Model-bounded monitoring of hybrid systems

Masaki Waga[1], Étienne André[2], Ichiro Hasuo[3]

Kyoto University[1], Université de Lorraine[2],
National Institute of Informatics[3]

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Safety Critical CPSs

Self-driving car crash in Arizona: Red light runner hits Waymo van

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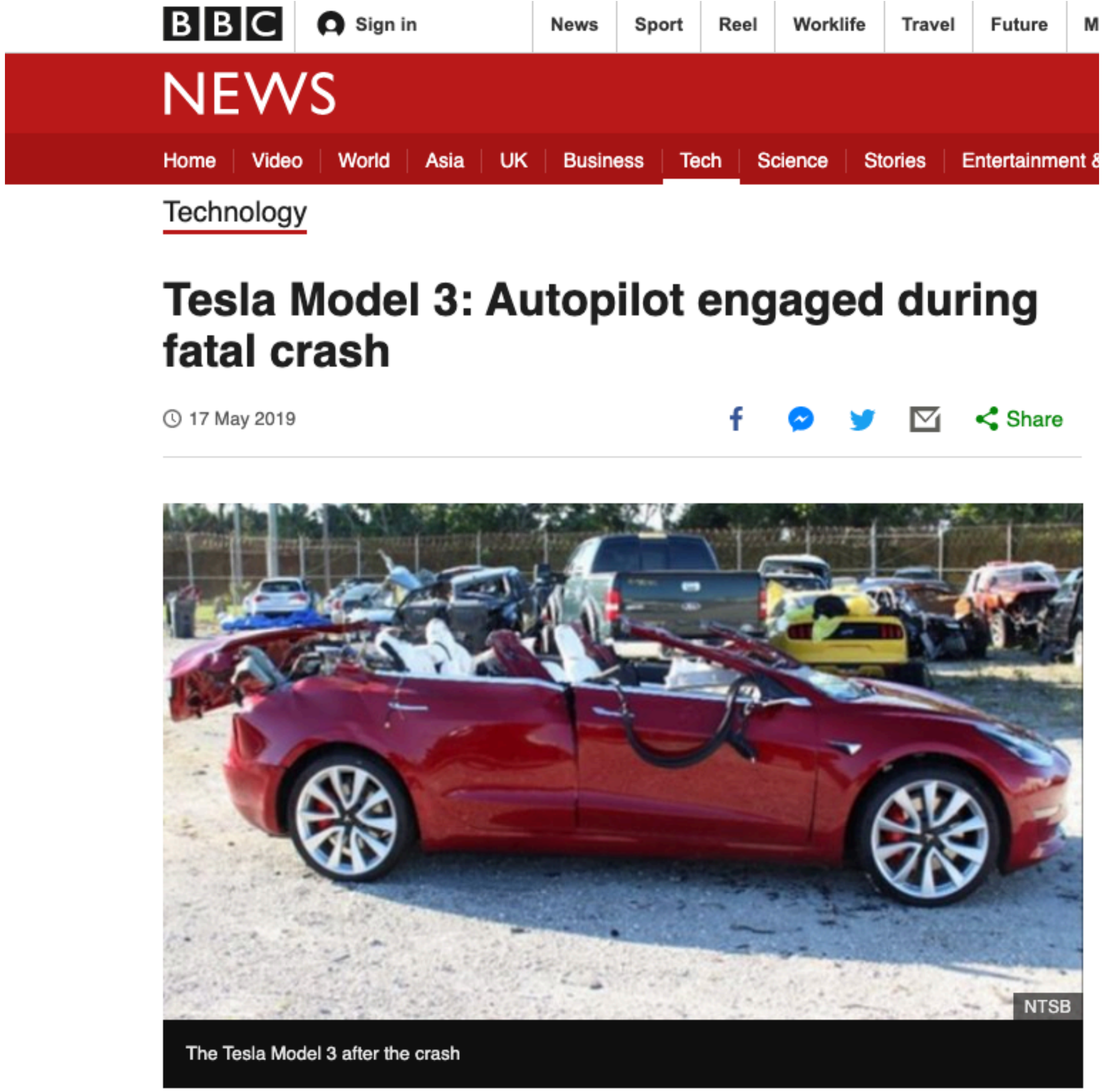
Photo by: Air15



Technology

Tesla Model 3: Autopilot engaged during fatal crash

17 May 2019

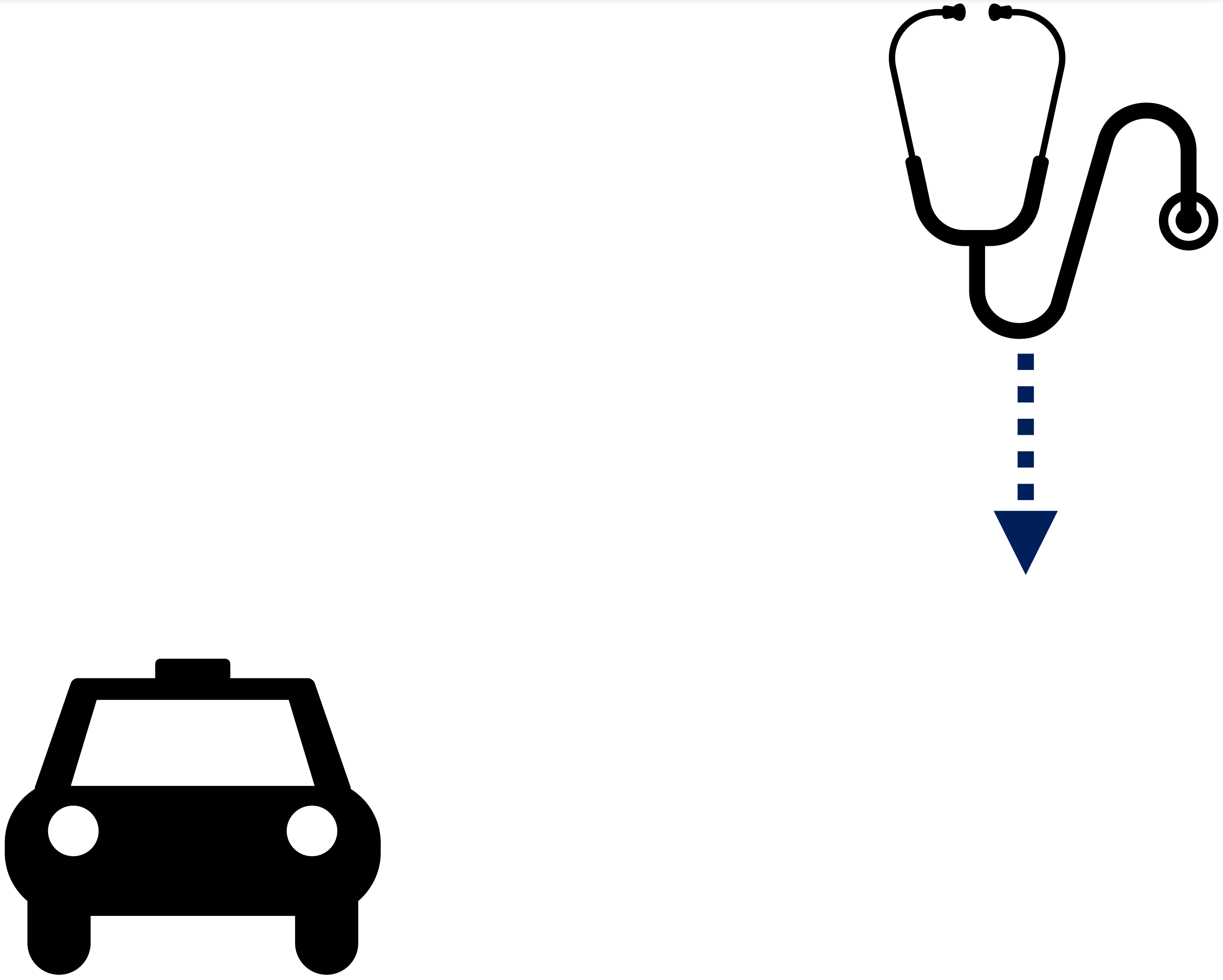
The Tesla Model 3 after the crash

https://www.abc15.com/news/region-southeast-valley/chandler/waymo-car-involved-in-chandler-arizona-crash

https://www.bbc.com/news/technology-48308852

Monitoring

Specification: No $(v > 120)$



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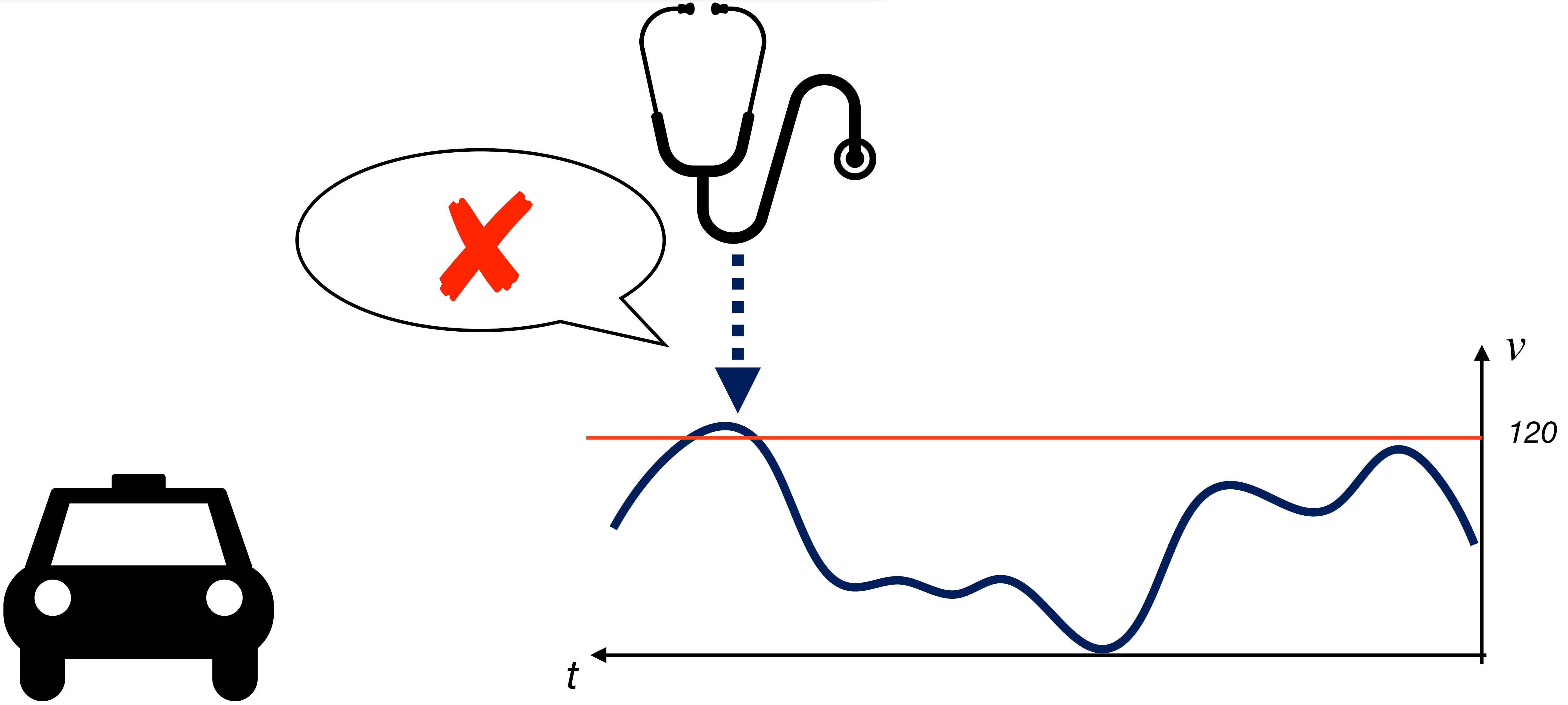

