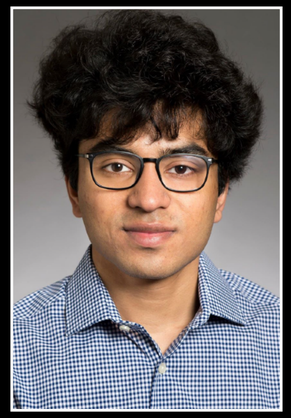
Active Safety Envelopes using Light Curtains with Probabilistic Guarantees

Website: *https://siddancha.github.io/projects/active-safety-envelopes-with-guarantees*



Siddharth Ancha

Gaurav Pathak

Srinivasa Narasimhan

David Held

Carnegie Mellon University

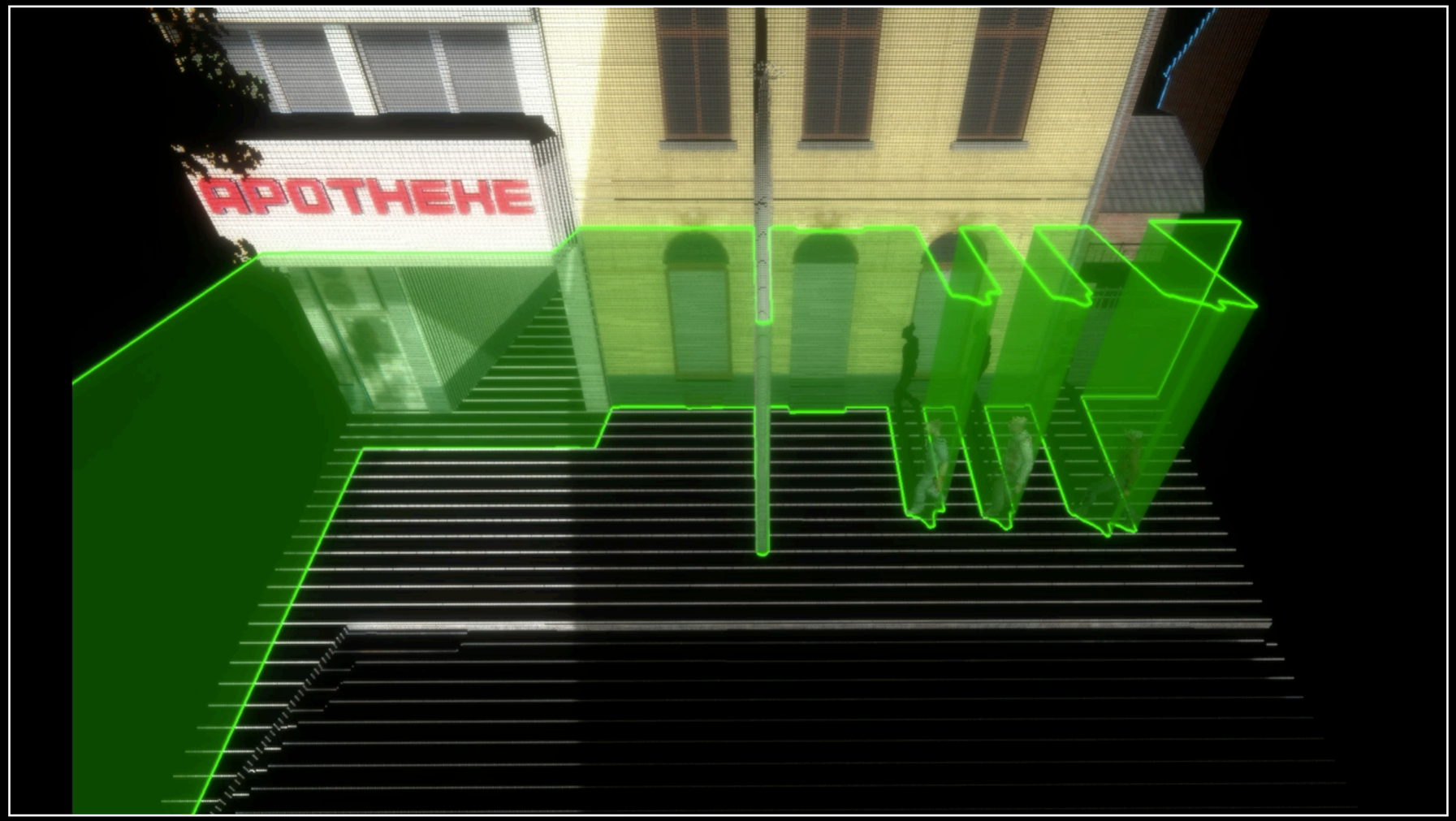
RpAd Robots Perceiving And Doing

THE ROBOTICS INSTITUTE

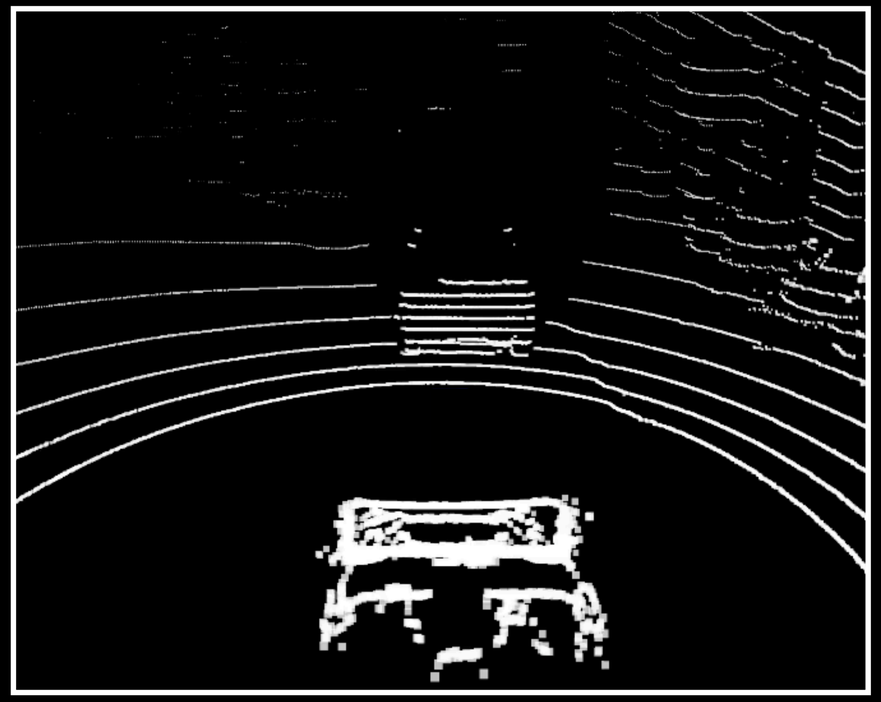
ML MACHINE LEARNING DEPARTMENT

What is a Safety Envelope?

What is a Safety Envelope?

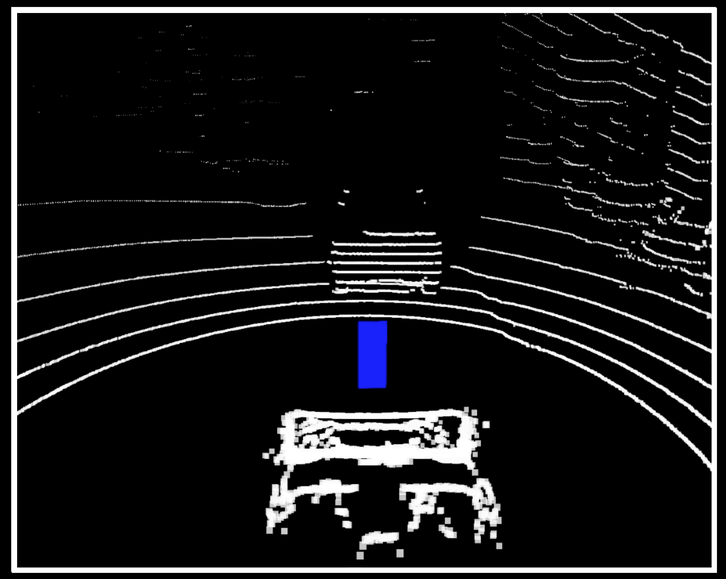


LiDAR



- Low resolution
- Expensive (> $80,000)
- Slow (5-20 Hz)

LiDAR vs. Light Curtain



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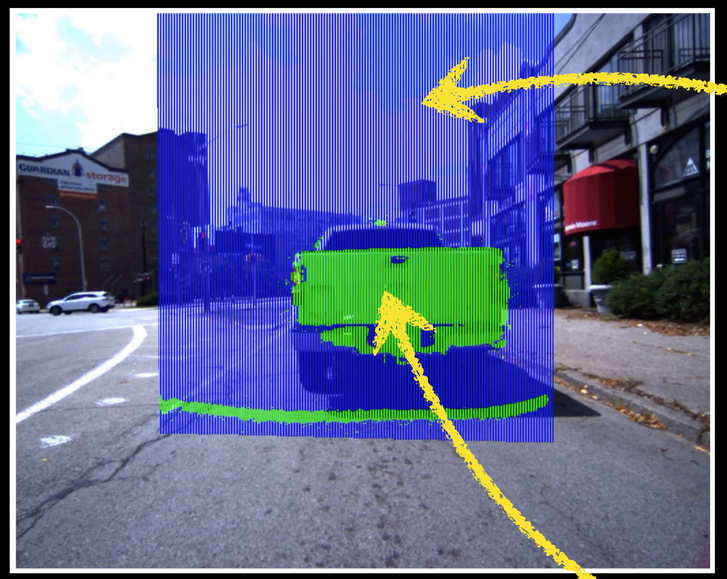


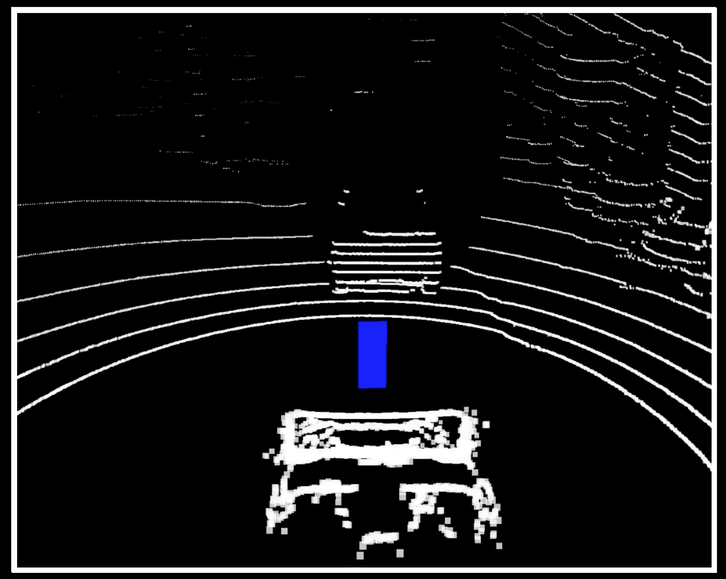
- High resolution
- Inexpensive (~$1000)
- Fast (60 Hz)

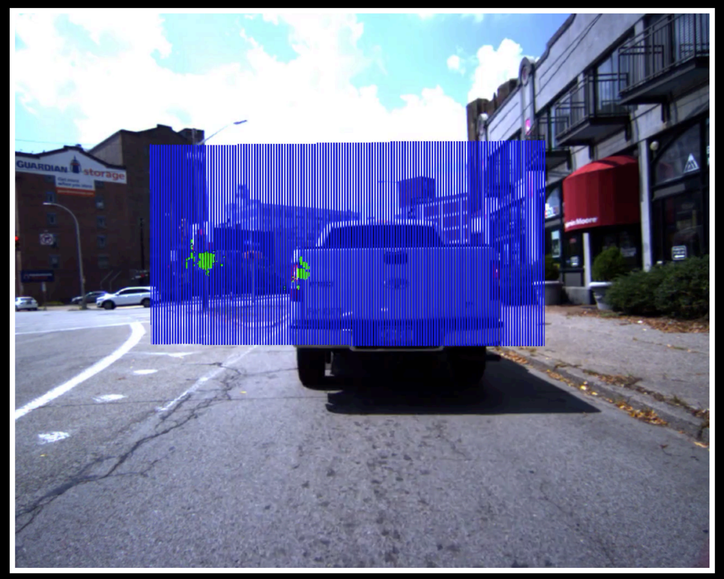
User-selected light curtain

Intersection points

**Agile Depth Sensing Using Triangulation Light Curtains,* Bartels et. al. 2019

LiDAR vs. Light Curtain



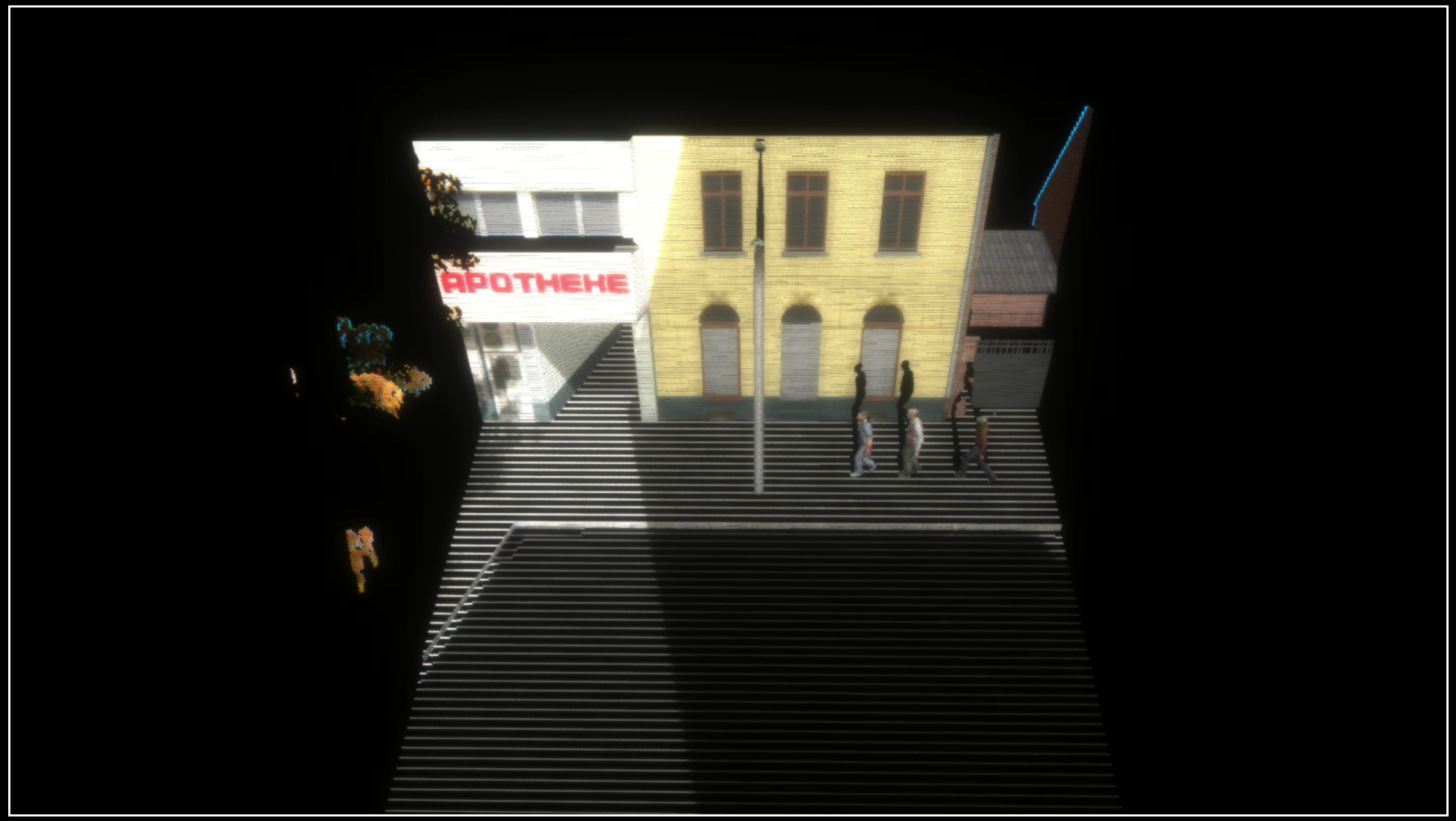


- Low resolution
- Expensive (> $80,000)
- Slow (5-20 Hz)

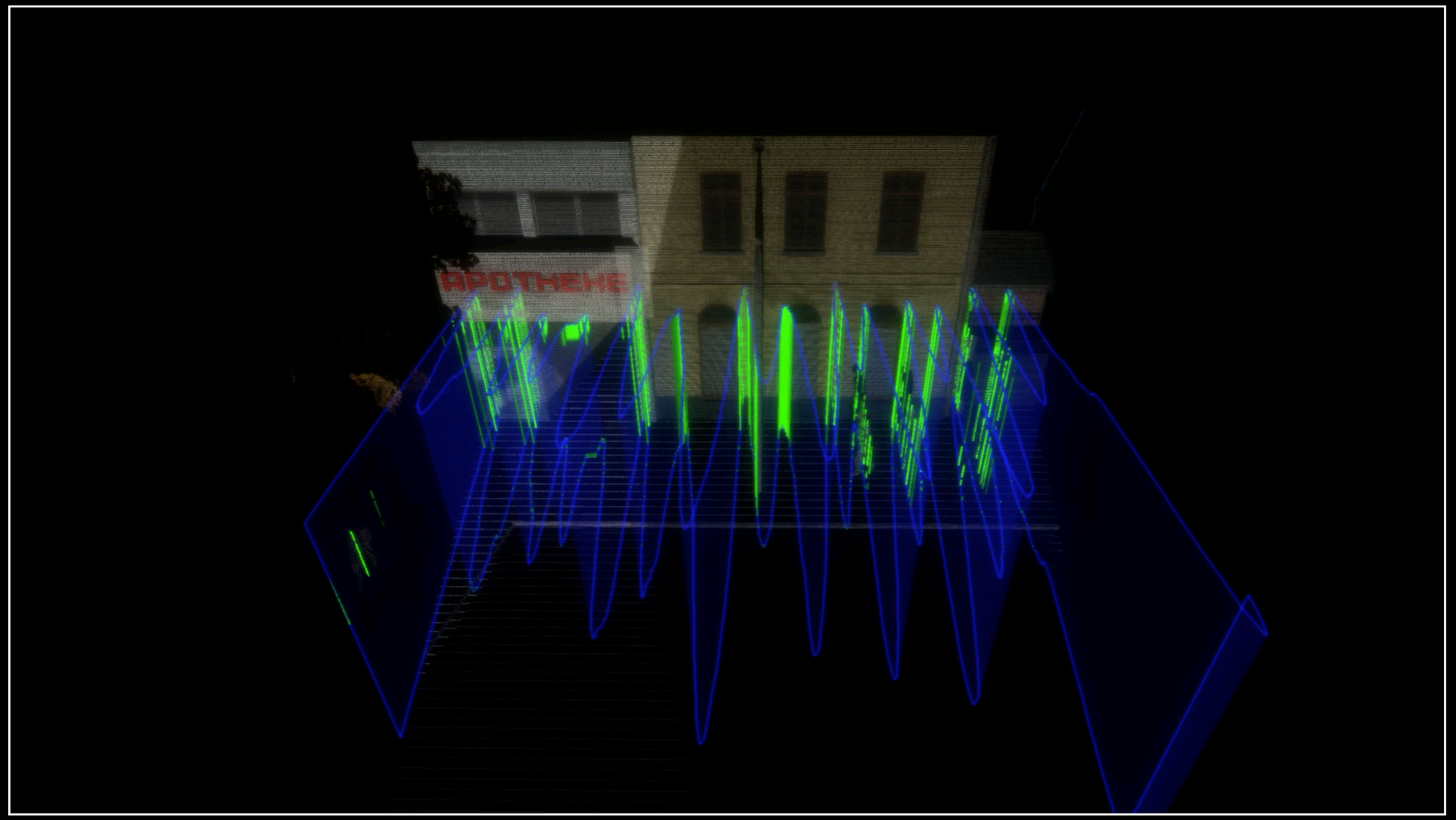
- High resolution
- Inexpensive (~$1000)
- Fast (60 Hz)
- User control required!

