cars

Conclusion

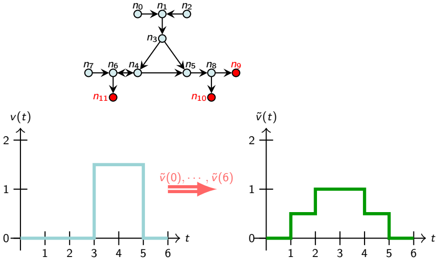
- SWA-SMT Solver

Automata-based model

Efficient algorithm
Abstract model with unrealistic speed model

Piecewise-affine speed graph

Bounded accelleration and deceleration
Different speed
SMT solver to model and solve the distance constraints



Conclusion

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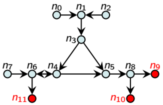
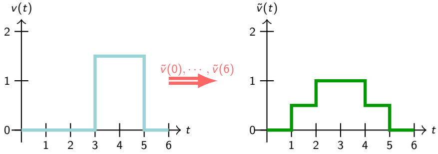




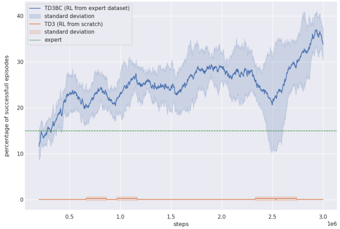
- RL training

Dataset

Trace generated with SWA-SMT solver
Random positions & speeds

Performance of RL (helped with SWA-SMT solver)

Better than single RL
Better than SWA-SMT solver
Runtime: $\sim$ *2 days*



Conclusion

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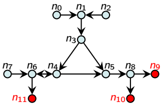

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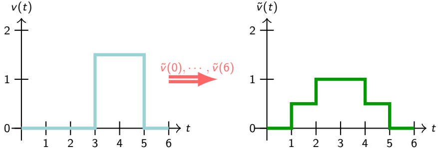

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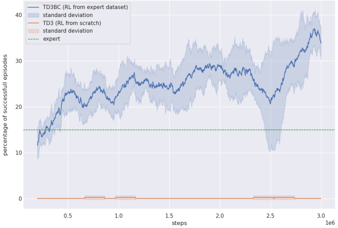

- Future work: Decentralized multi-agent systems