Monitoring with Sampling

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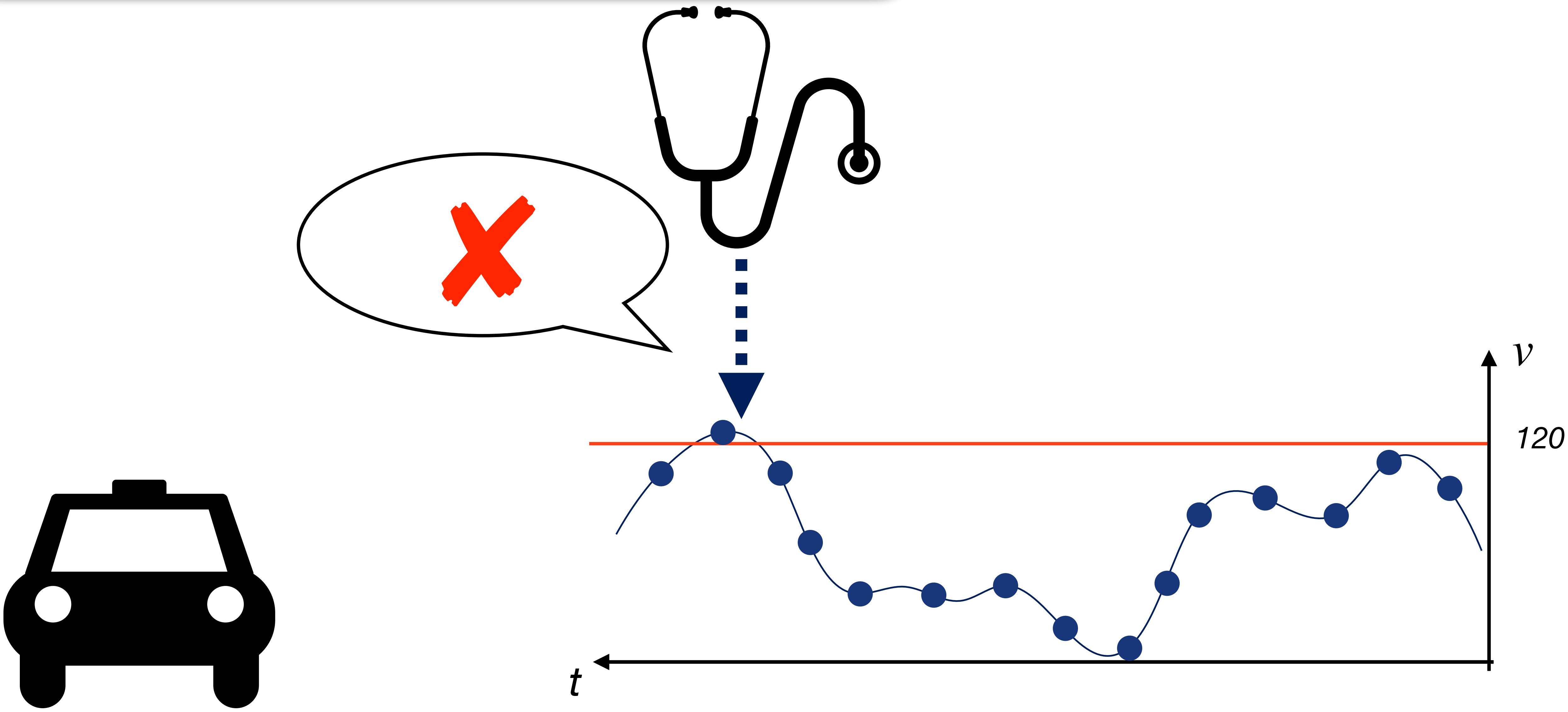

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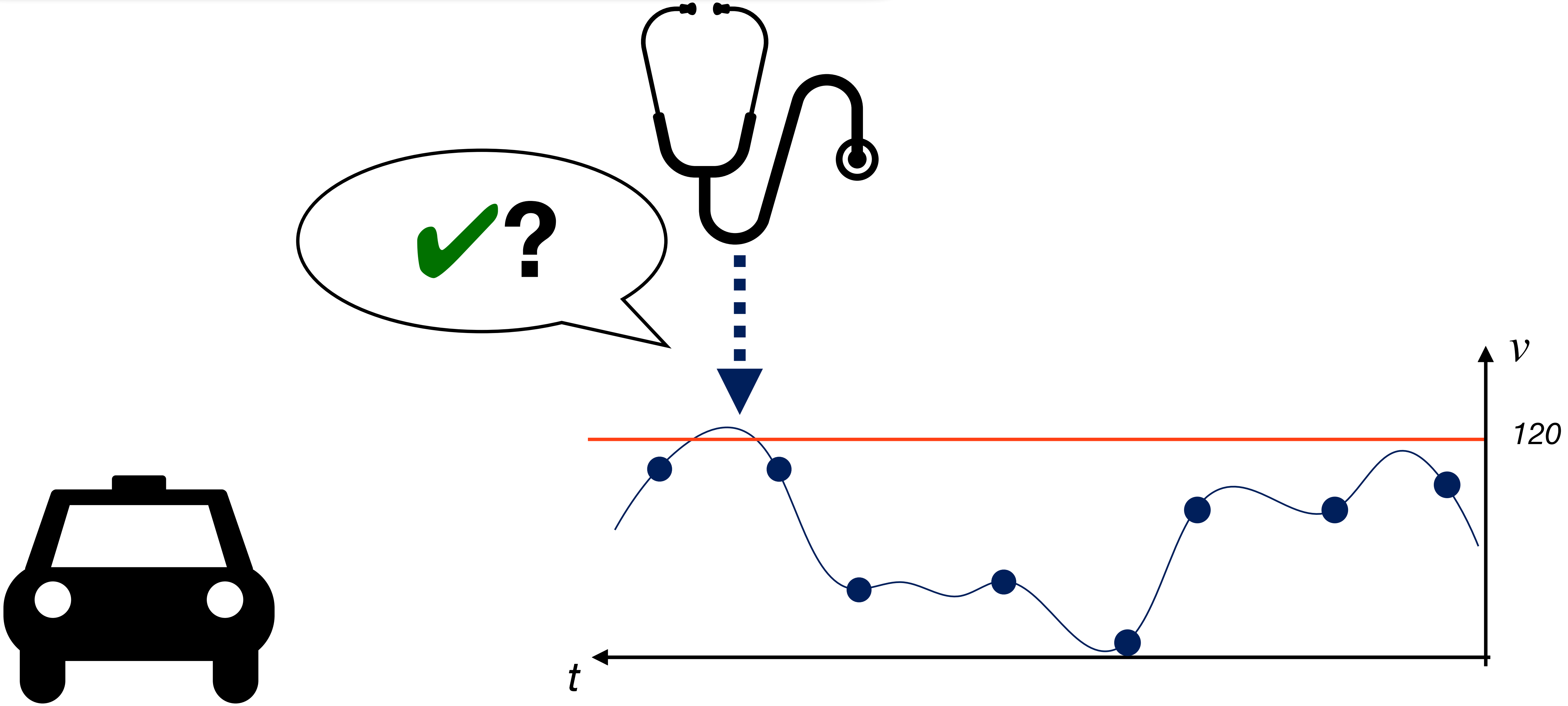