**Agile Depth Sensing Using Triangulation Light Curtains,* Bartels et. al. 2019

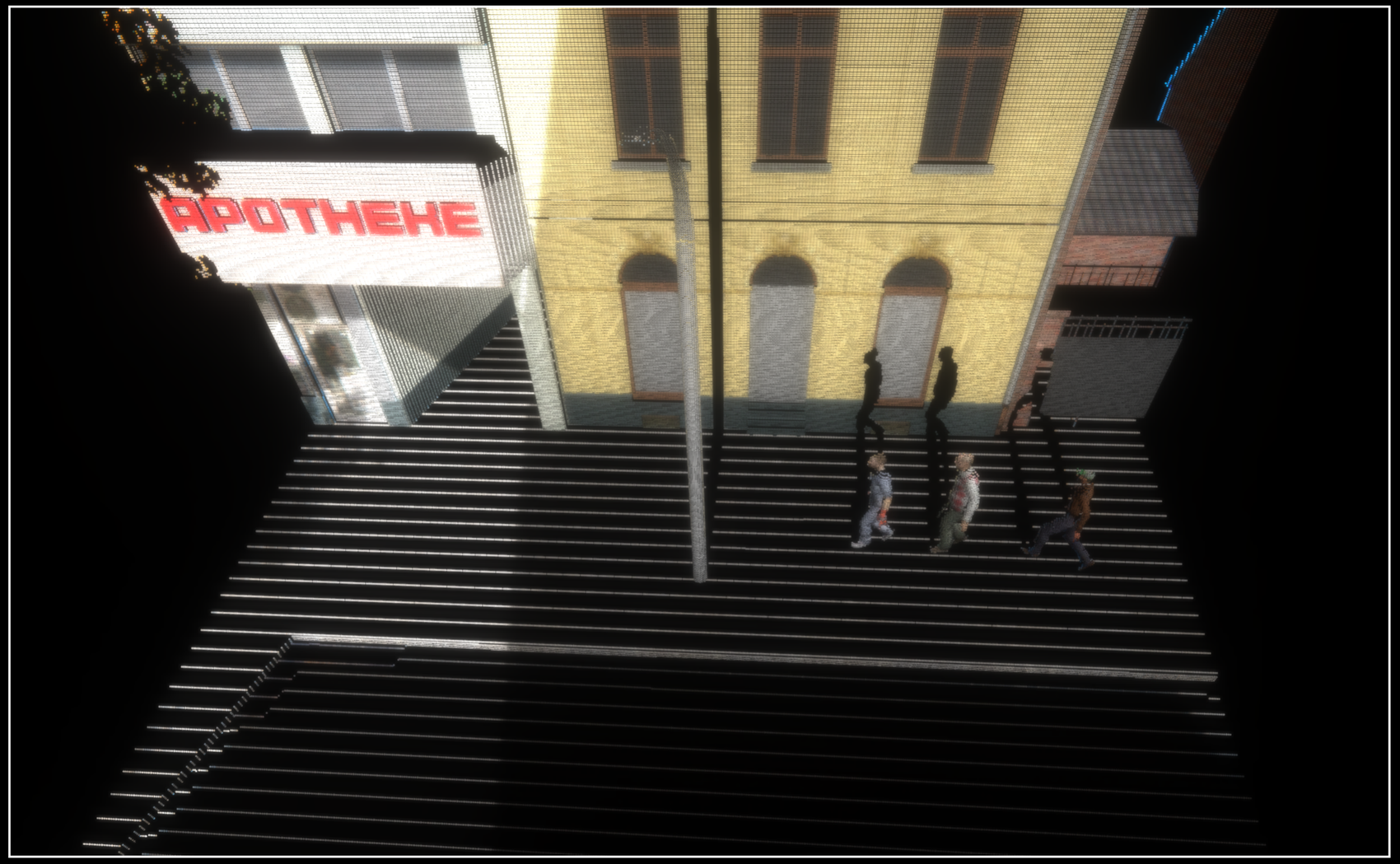
Random Curtains can Discover Obstacles



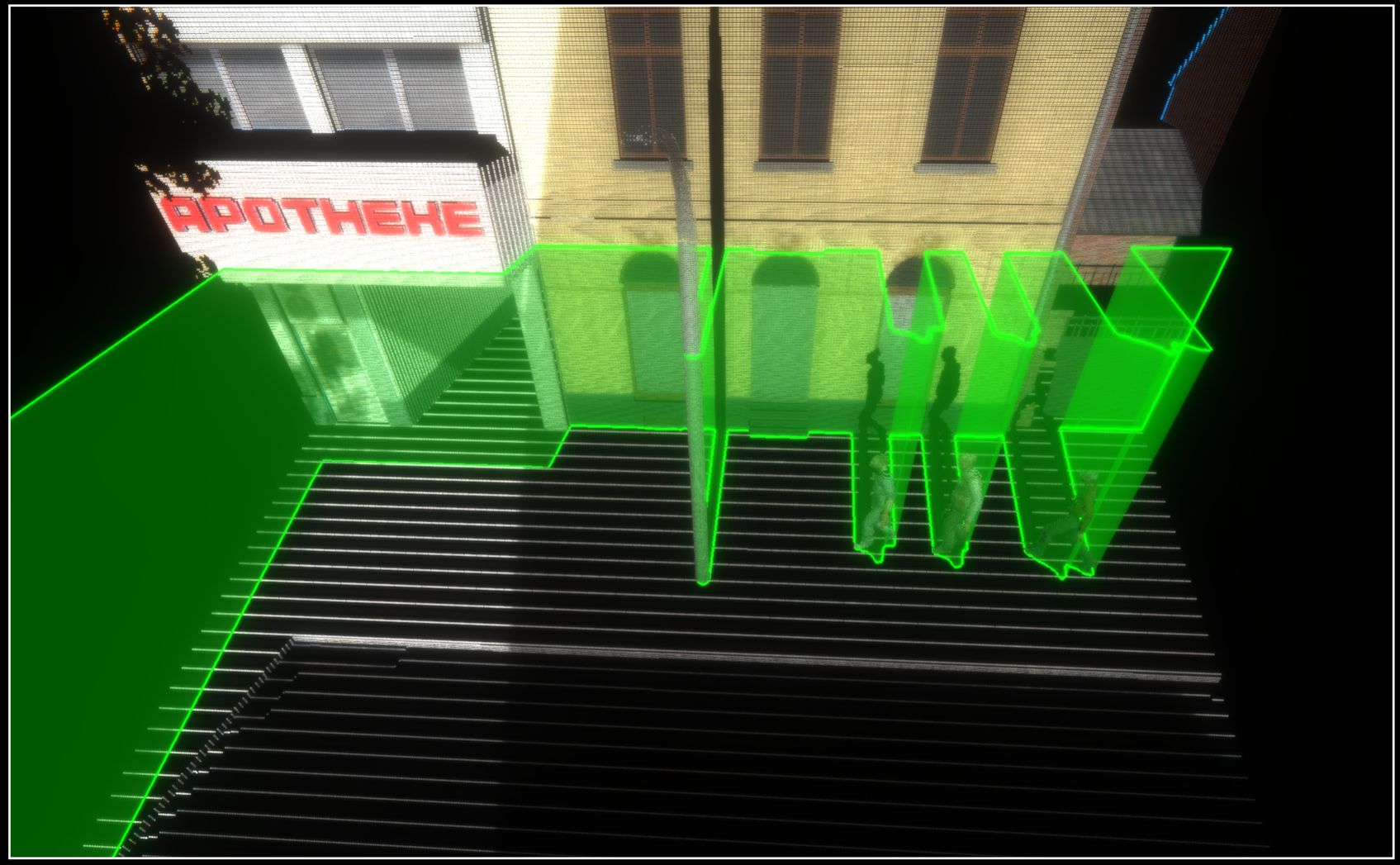
Random Curtains can Discover Obstacles



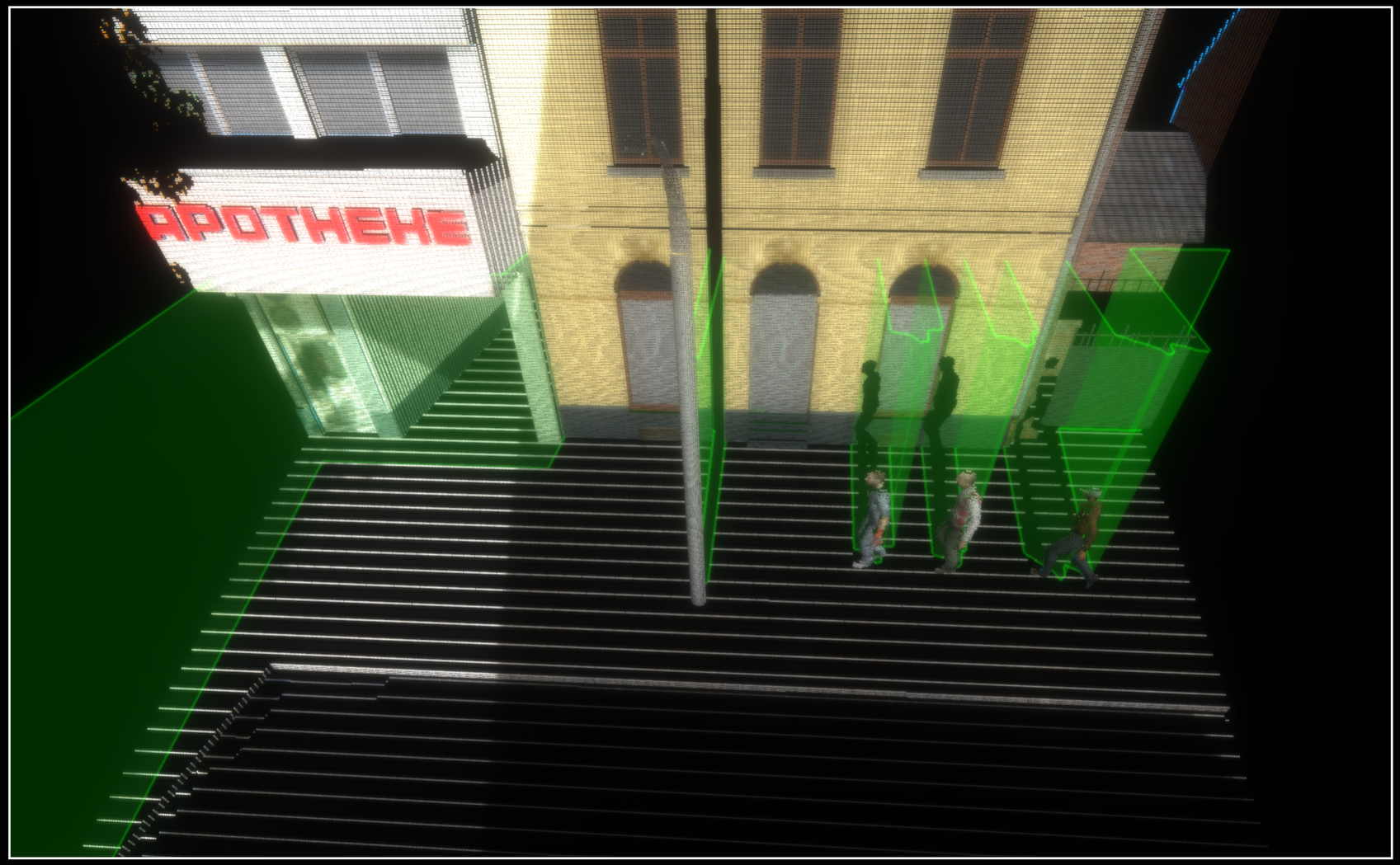
Forecasting Safety Envelopes



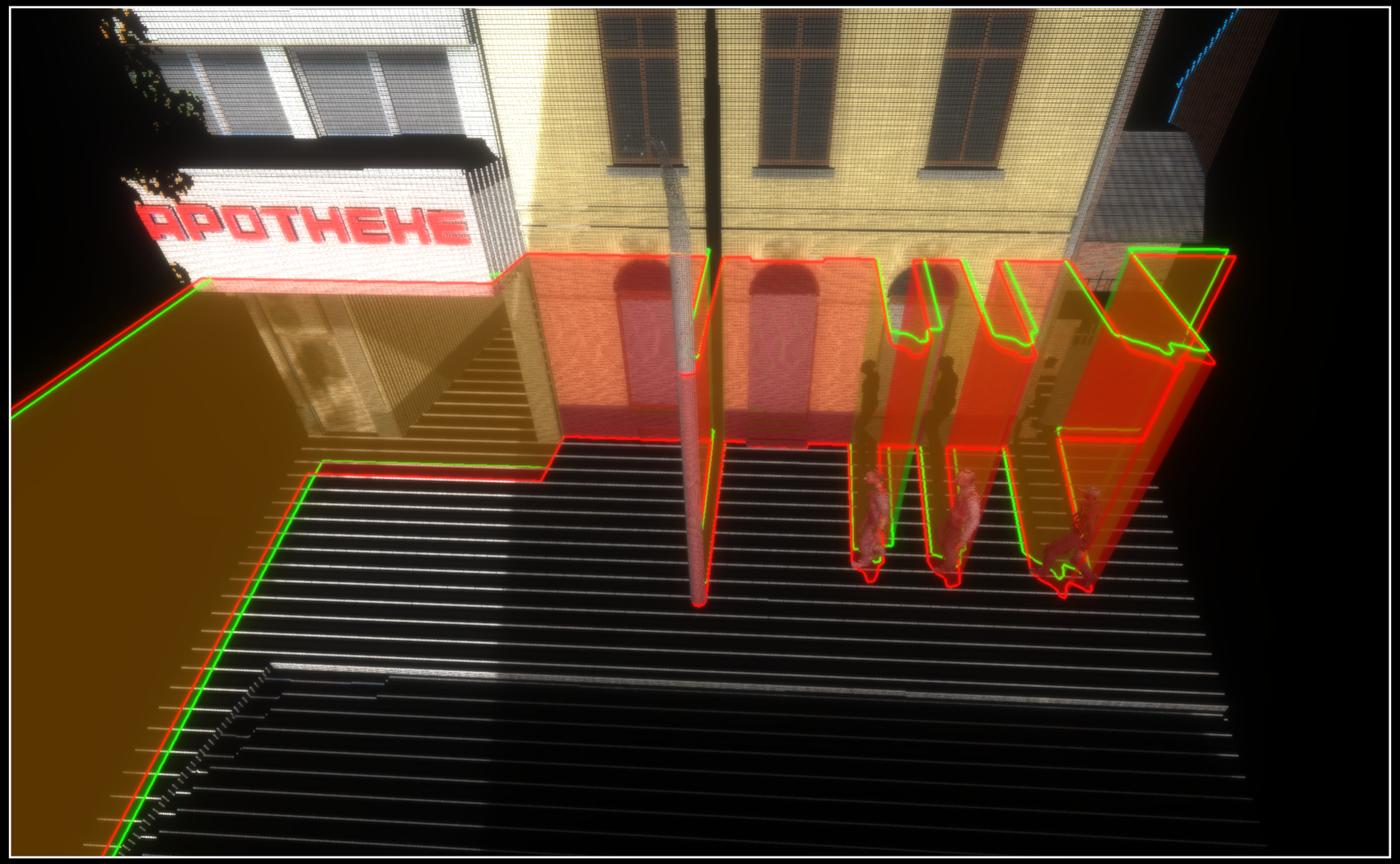
Safety Envelope of Current Frame



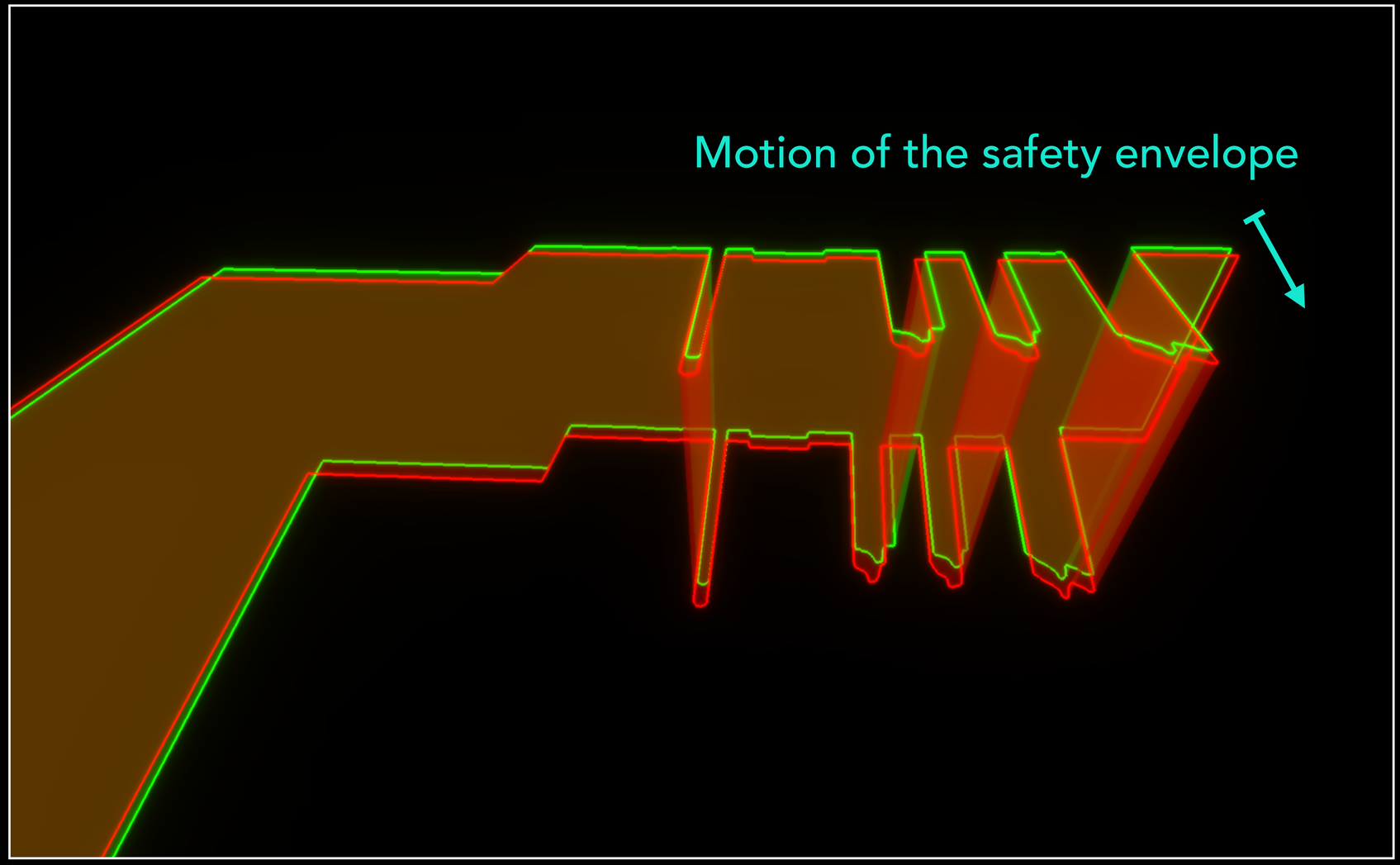
Scene changes in the next timestep



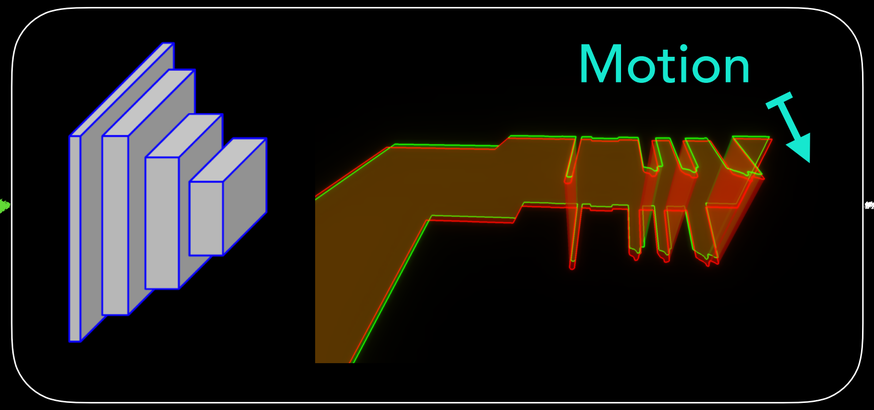
Safety Envelope of Next Frame



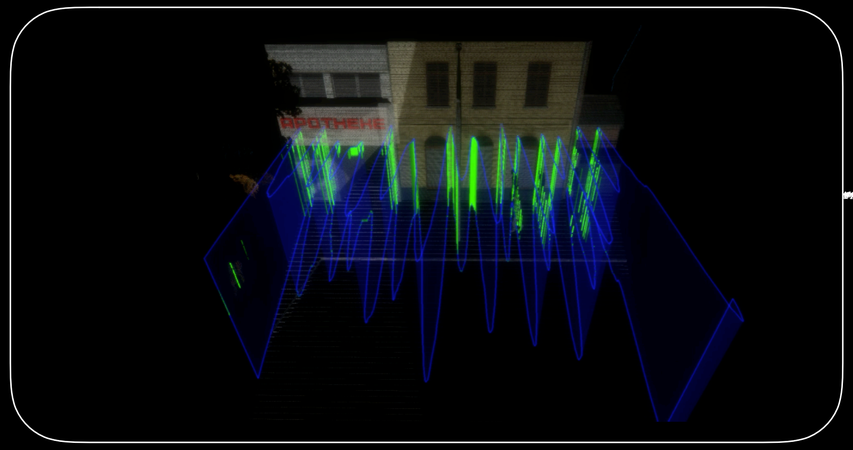
Forecasting Safety Envelopes



Active Light Curtain Placement Pipeline

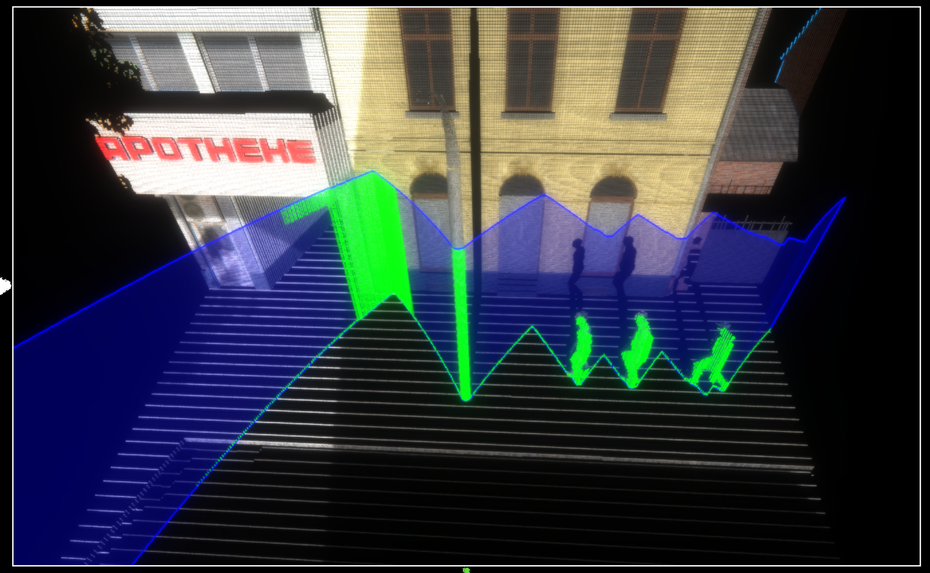


Neural Network Forecasting



Random Curtains

Curtain placed at
predicted safety envelope



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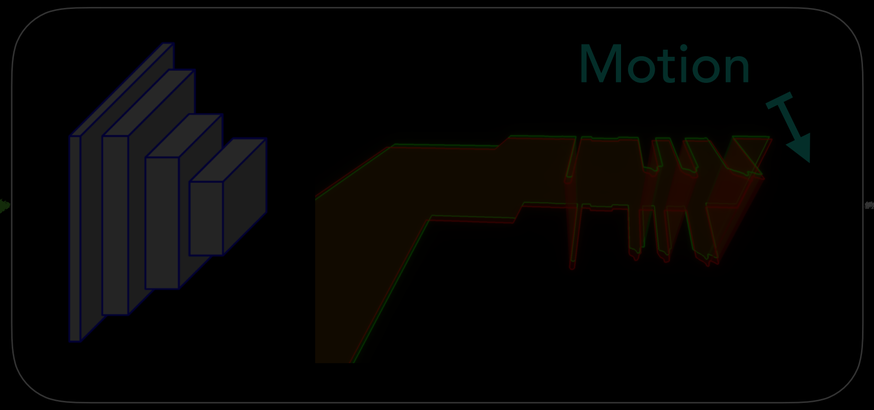
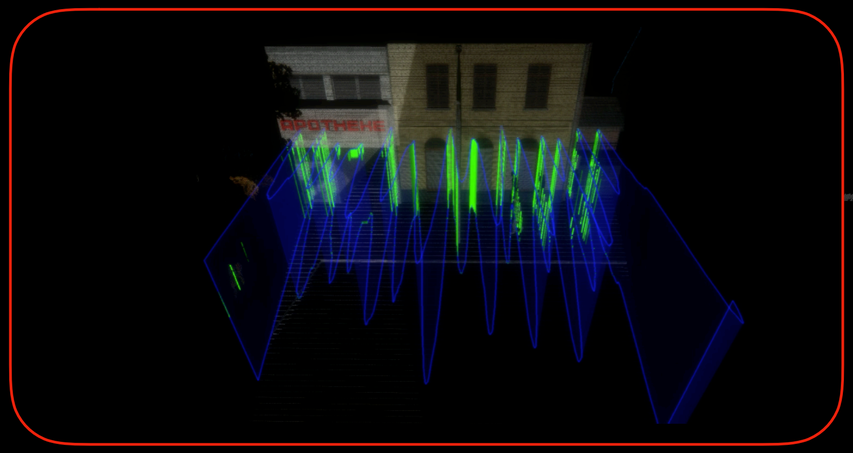


Theoretical analysis?



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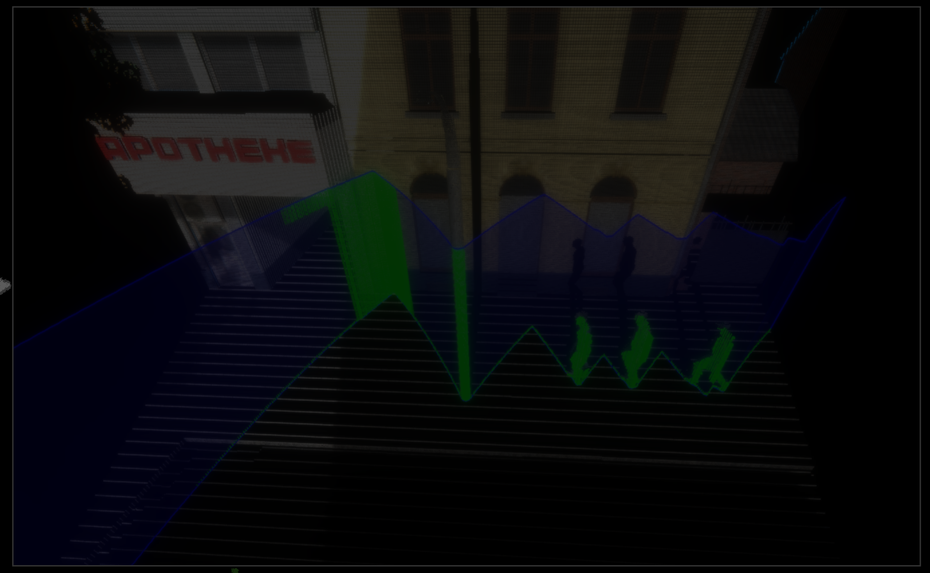
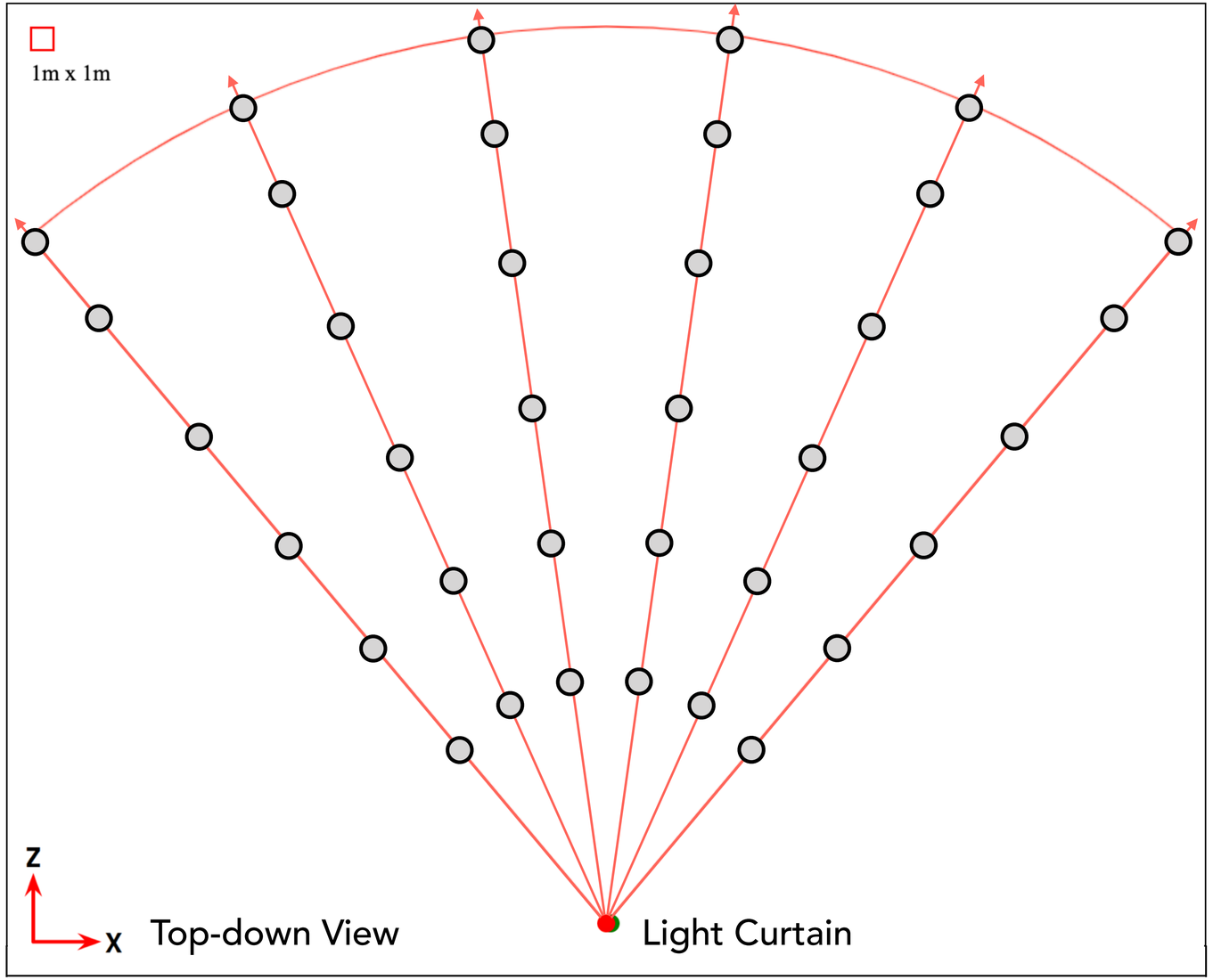