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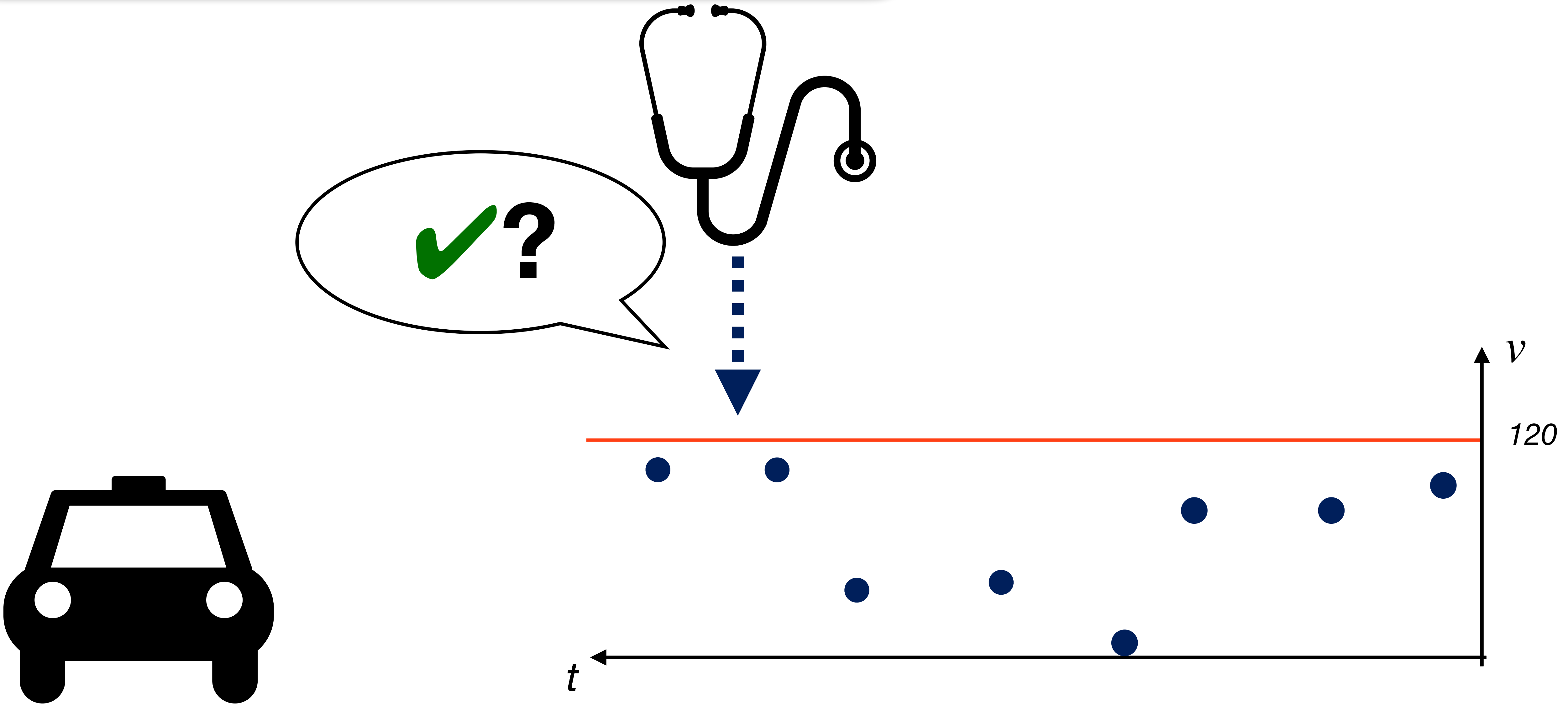
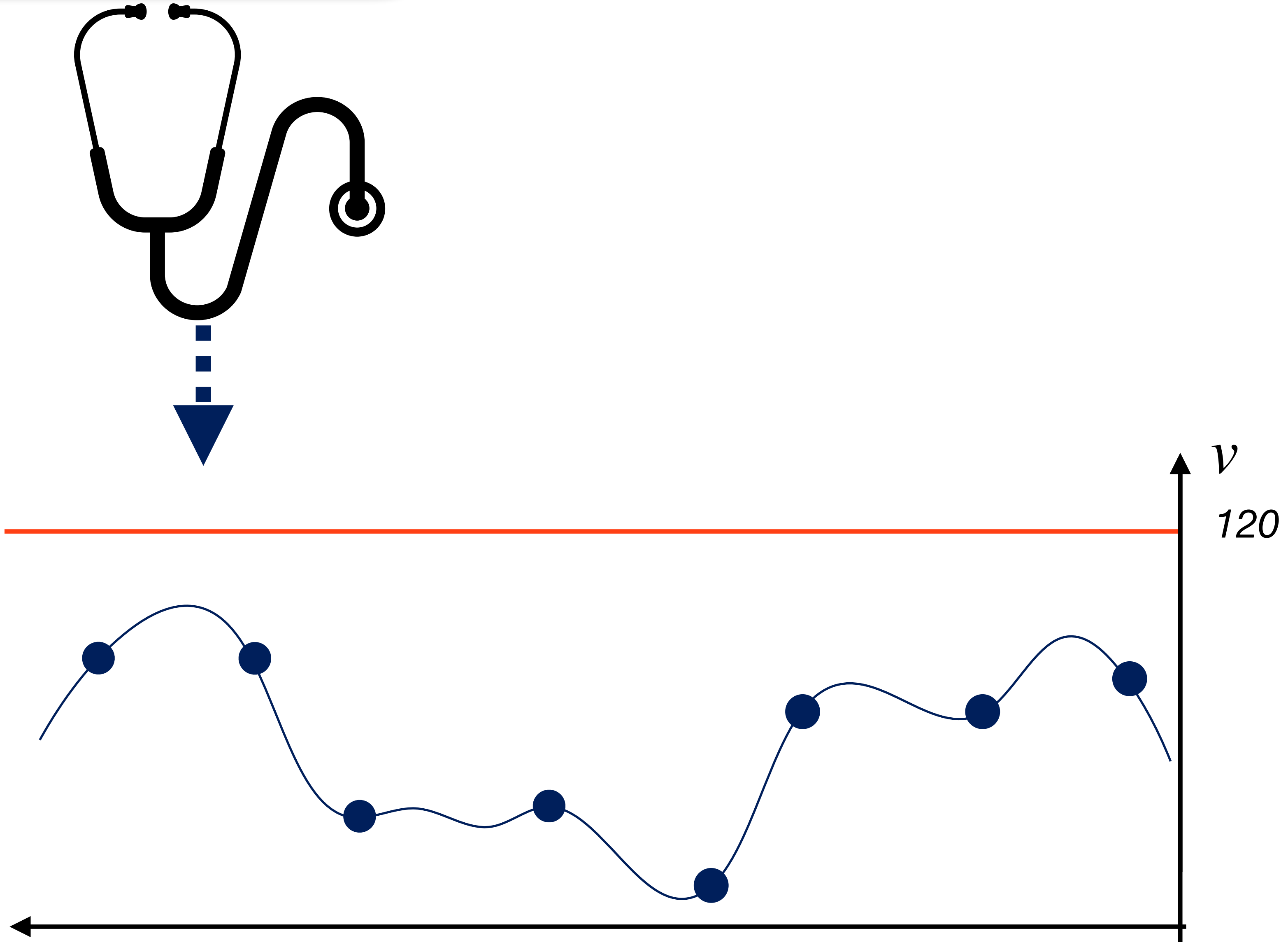


Signal Interpolation

Specification: **No** $(v > 120)$



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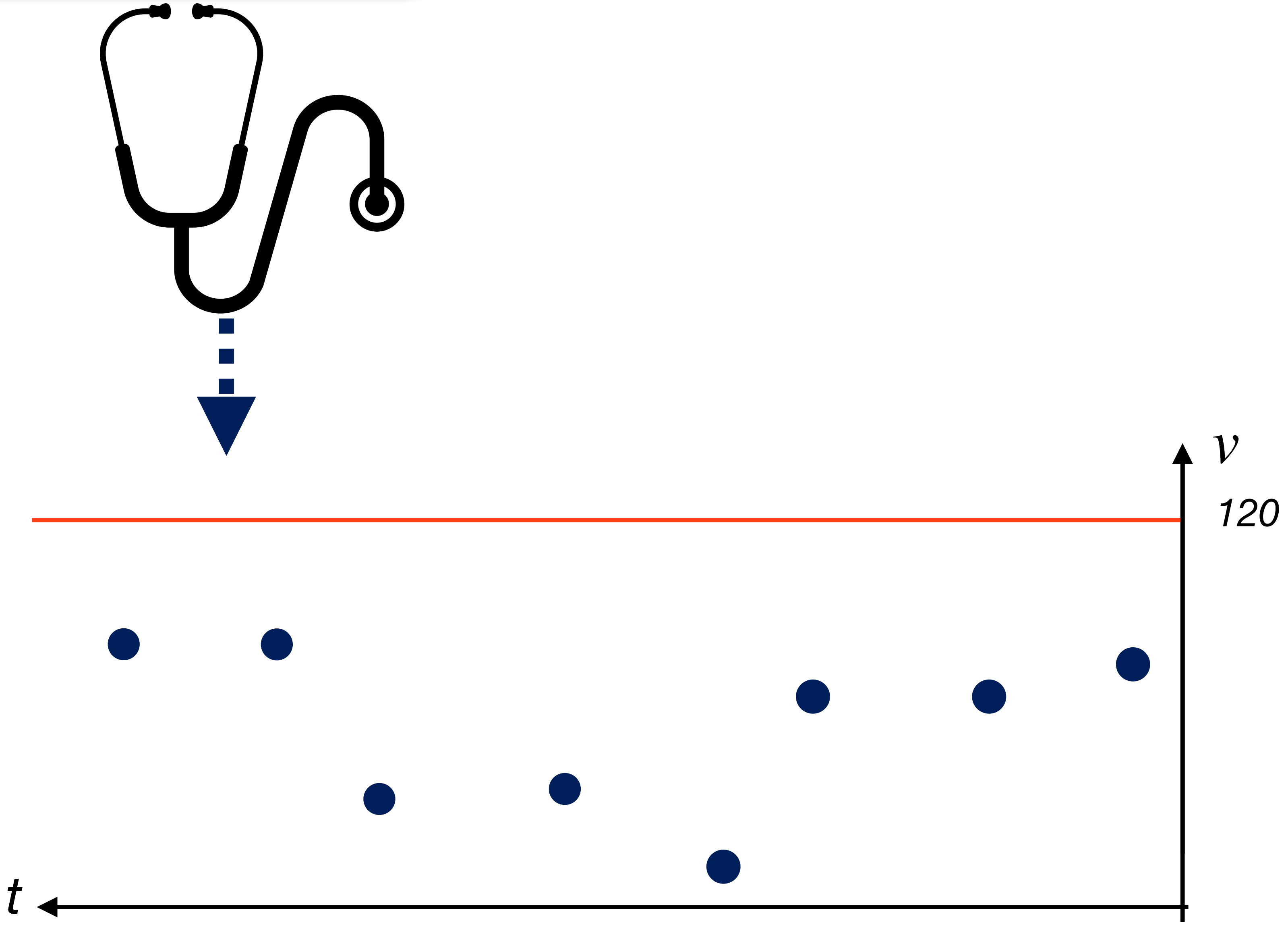

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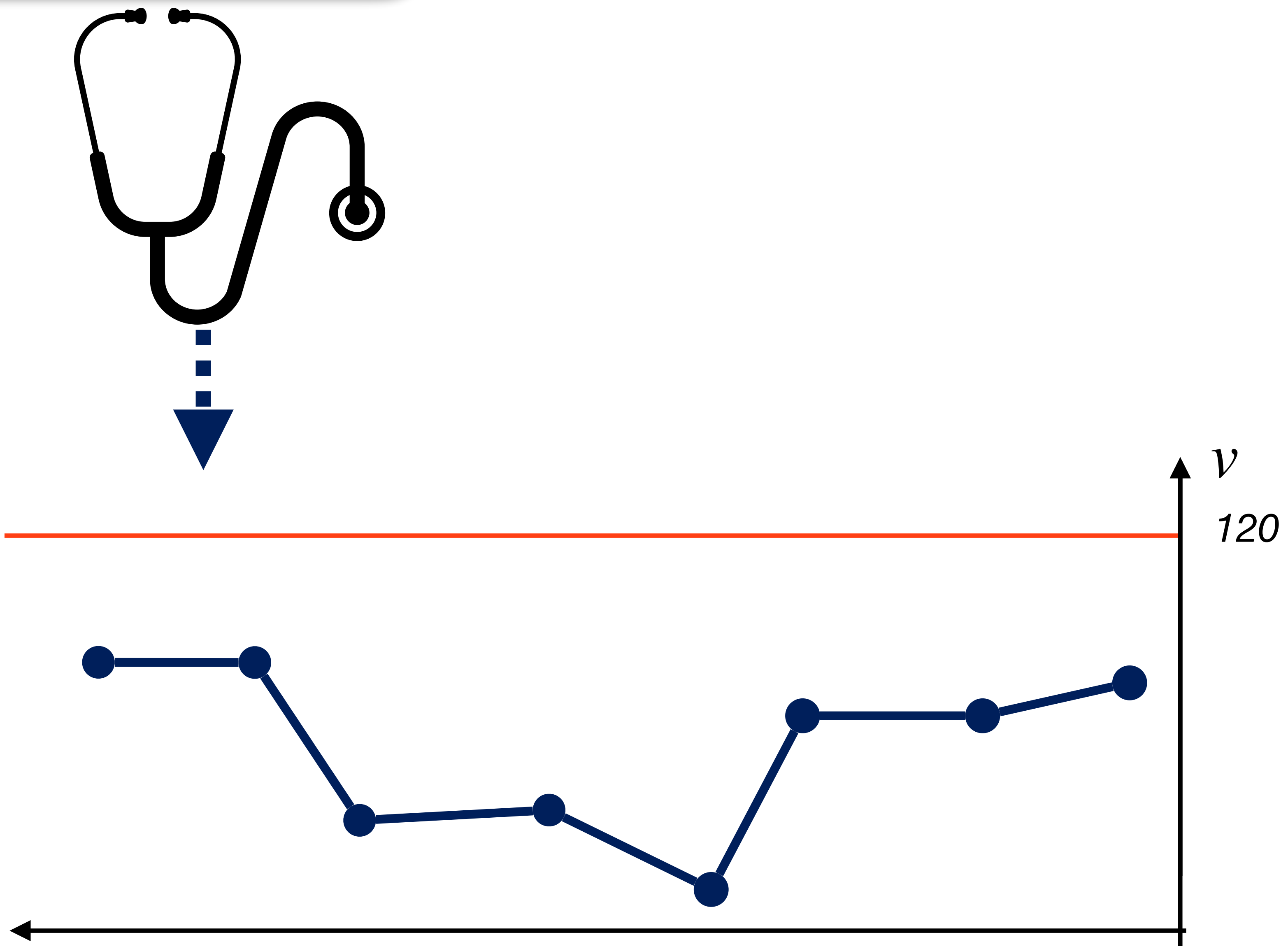

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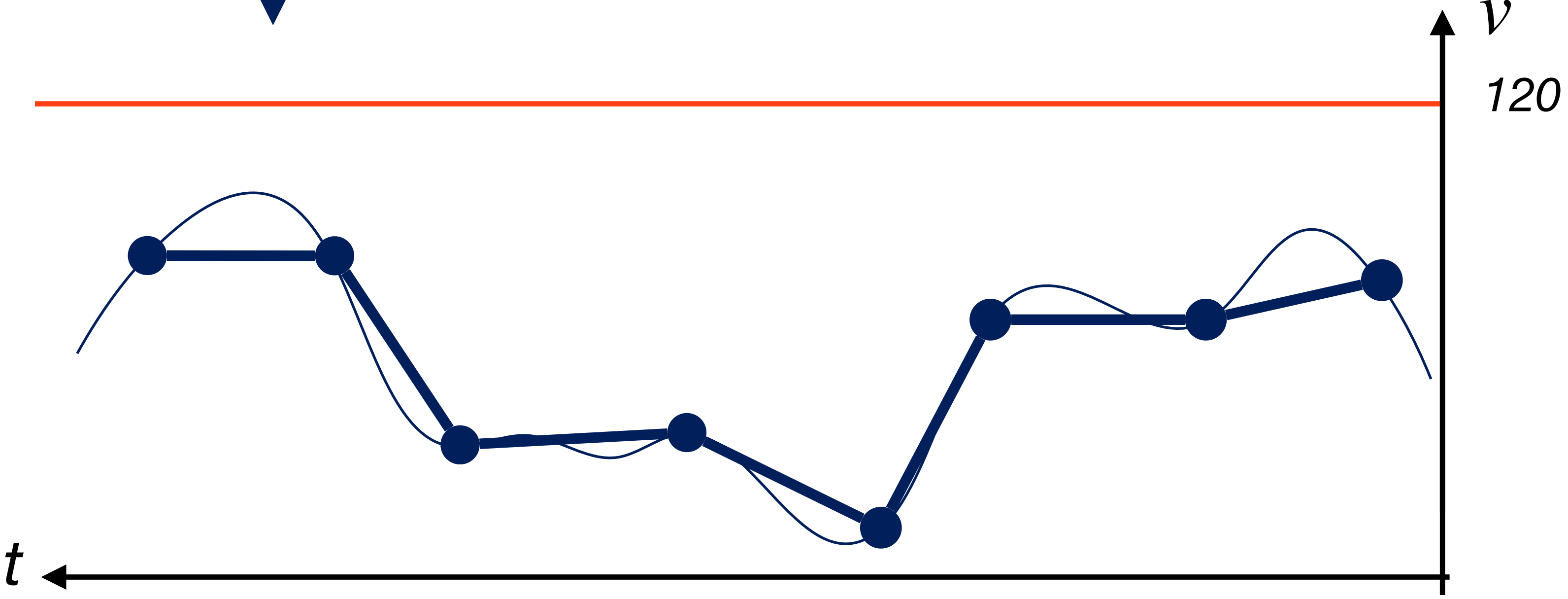

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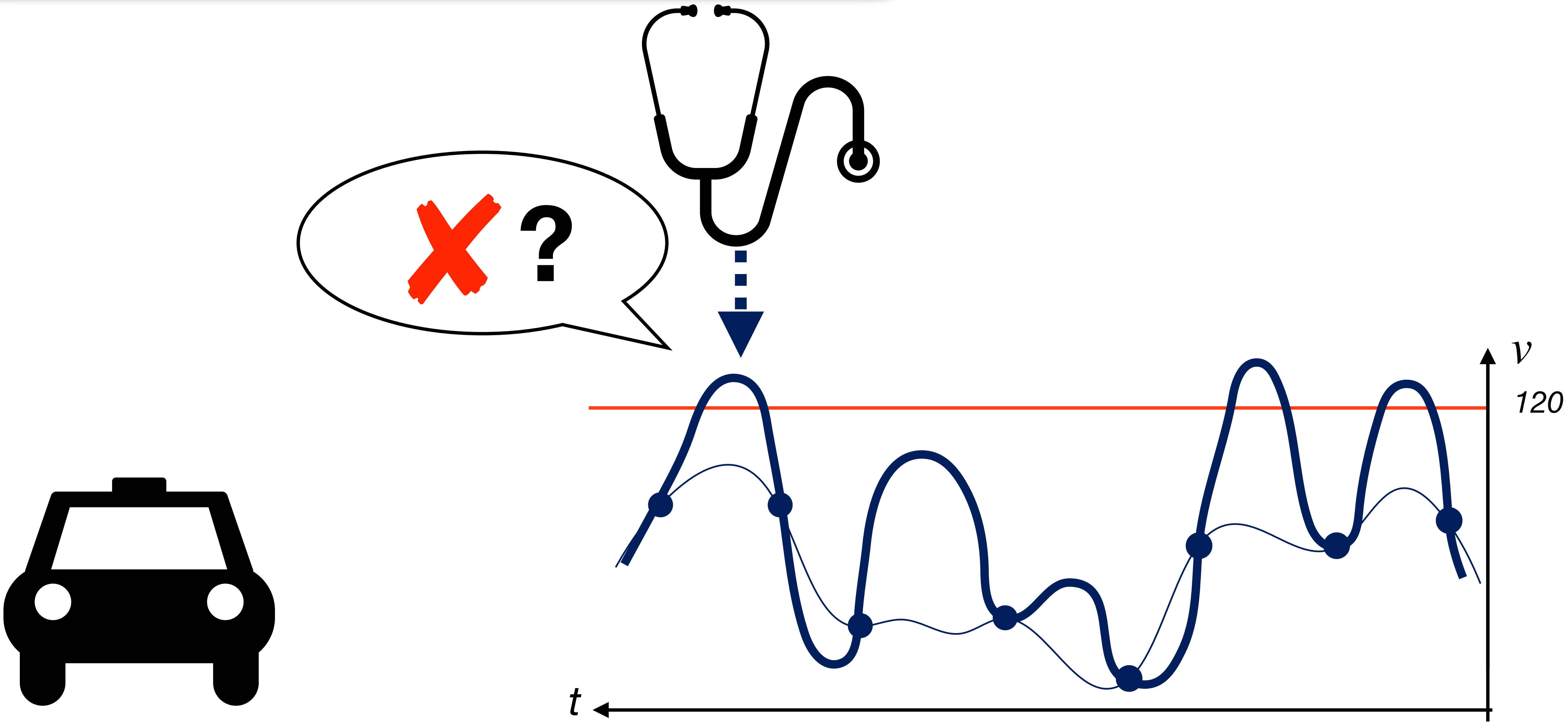
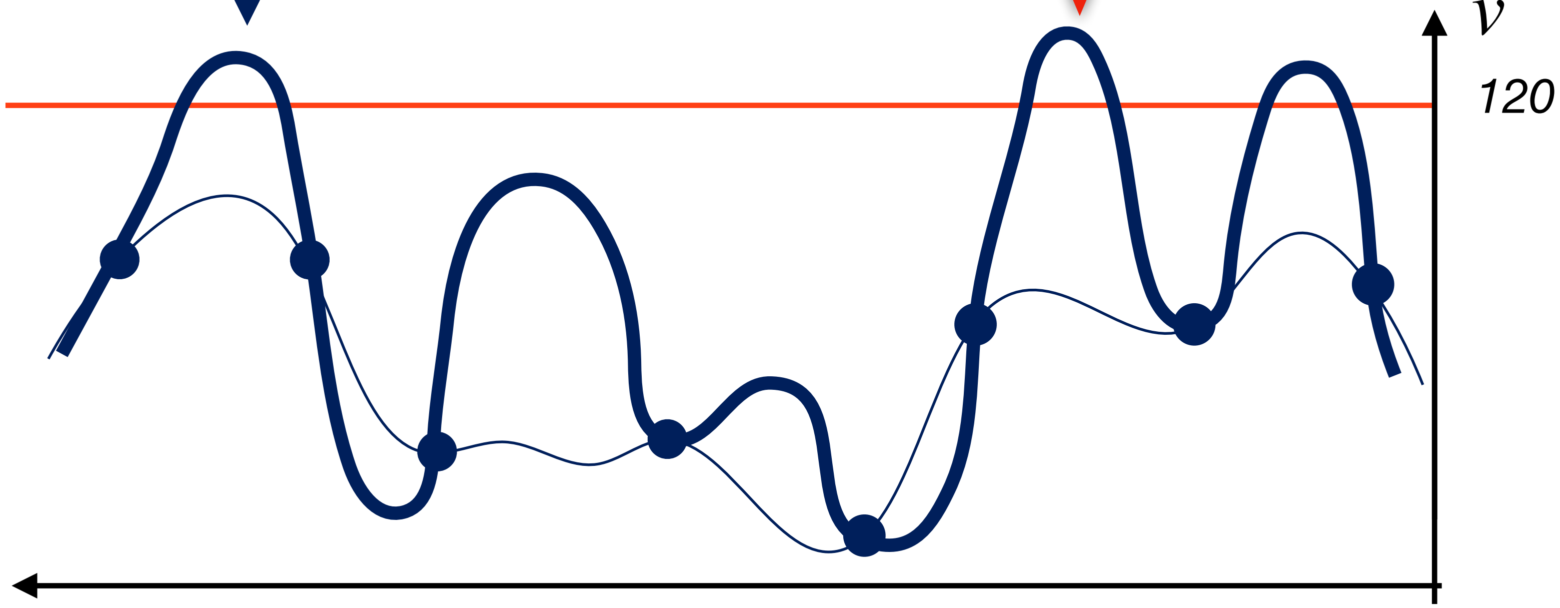