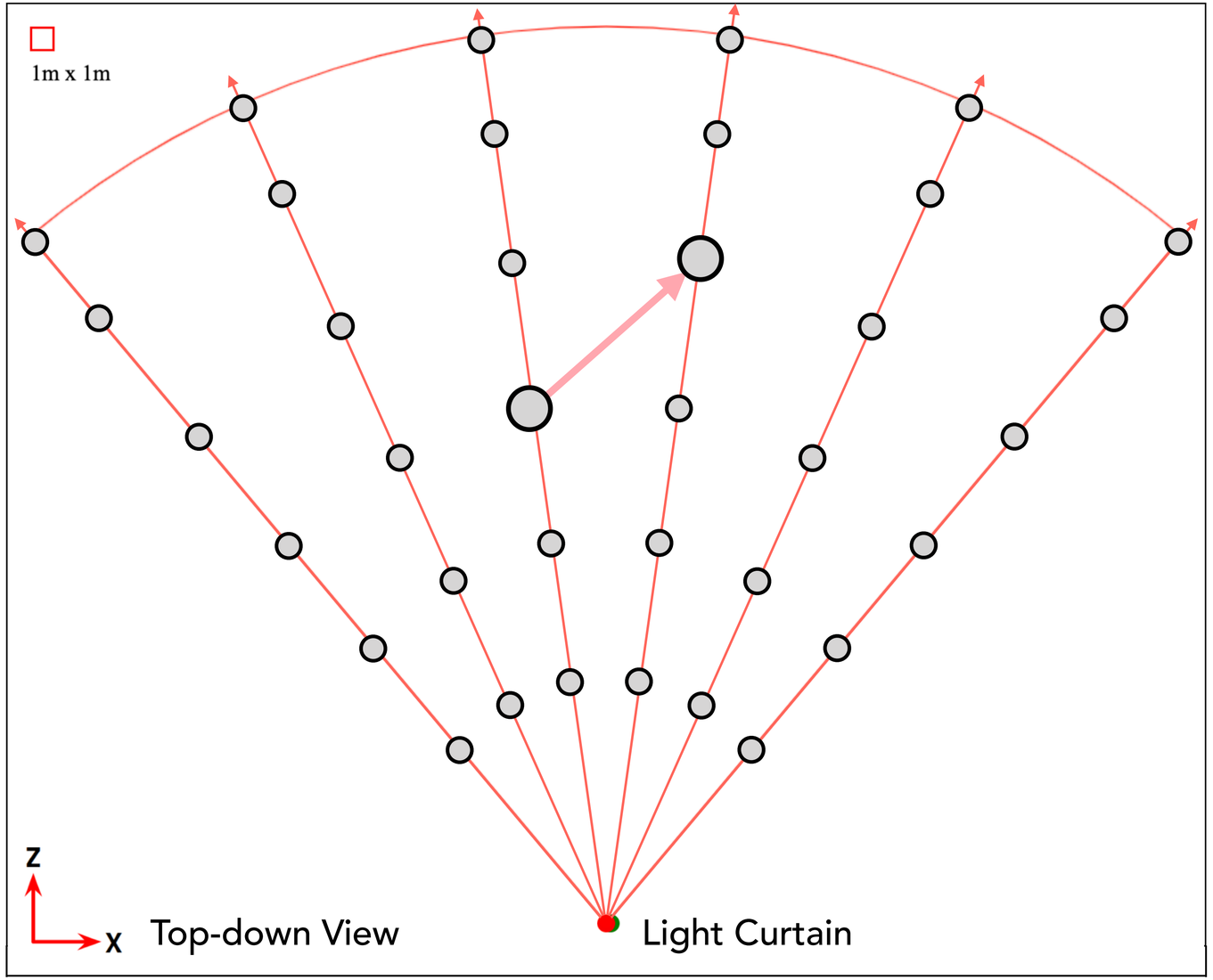
Light Curtain

Intersection Points

Constraint Graph



Constraint Graph



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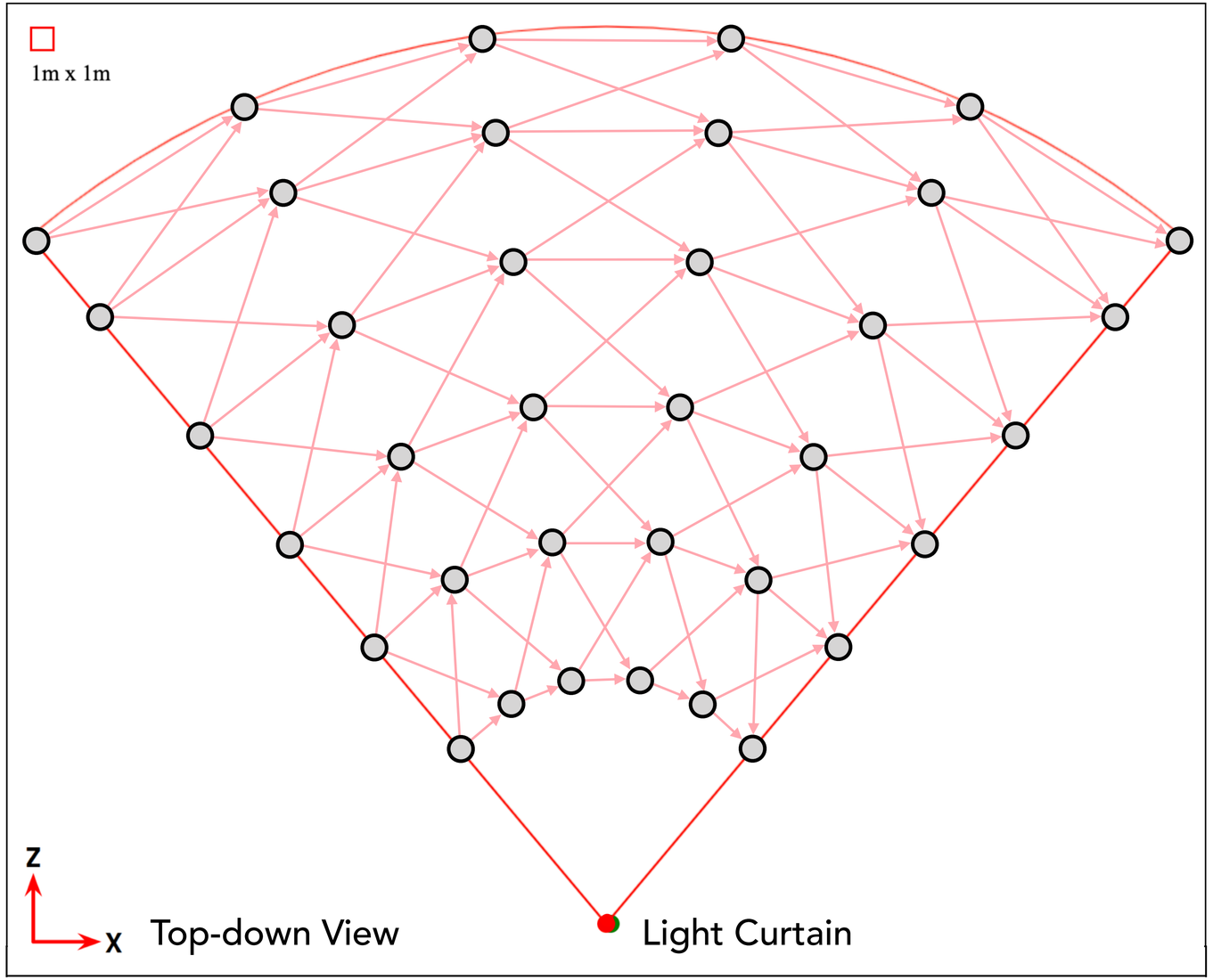
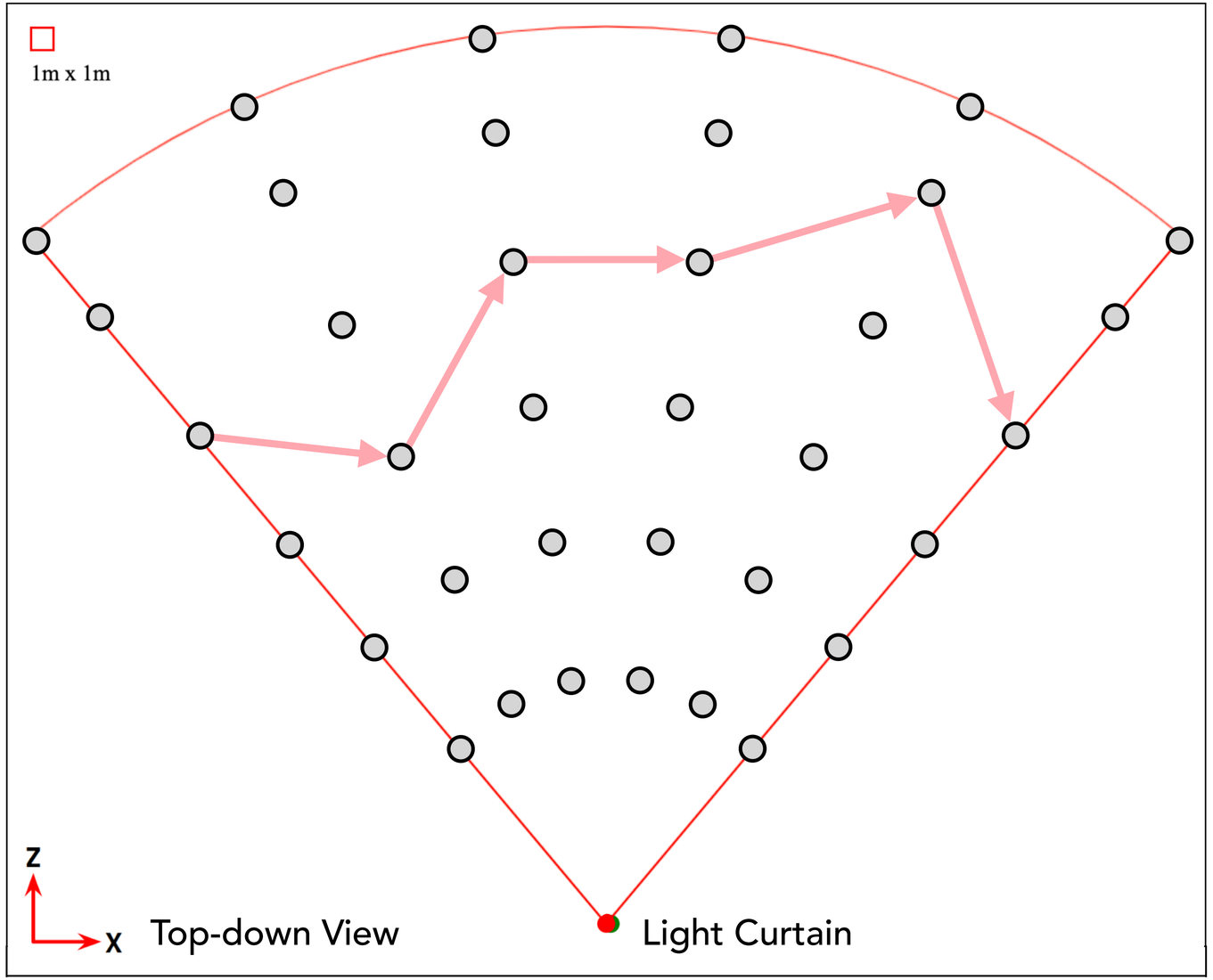


Feasible Curtain



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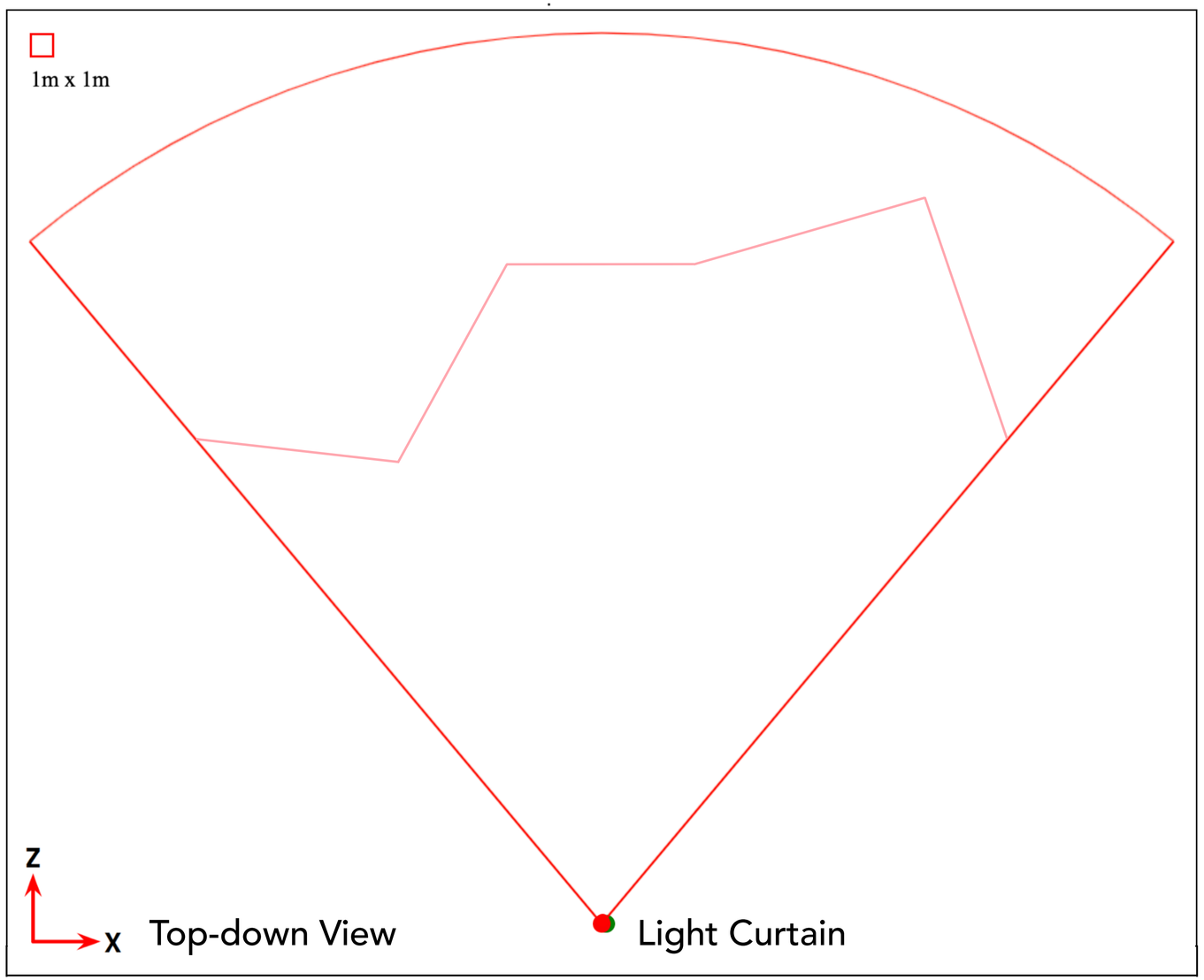
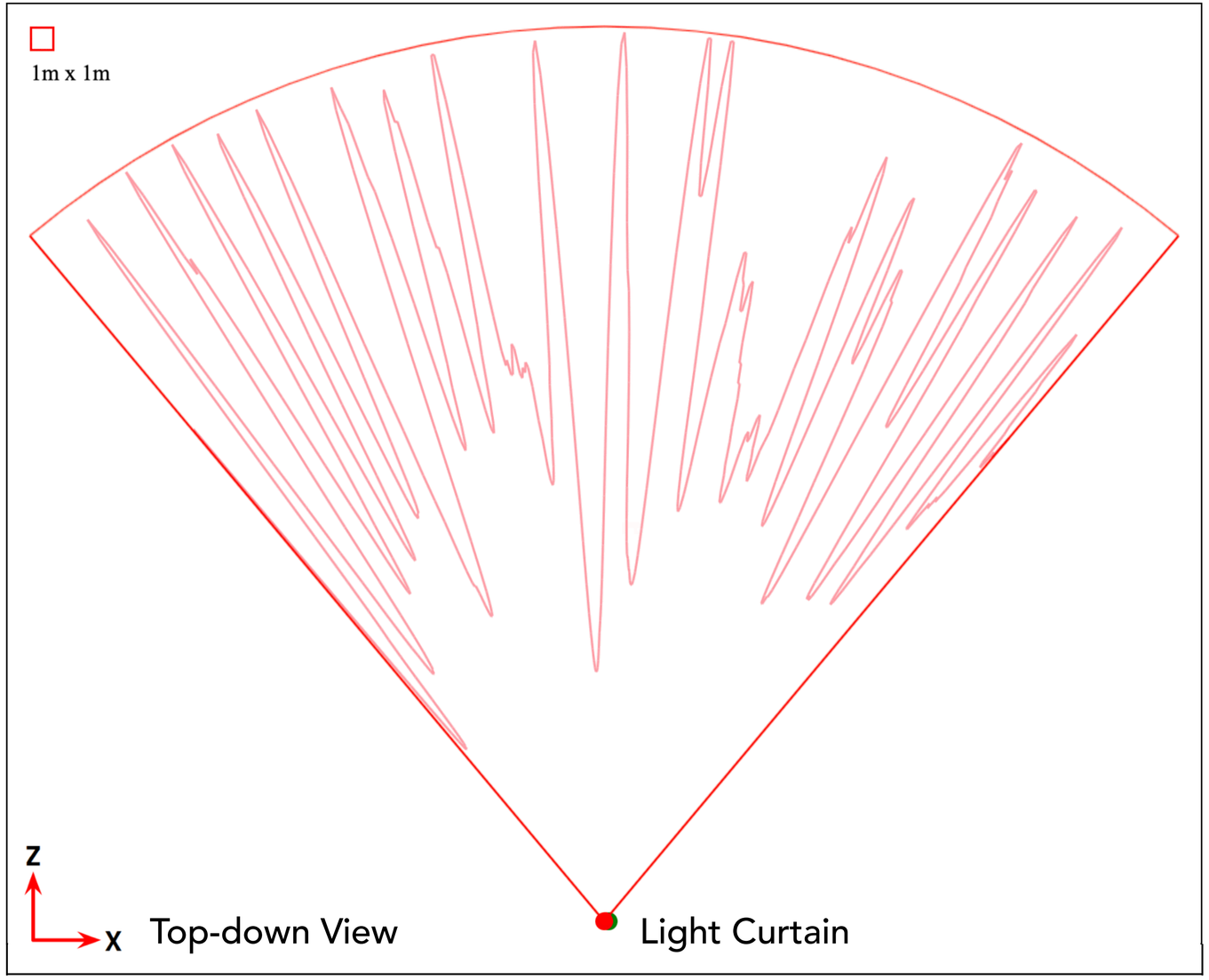
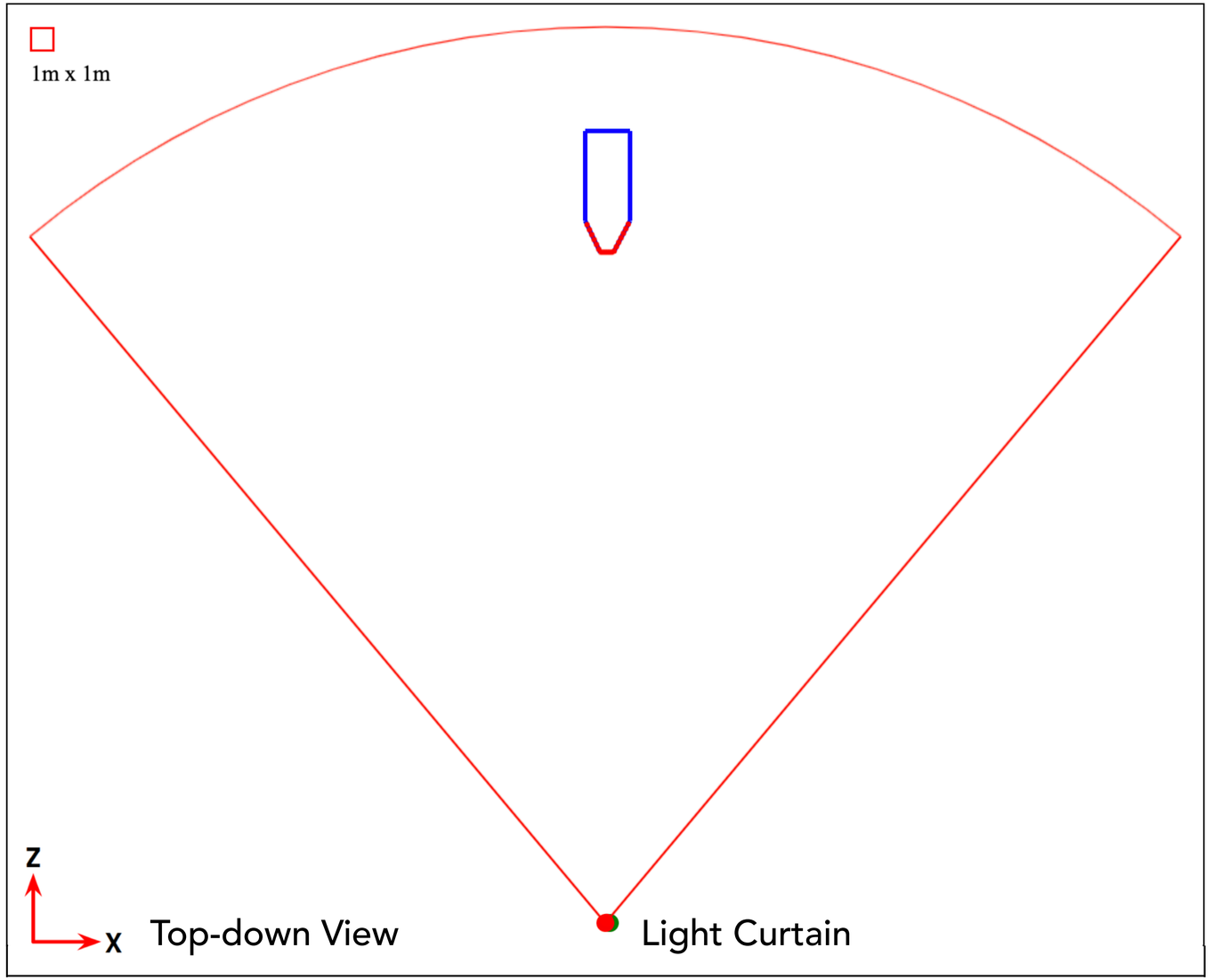