Interpolation with Prior Knowledge

Specification: No $(v > 120)$

Impossible because

$$\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$$



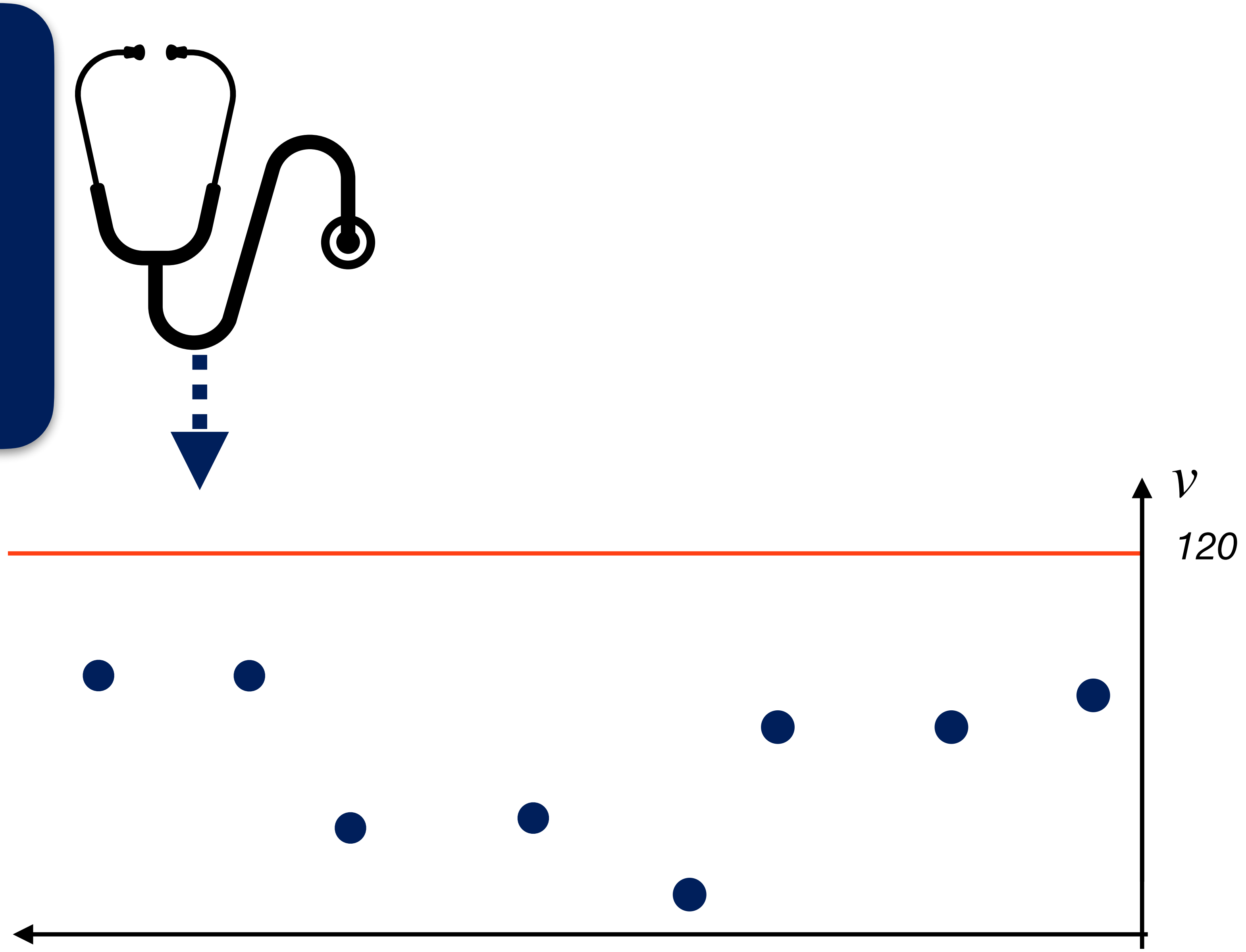
Model-Bounded Monitoring

Our Contribution

Specification: **No** $(v > 120)$

Knowledge (bounding model)

$$\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$$



Model-Bounded Monitoring

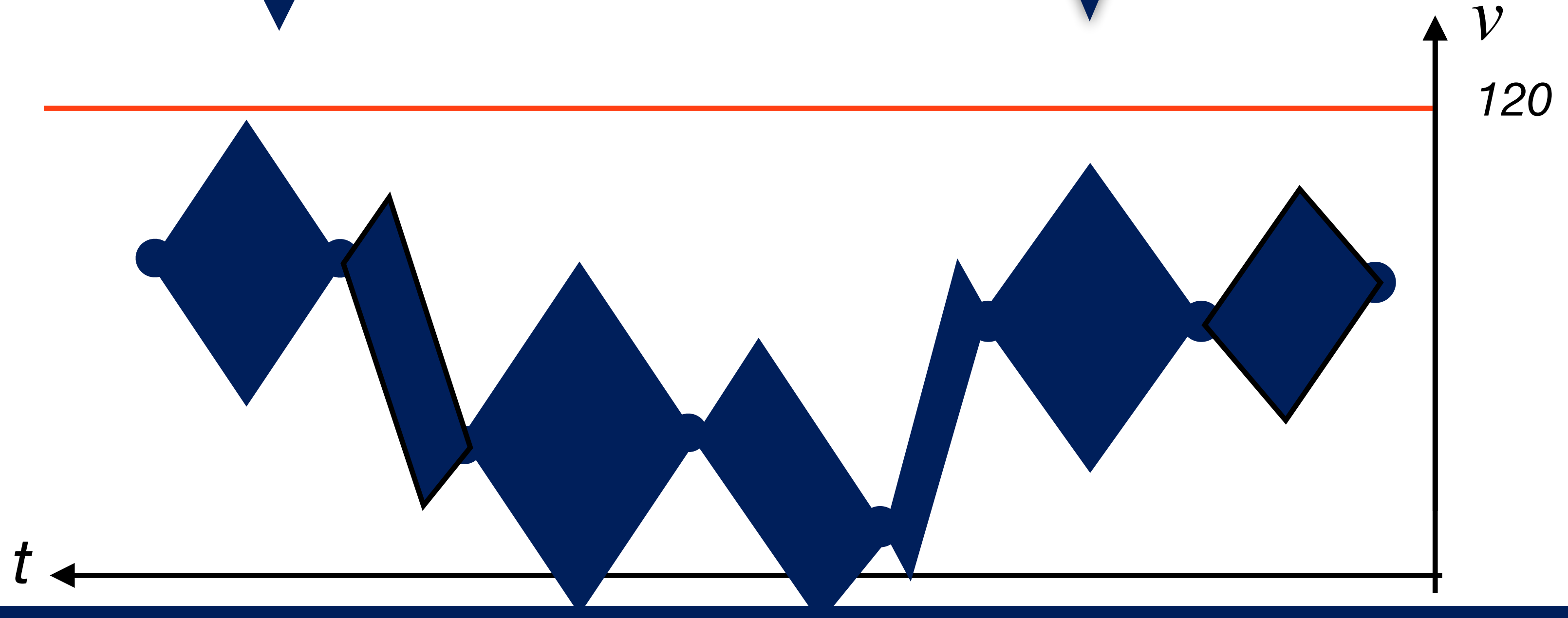
Our Contribution

Specification: No $(v > 120)$

Knowledge (bounding model)

$$\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$$

Feasible execution with $\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$



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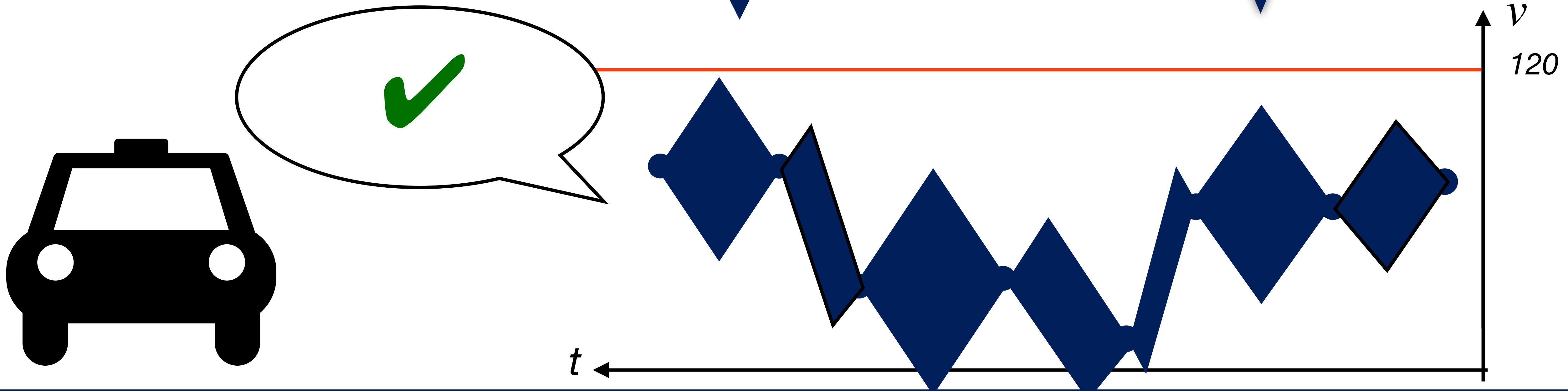
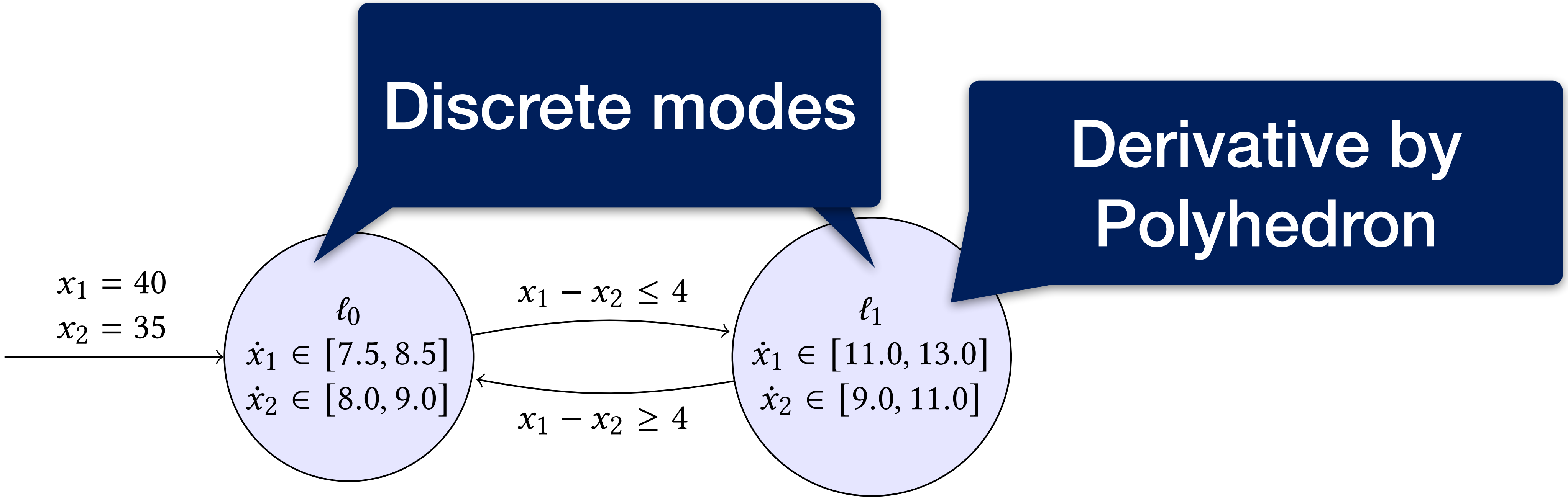


Q. How to Represent Bounding Model?

Knowledge (bounding model)

$$\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$$

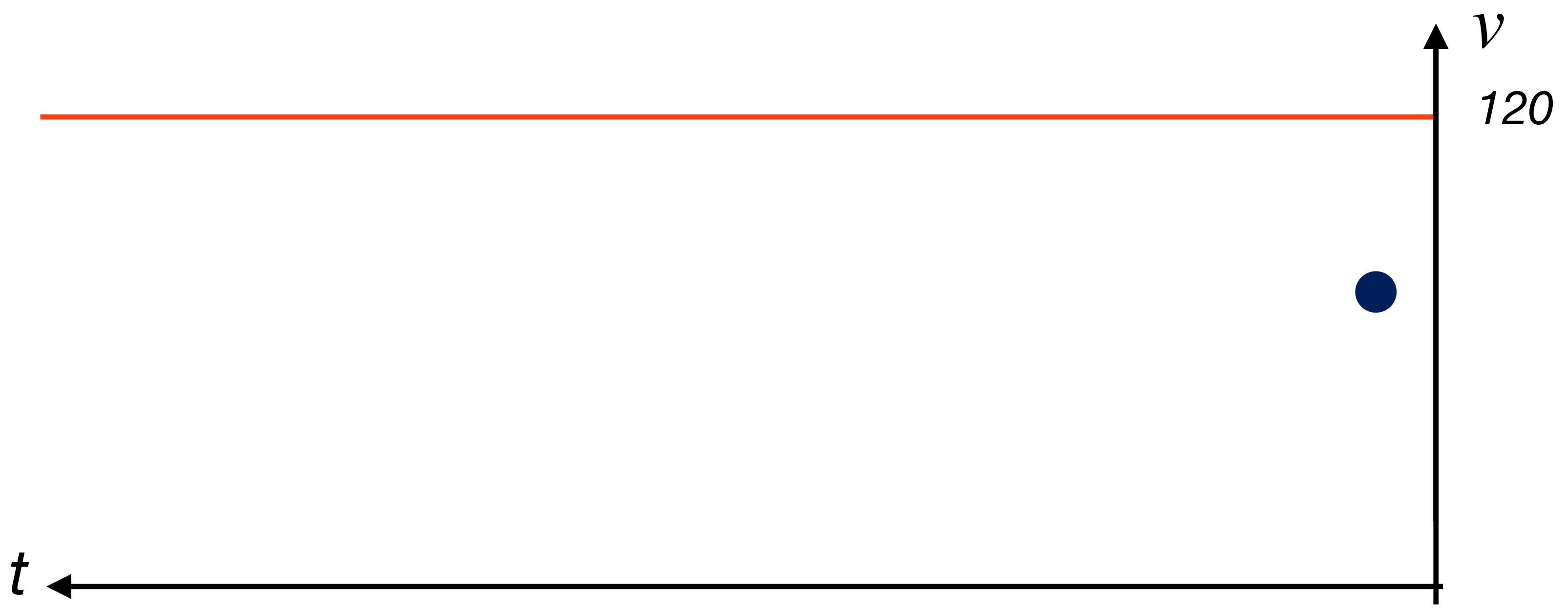
A. Linear Hybrid Automata


Discrete modes

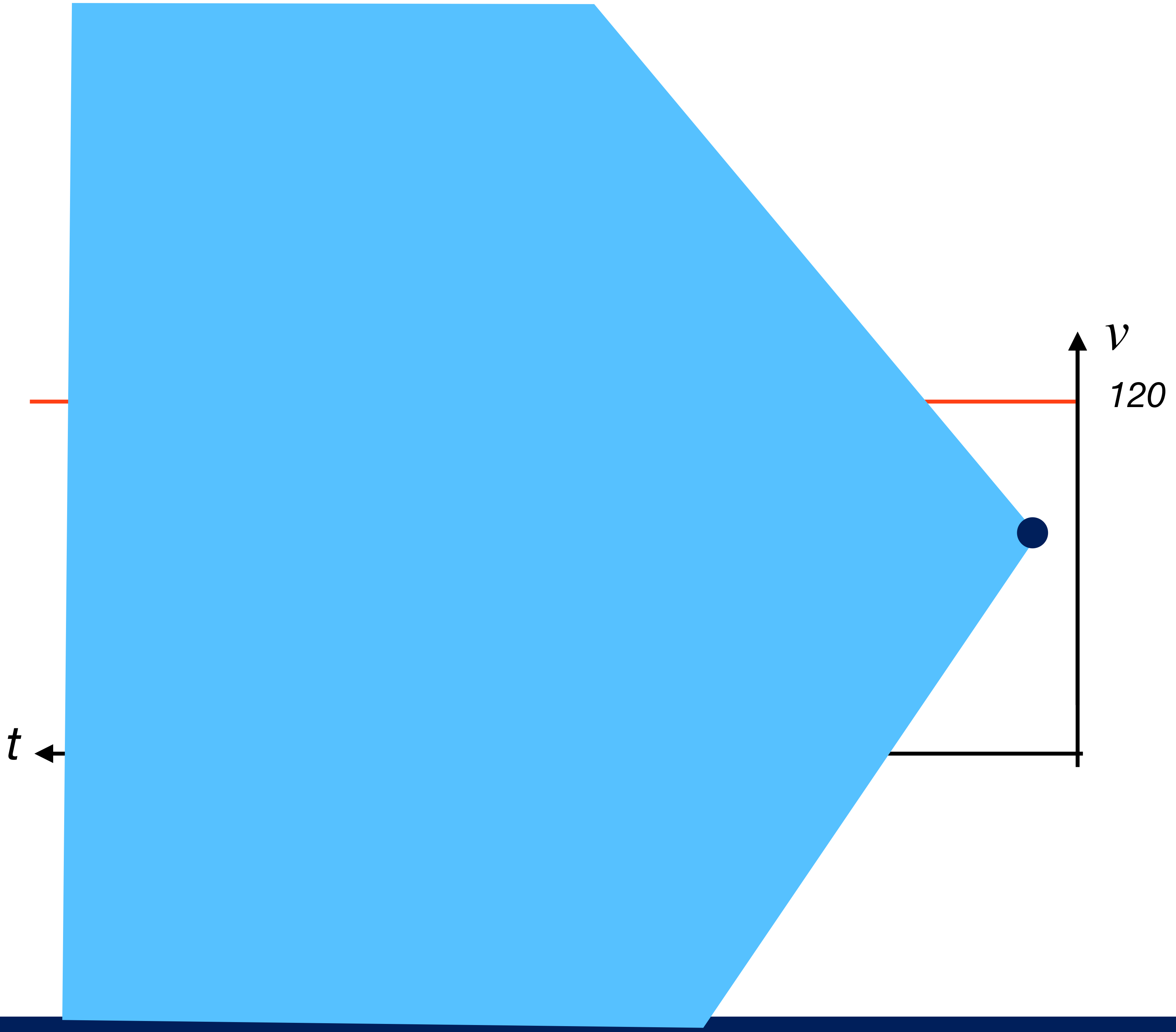
Derivative by Polyhedron

$x_1 = 40$
$x_2 = 35$
ℓ_0
$\dot{x}_1 \in [7.5, 8.5]$
$\dot{x}_2 \in [8.0, 9.0]$
$x_1 - x_2 \leq 4$
$x_1 - x_2 \geq 4$
ℓ_1
$\dot{x}_1 \in [11.0, 13.0]$
$\dot{x}_2 \in [9.0, 11.0]$