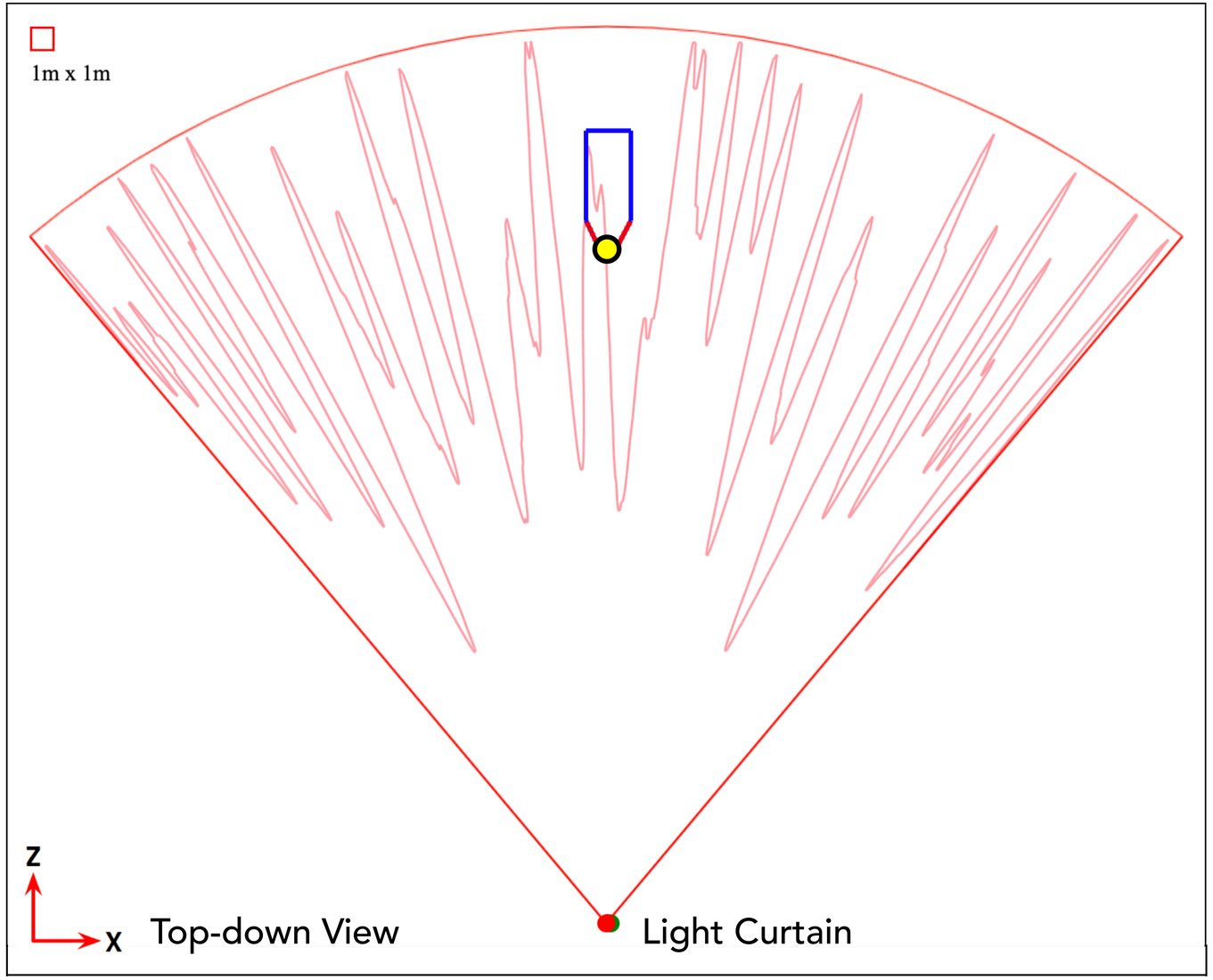
Random Curtains



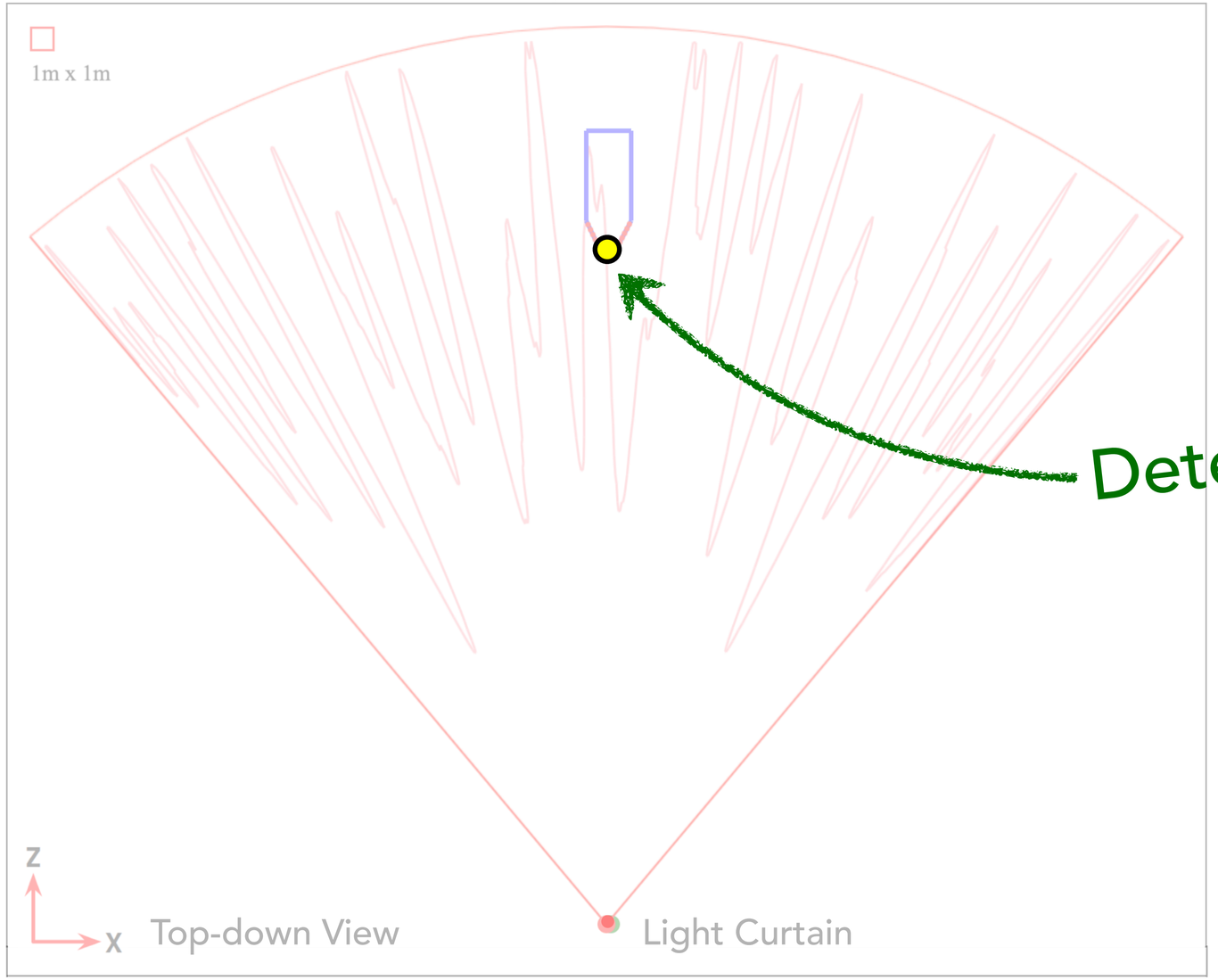
Theoretical Analysis of Random Curtain Detection



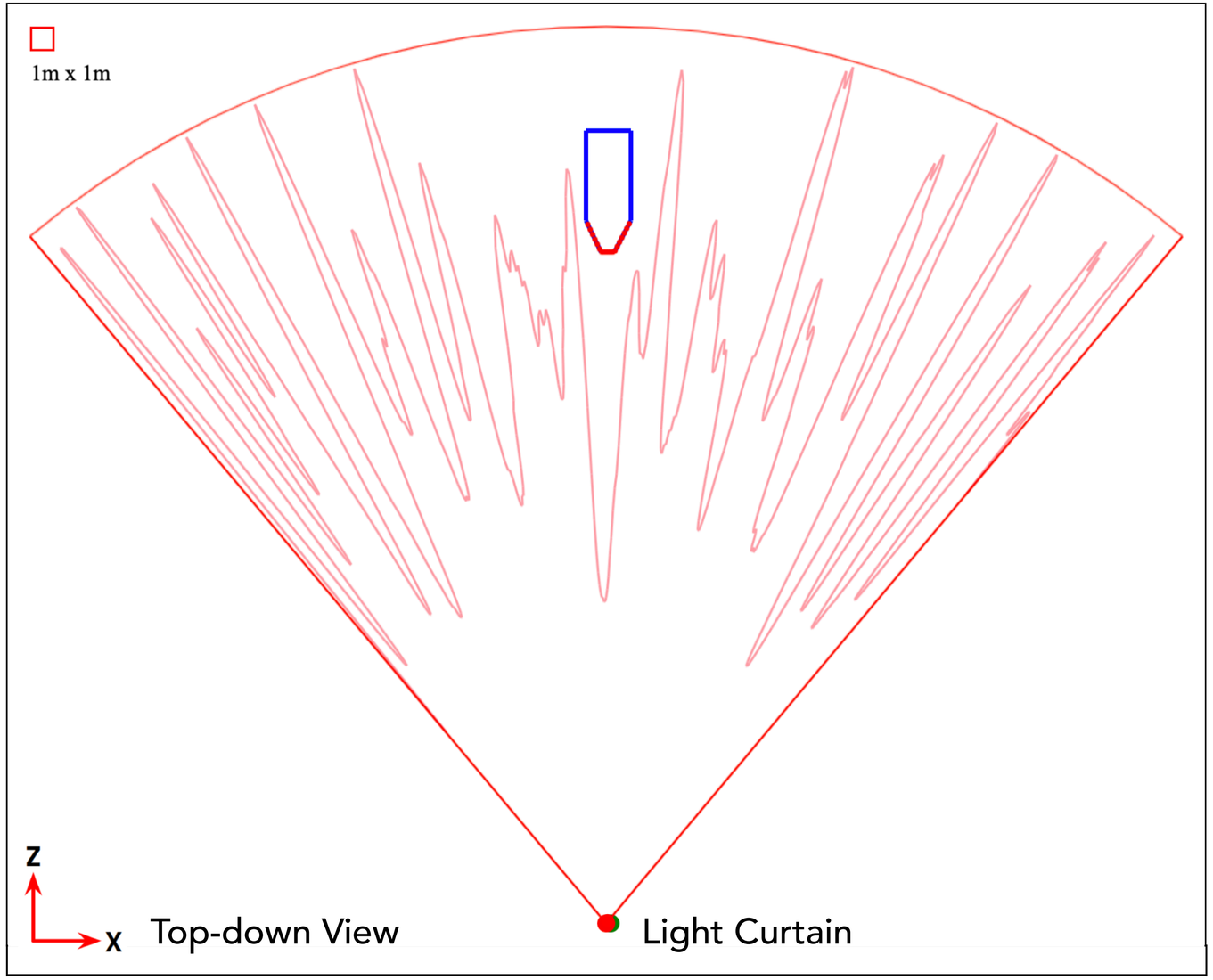
Obstacle Detected by Random Curtain



Obstacle Detected by Random Curtain



Obstacle Missed by Random Curtain



Computing detection probability: Naive approach

$$\mathrm{P}(\textbf{Detection}) = \sum_{\mathbf{C} \in \mathscr{C}} \mathrm{P}(\mathbf{C}) \cdot \mathbb{1}\{\mathbf{C} \textbf{ detects obstacle}\}$$

Computing detection probability: Naive approach

$$\mathrm{P}(\textbf{Detection}) = \sum_{\mathbf{C} \in \mathscr{C}} \mathrm{P}(\mathbf{C}) \cdot \mathbb{1}\{\mathbf{C} \textbf{ detects obstacle}\}$$

Set of all feasible curtains

Computing detection probability: Naive approach

$$\mathrm{P}(\textbf{Detection}) = \sum_{\mathbf{C} \in \mathscr{C}} \mathrm{P}(\mathbf{C}) \cdot \mathbb{1}\{\mathbf{C} \textbf{ detects obstacle}\}$$

Curtain sampling probability

Computing detection probability: Naive approach

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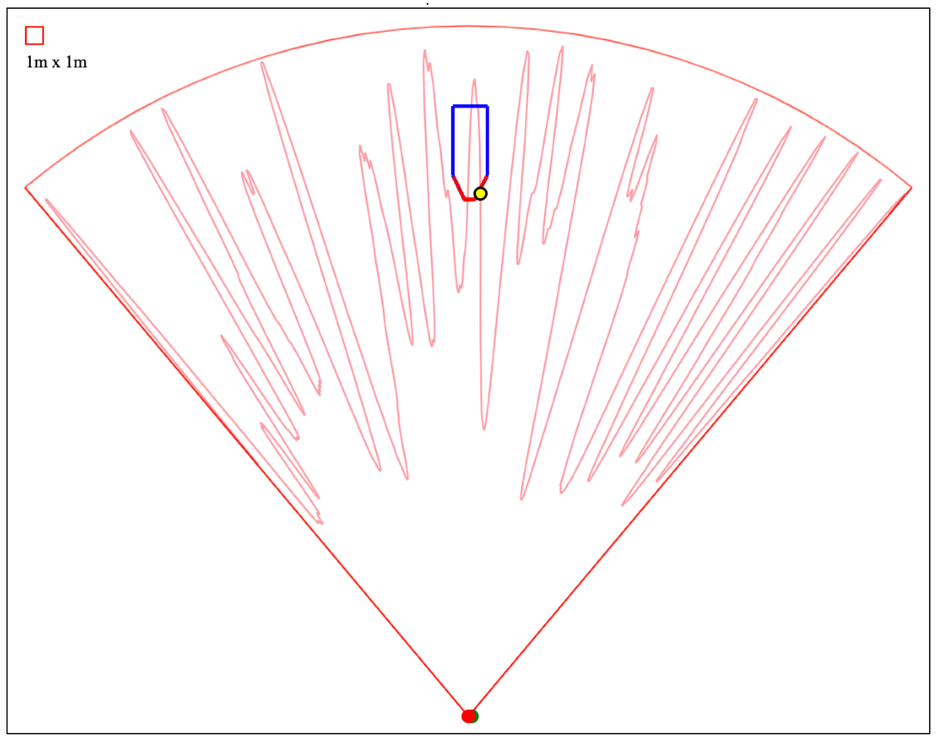
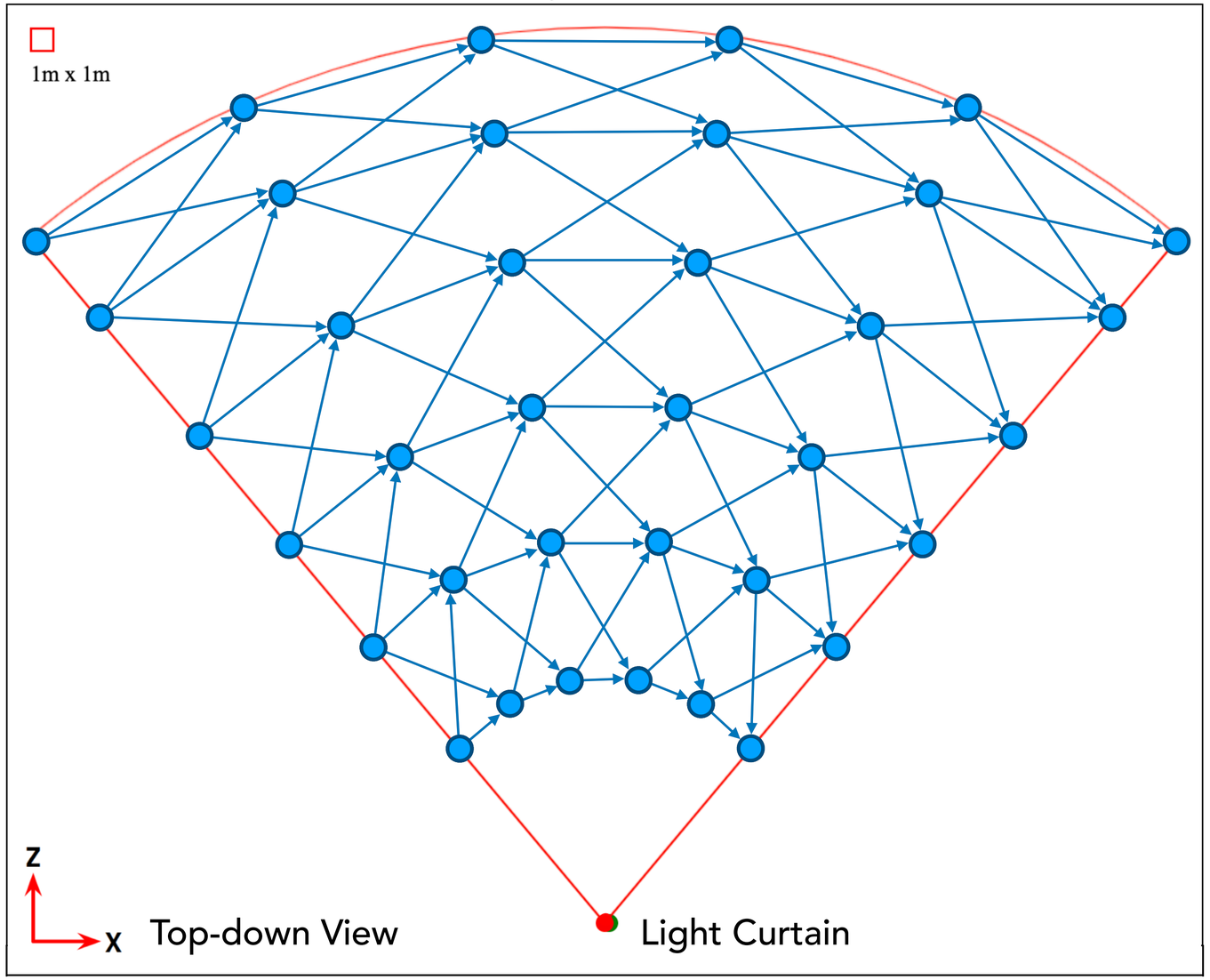
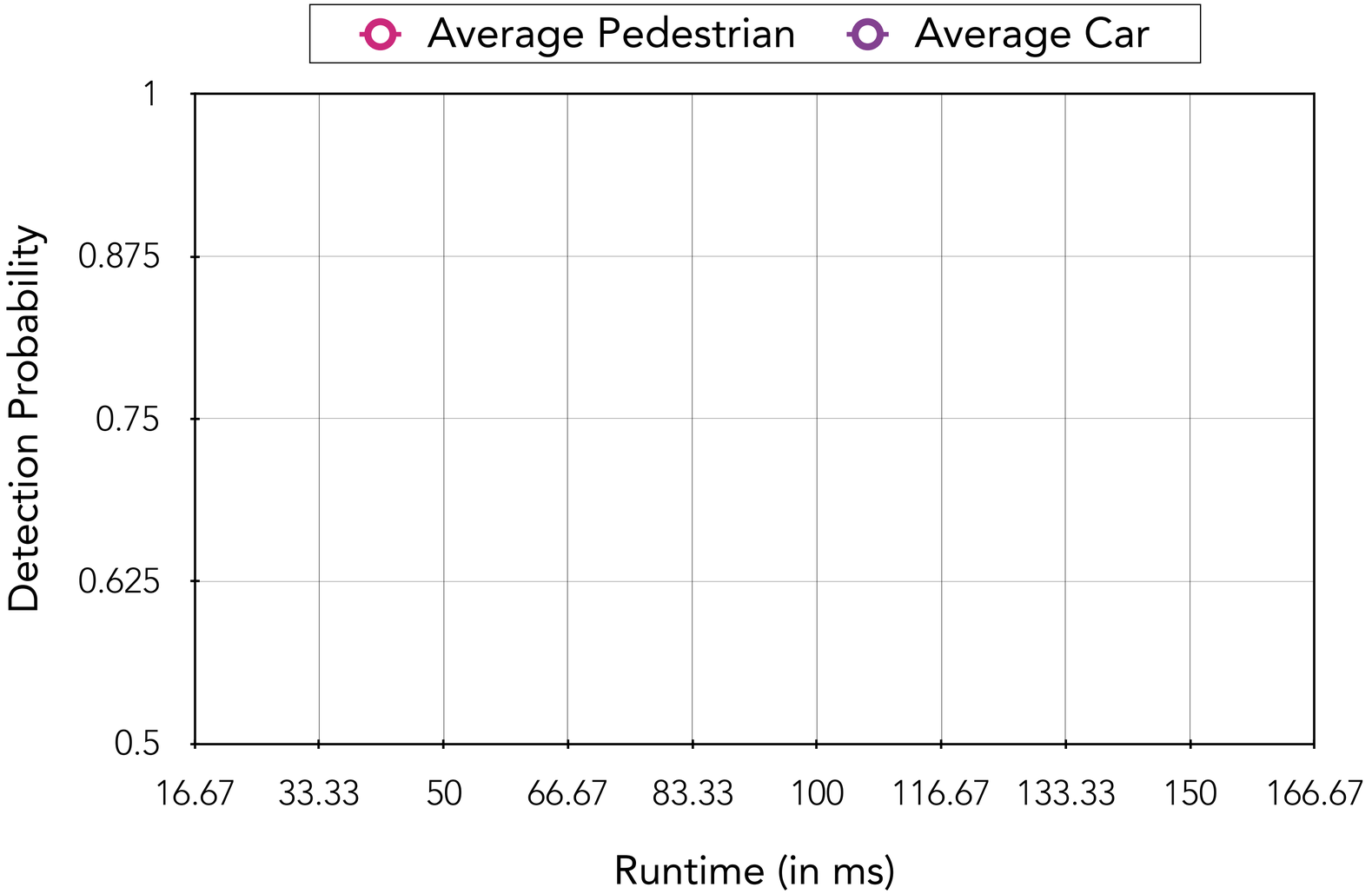