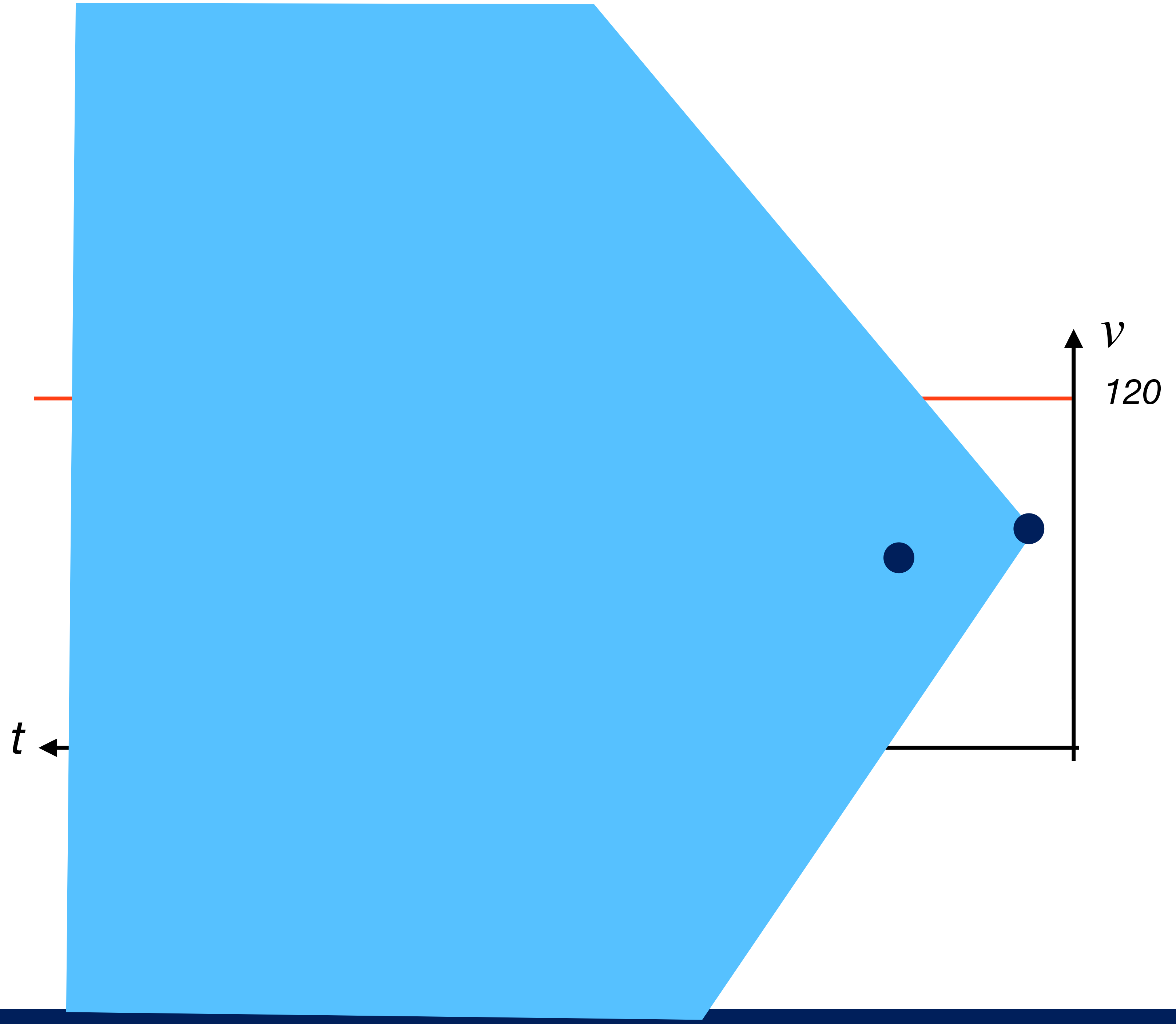
Algorithm: Bounded-time Reachability



Algorithm:
Bounded-time Reachability



Algorithm: Bounded-time Reachability



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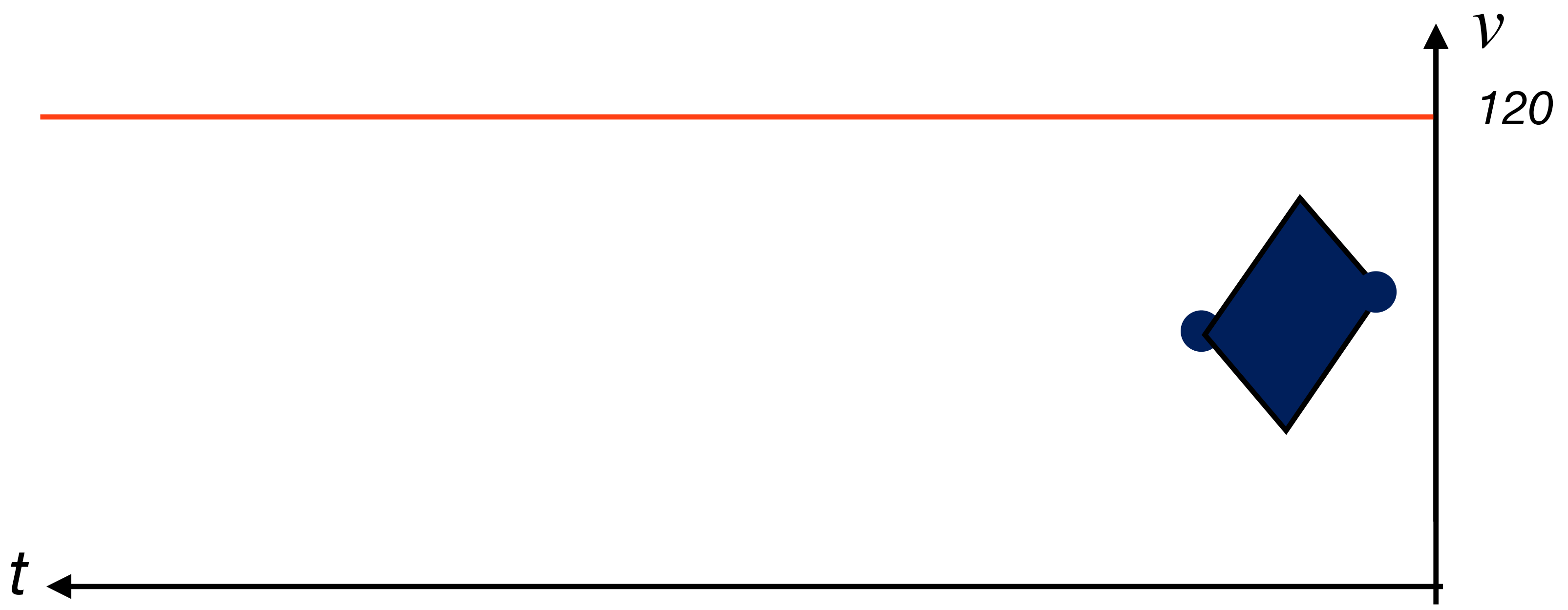

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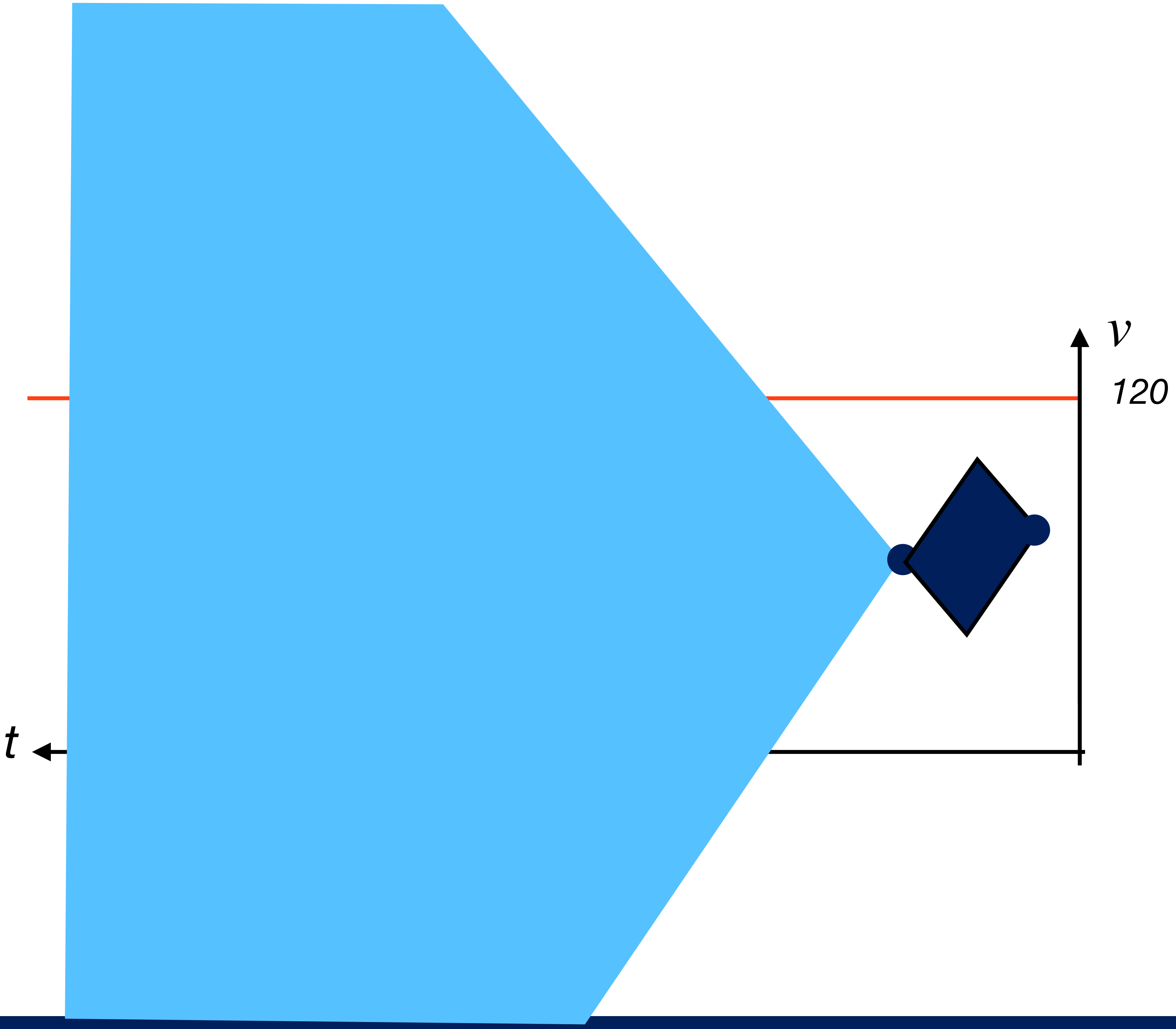

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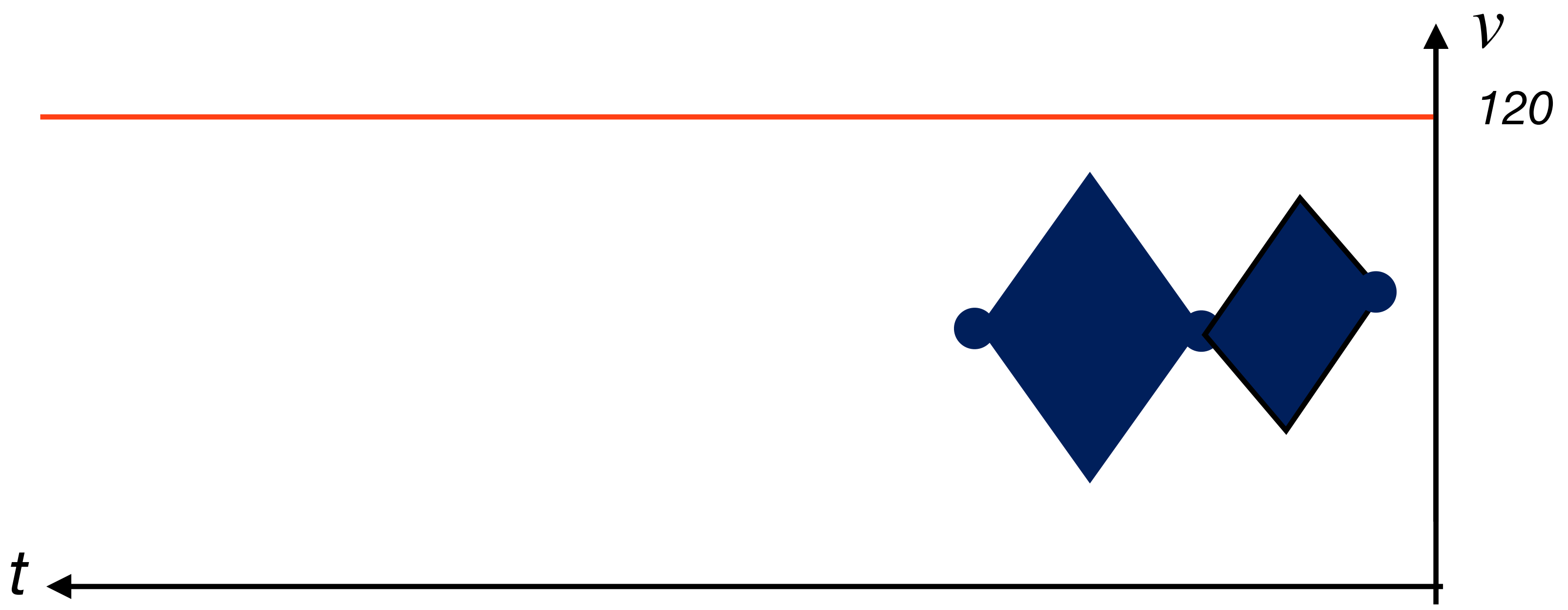

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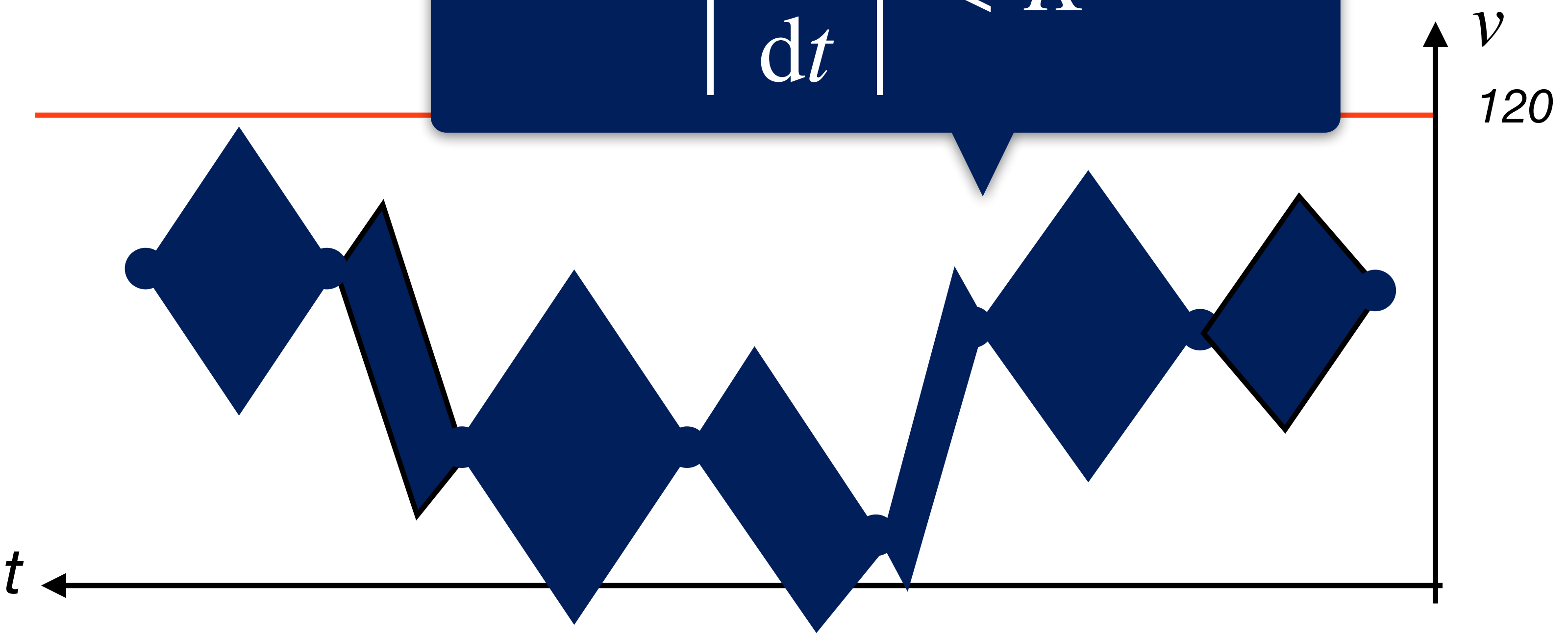


Feasible execution with
$$\left|\frac{\mathrm{d}v}{\mathrm{d}t}\right| < K$$

Implementations

Approach 1: Utilize existing model-checker (PHAVerLite)

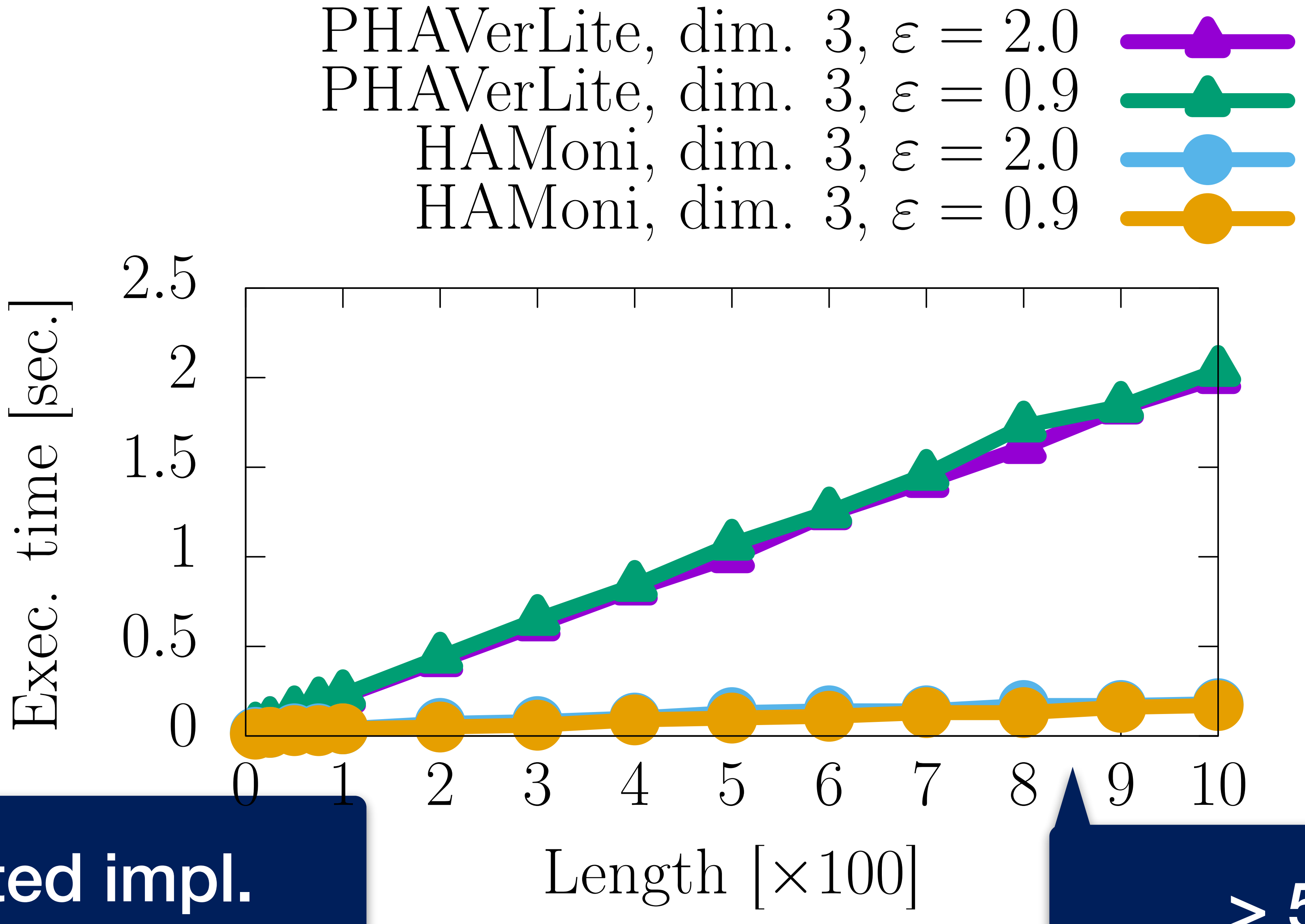
Pros: Highly-optimized reachability analysis impl.

Approach 2: Implement dedicated monitor (HAMoni)

Pros: Best performance in theory

Experiment Results

Changing Observation Length

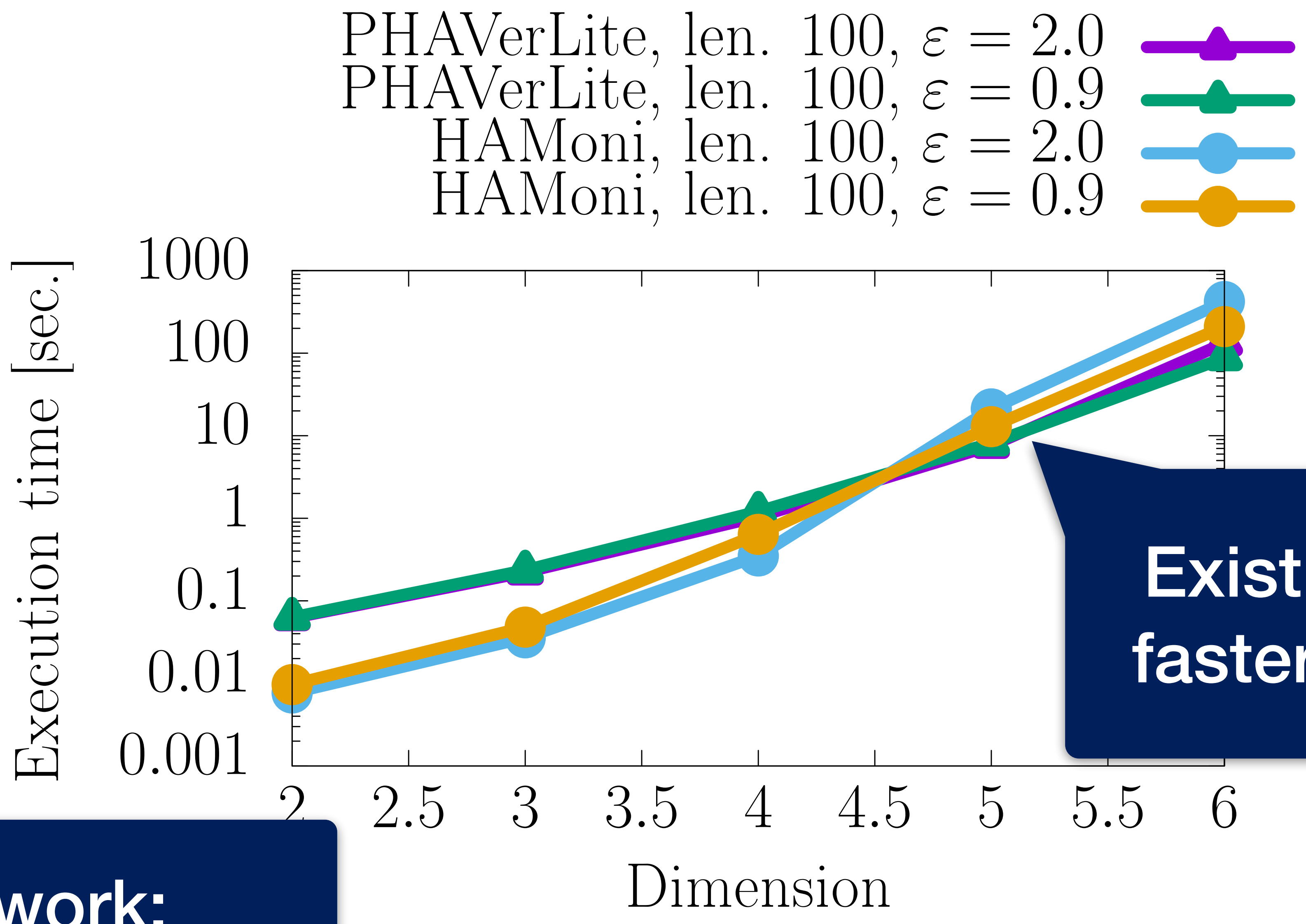


Dedicated impl.
≈ 10x faster

> 5000
samples / sec.

Experiment Results

Changing Model Dimension



Existing tool was faster for dim. > 6

Future work: further optimization

Conclusions

- Proposed model-bounded monitoring

  Bounding model (knowledge): linear HAs $\mathscr{M}$

- Algorithms + implementations

  Idea: bounded-time reachability

- Experiment → effectively monitorable