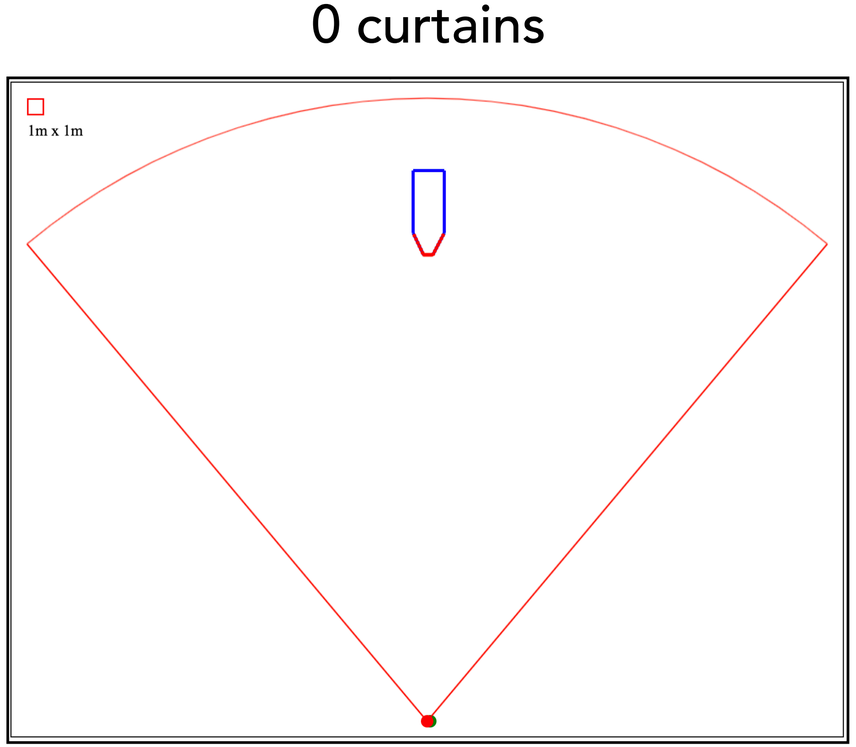
Too large!

Our approach: Dynamic Programming



Example of Random Curtain Analysis





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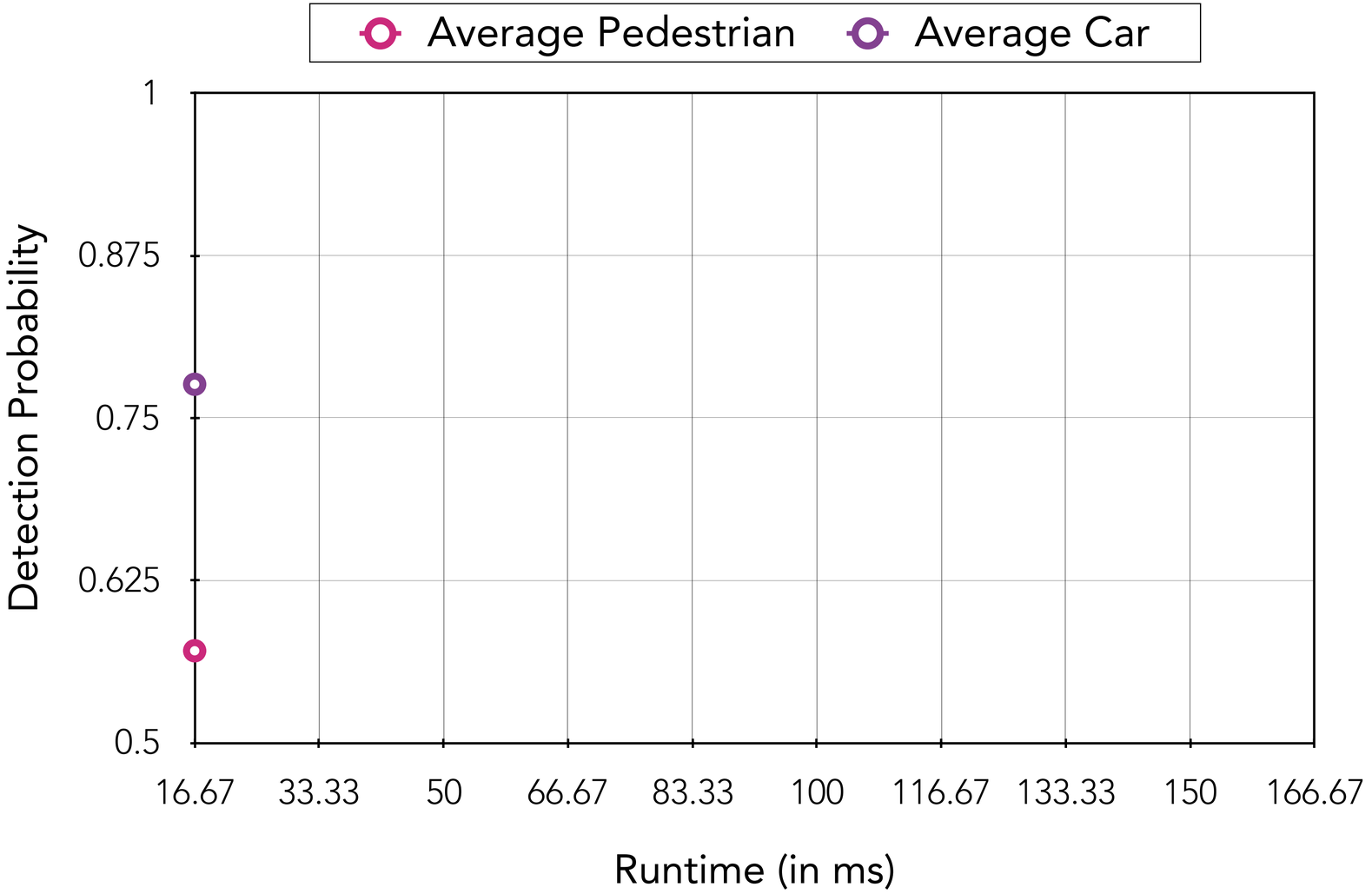

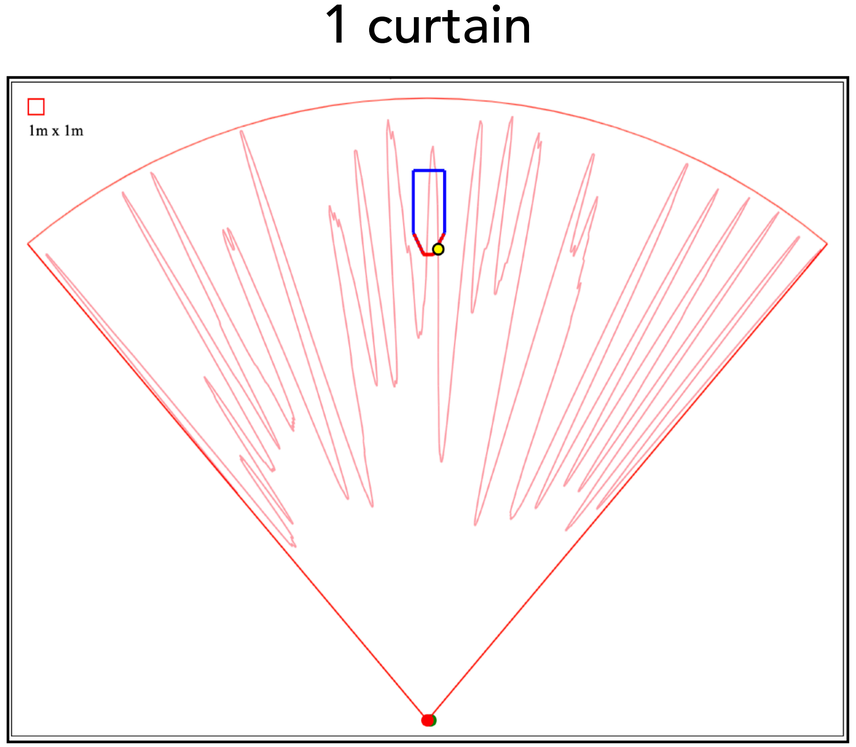

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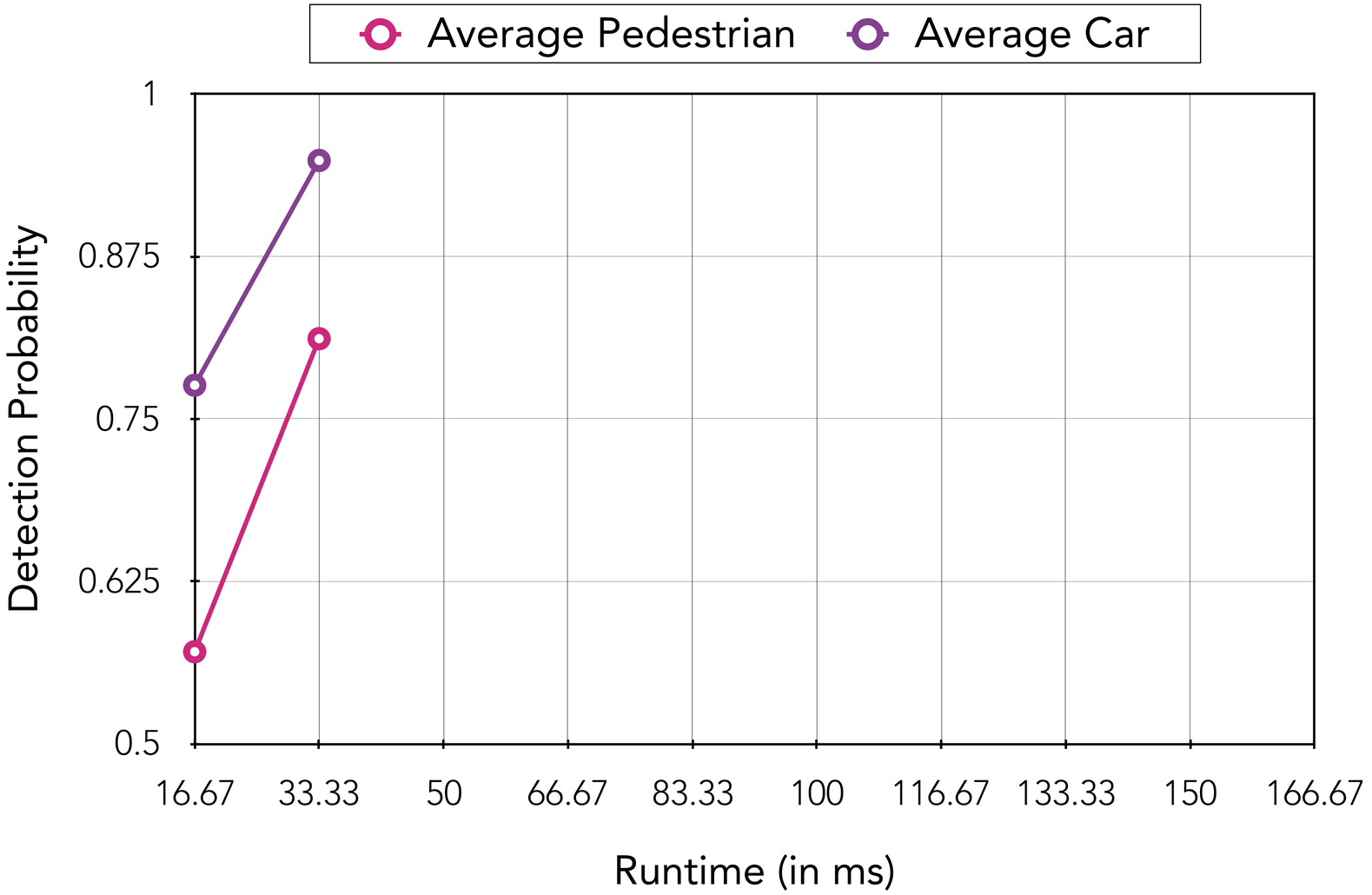

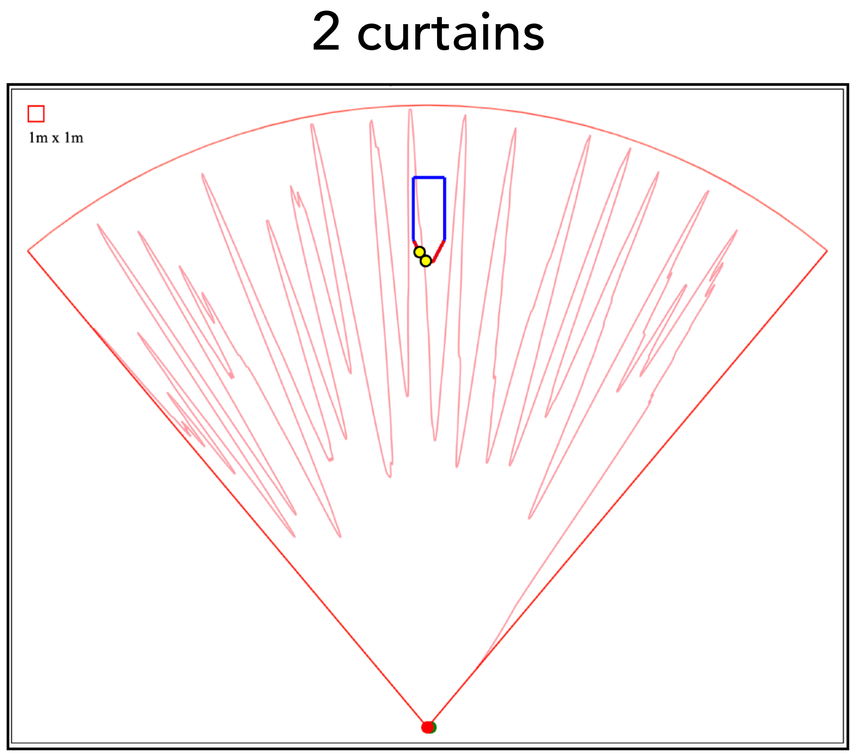

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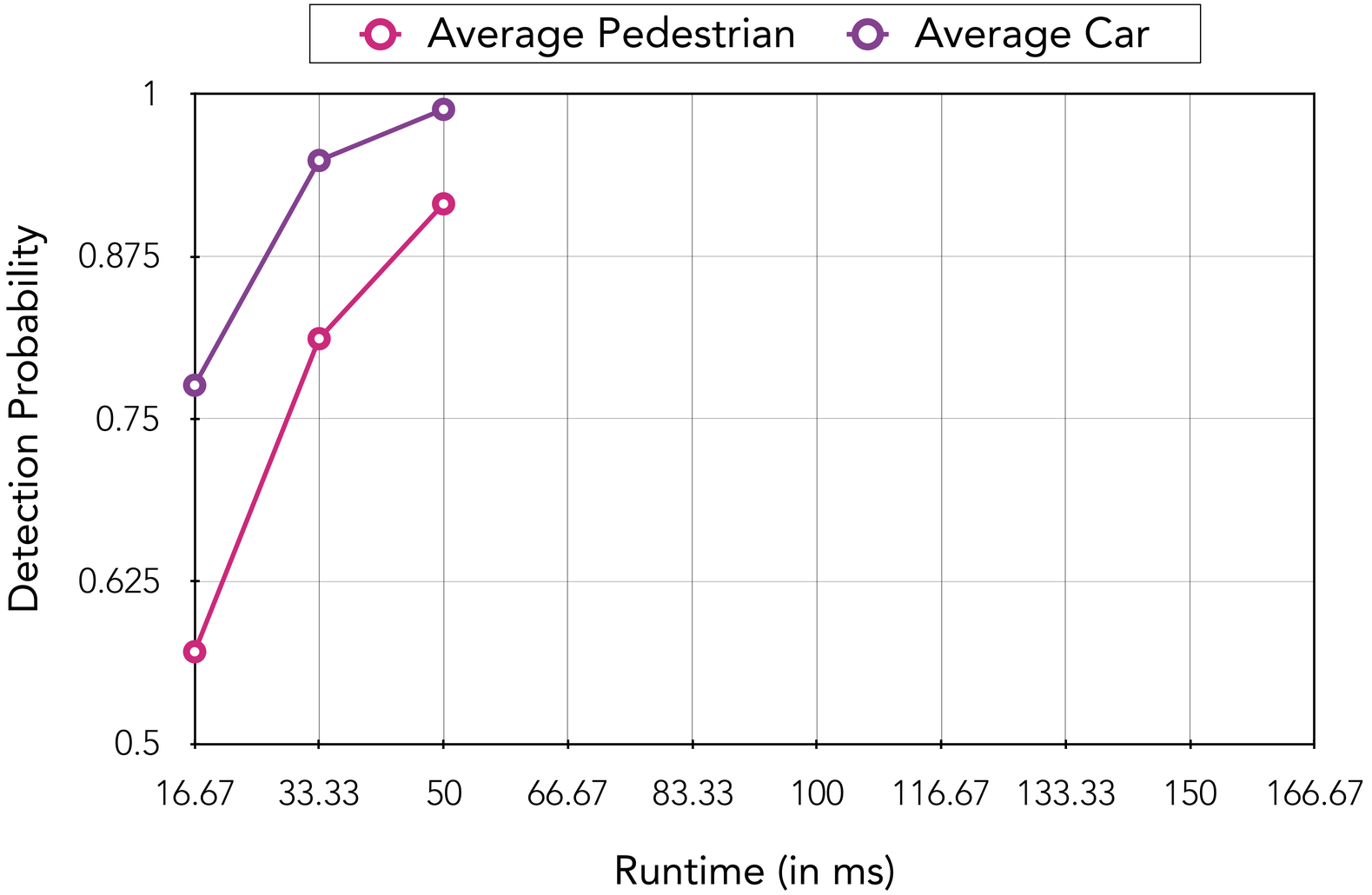
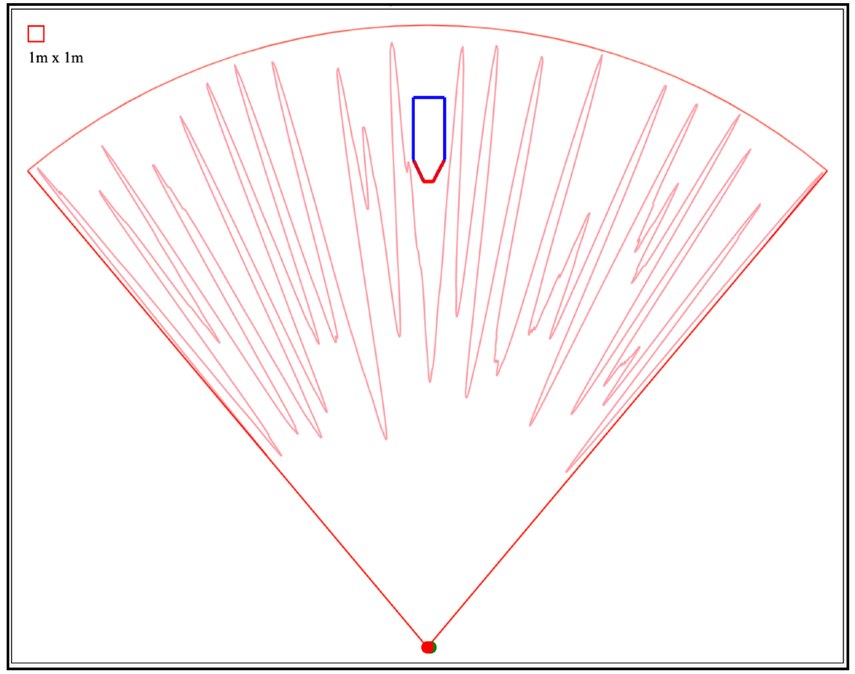
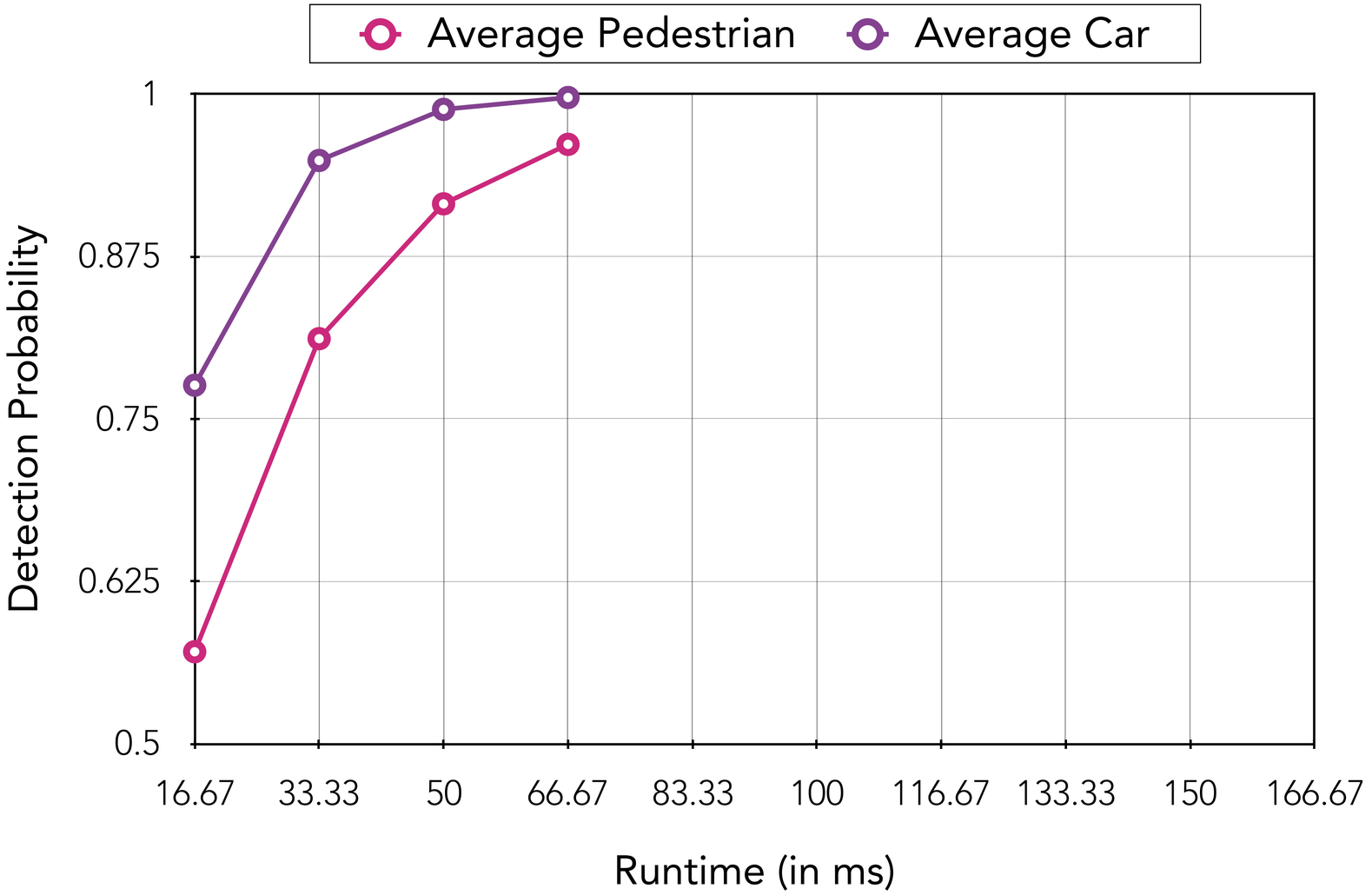


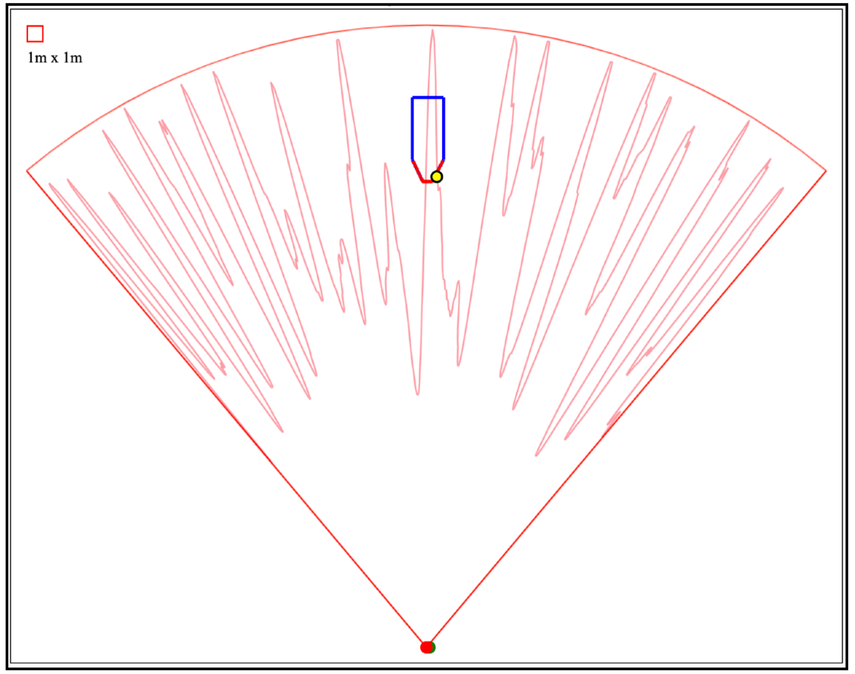
3 curtains



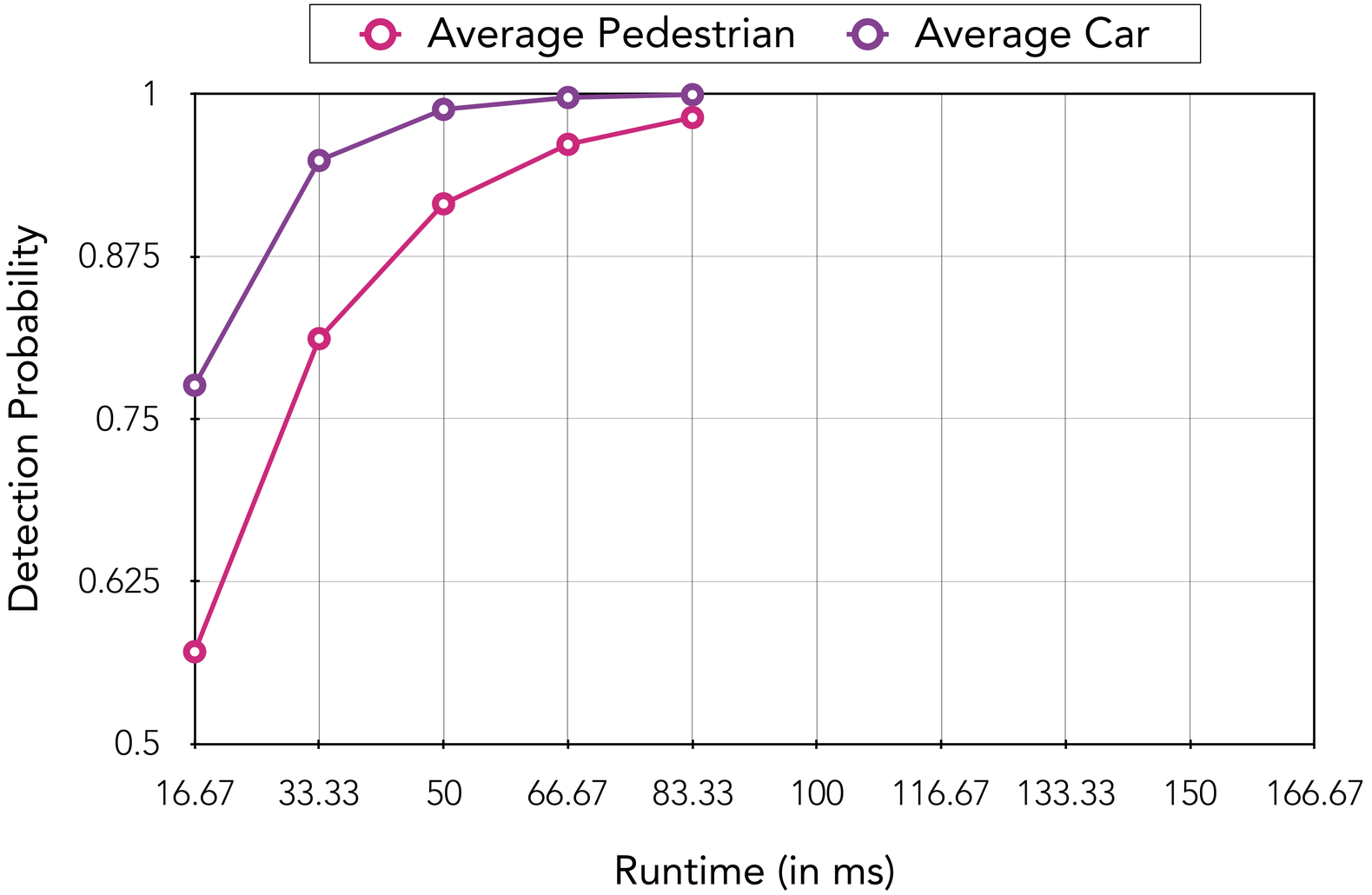
Example of Random Curtain Analysis



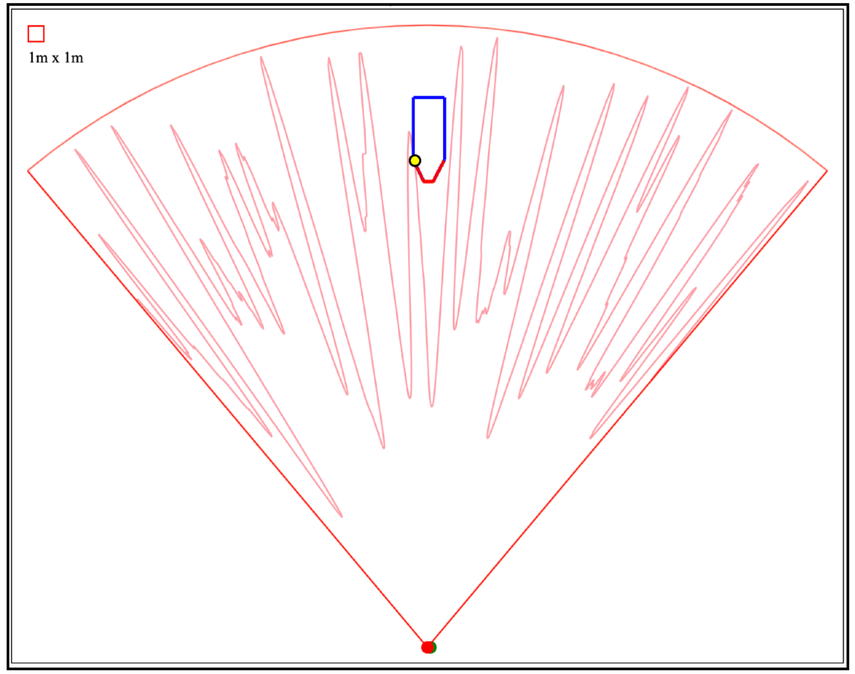
4 curtains



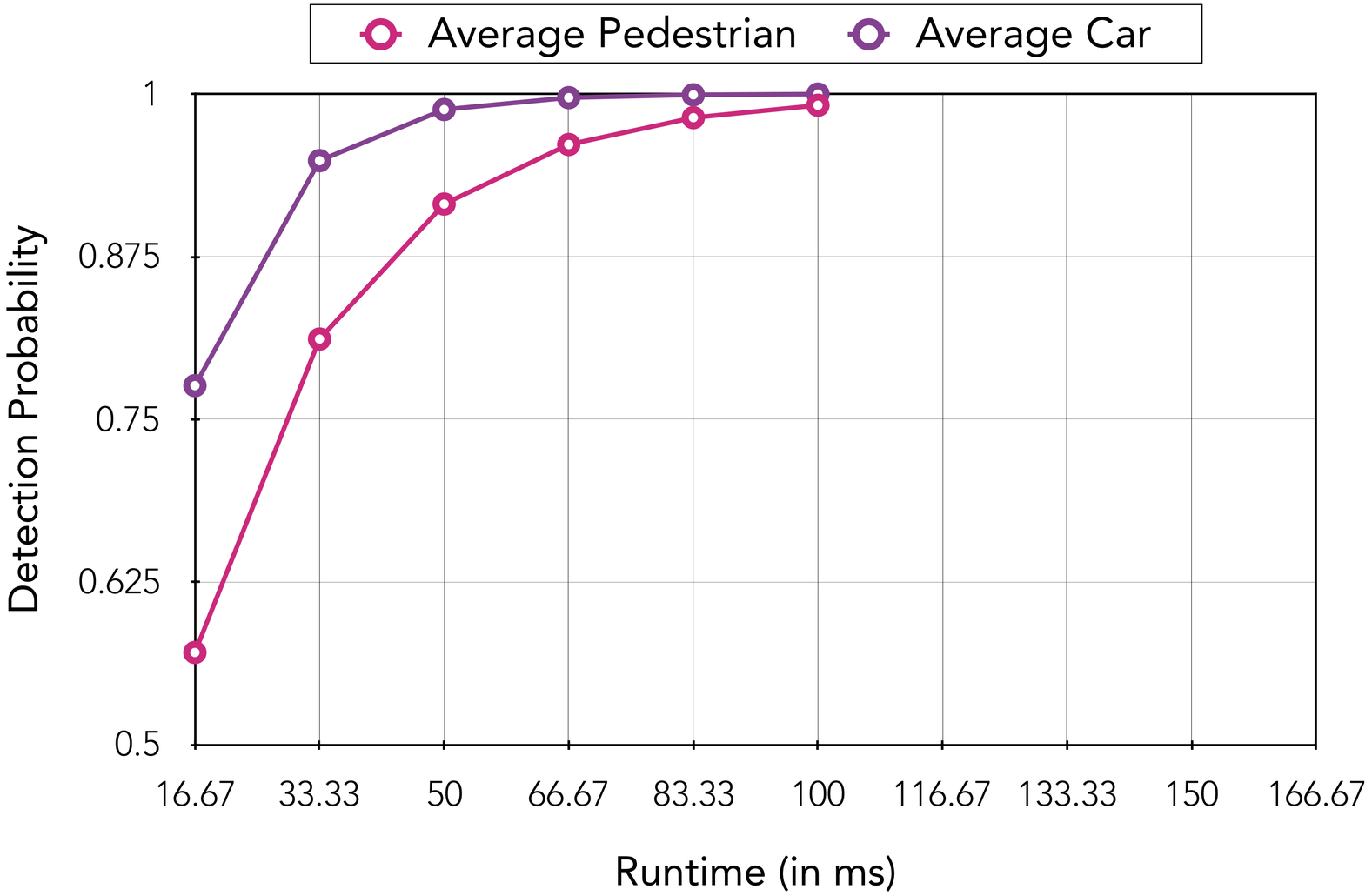
Example of Random Curtain Analysis



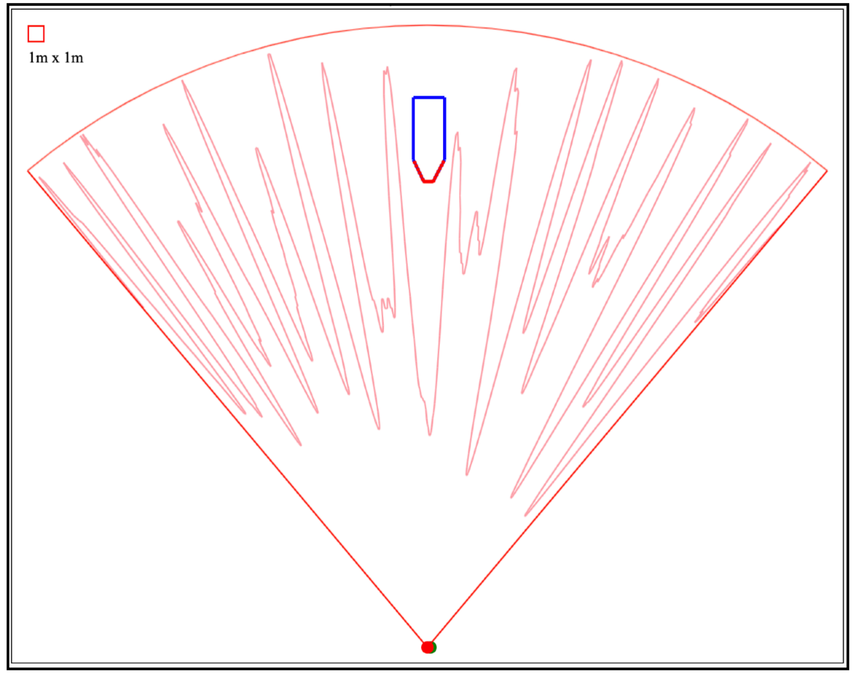
5 curtains



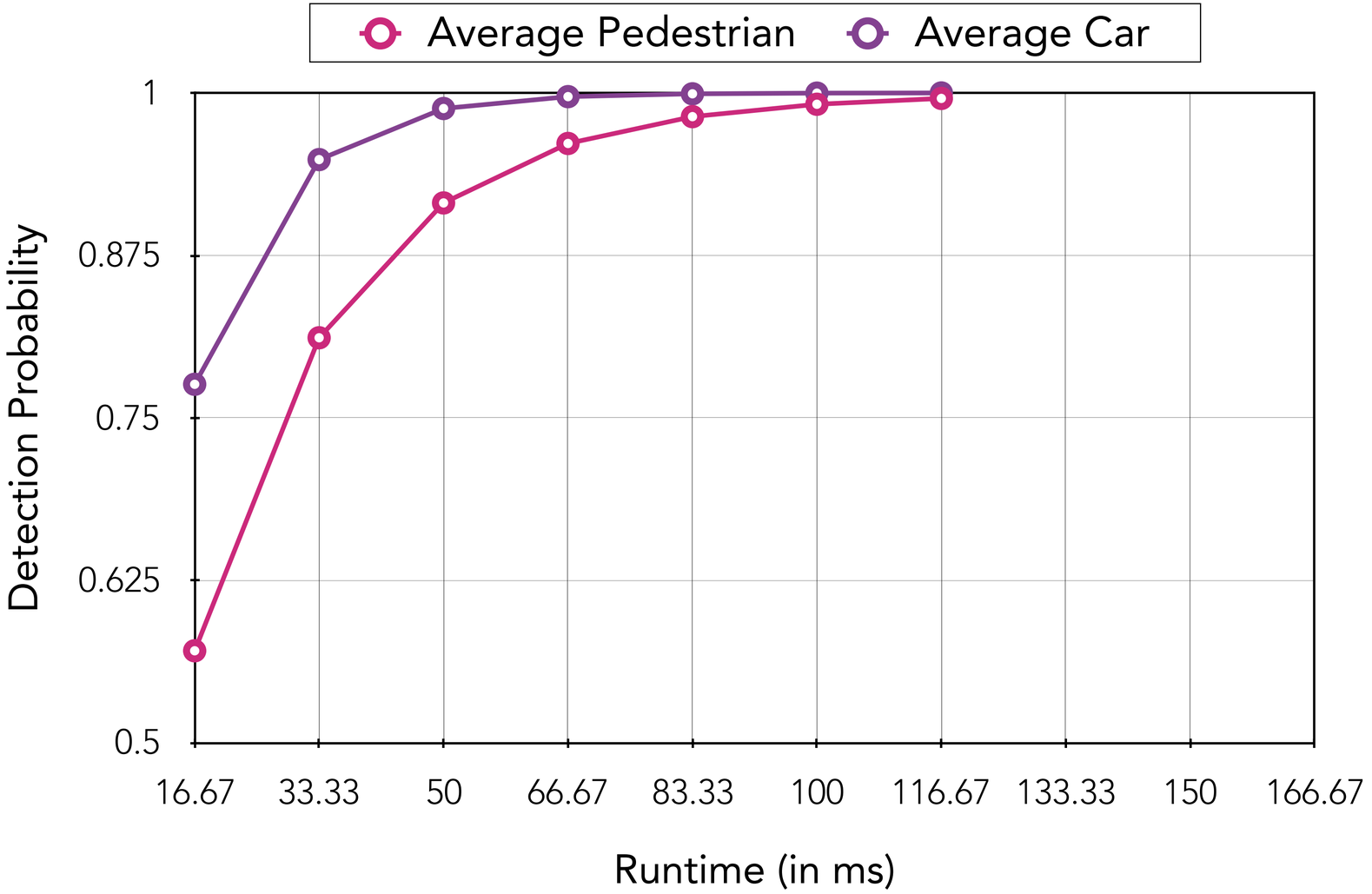
Example of Random Curtain Analysis



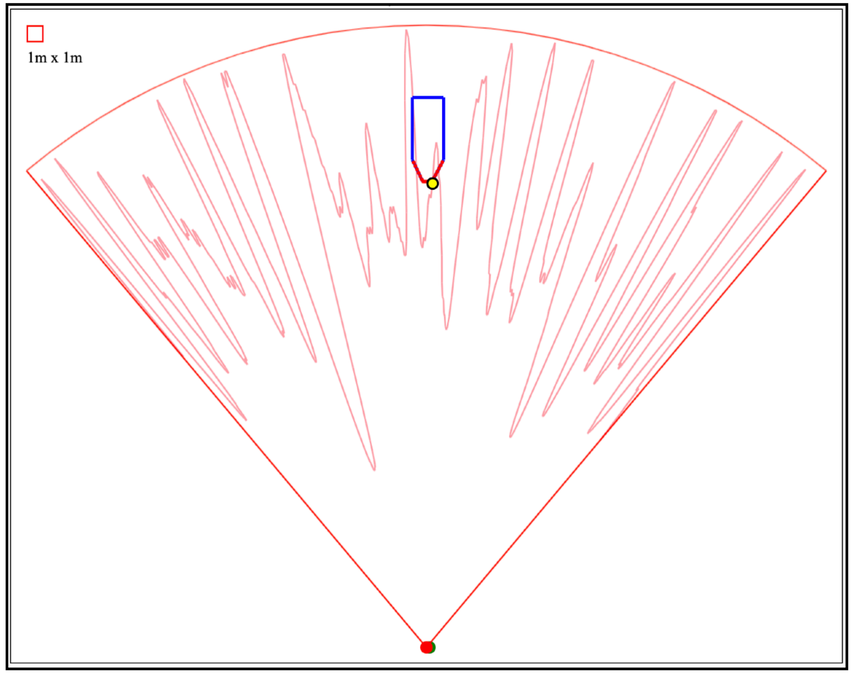
6 curtains



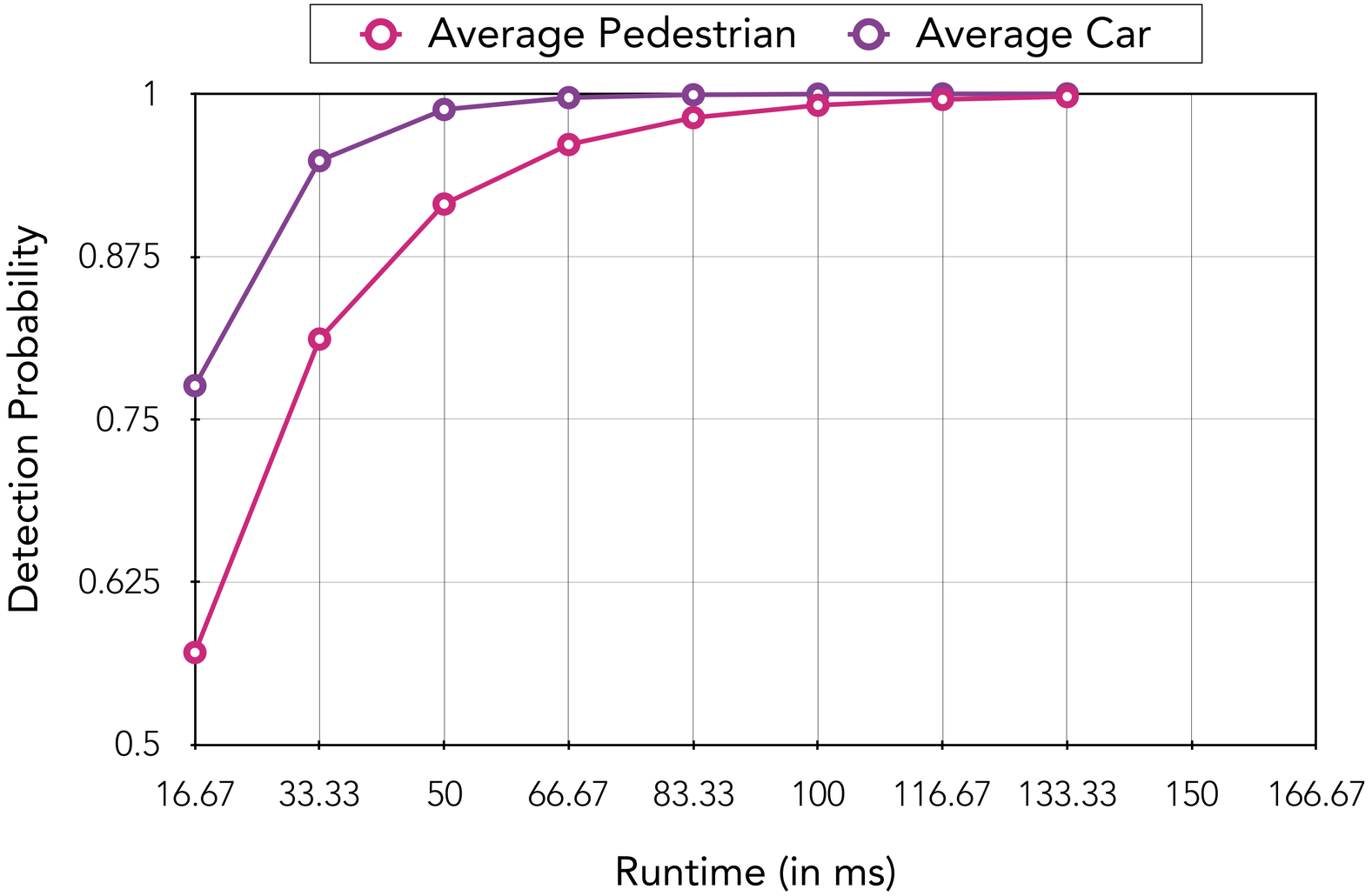
Example of Random Curtain Analysis



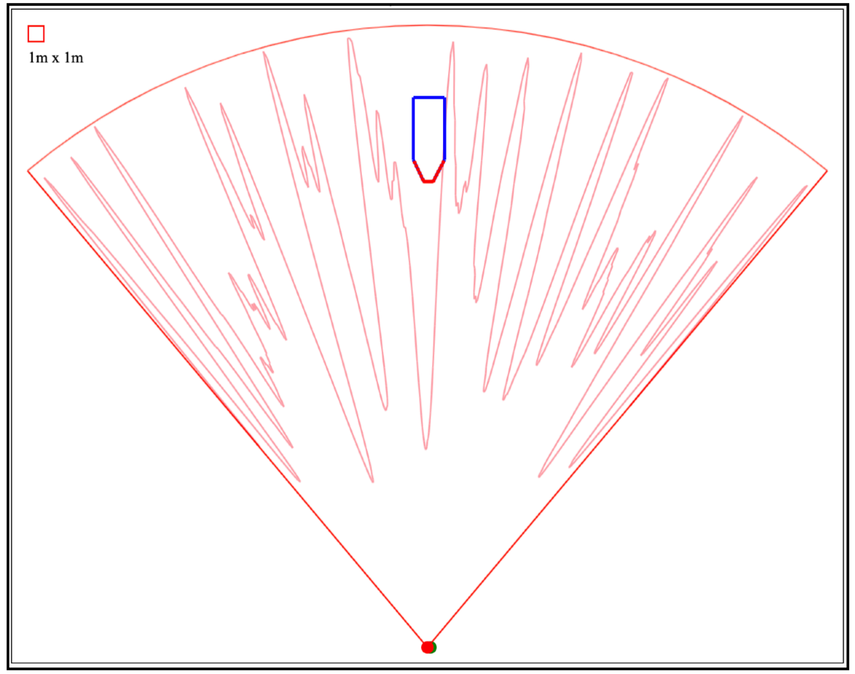
7 curtains



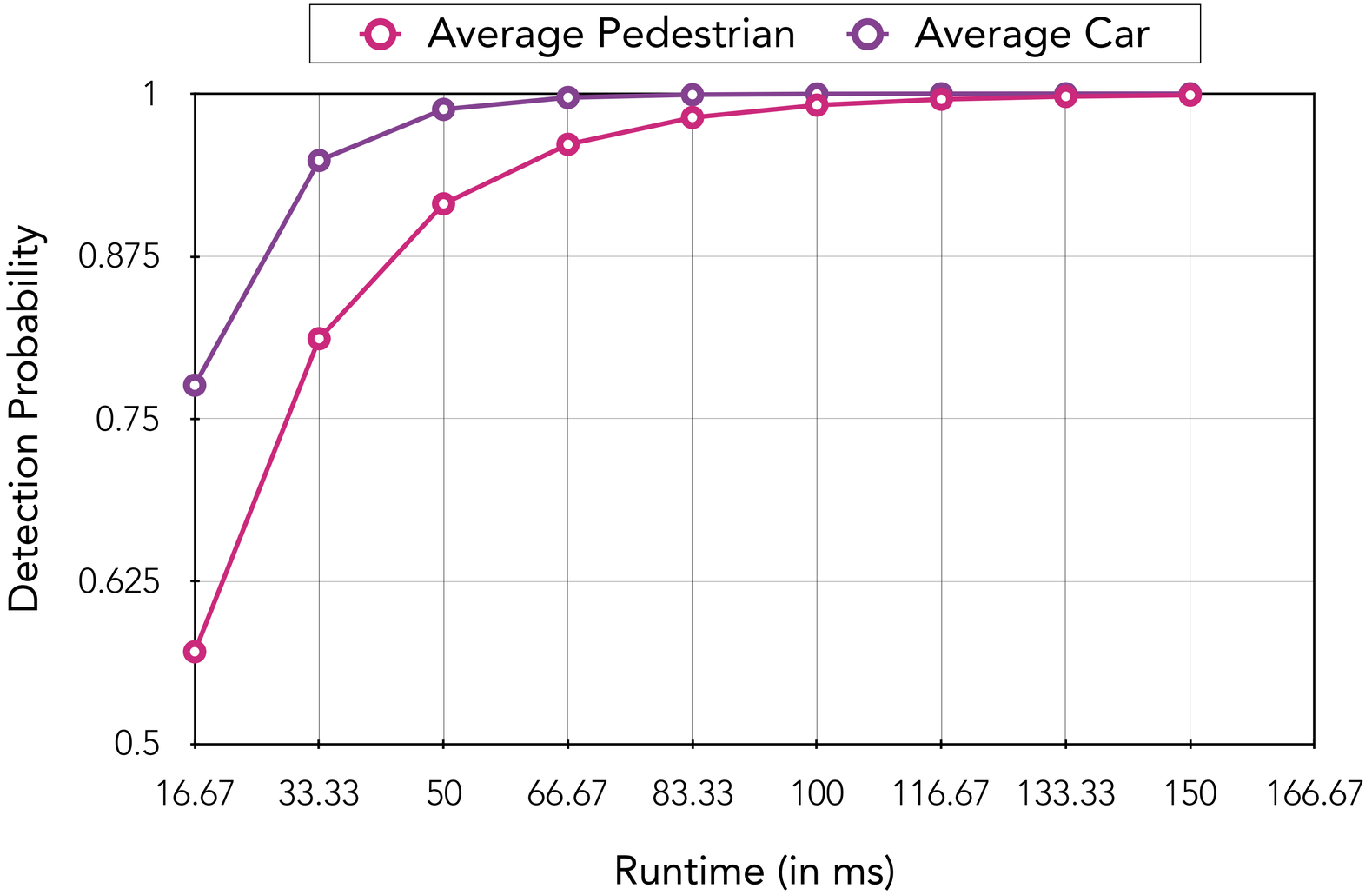
Example of Random Curtain Analysis



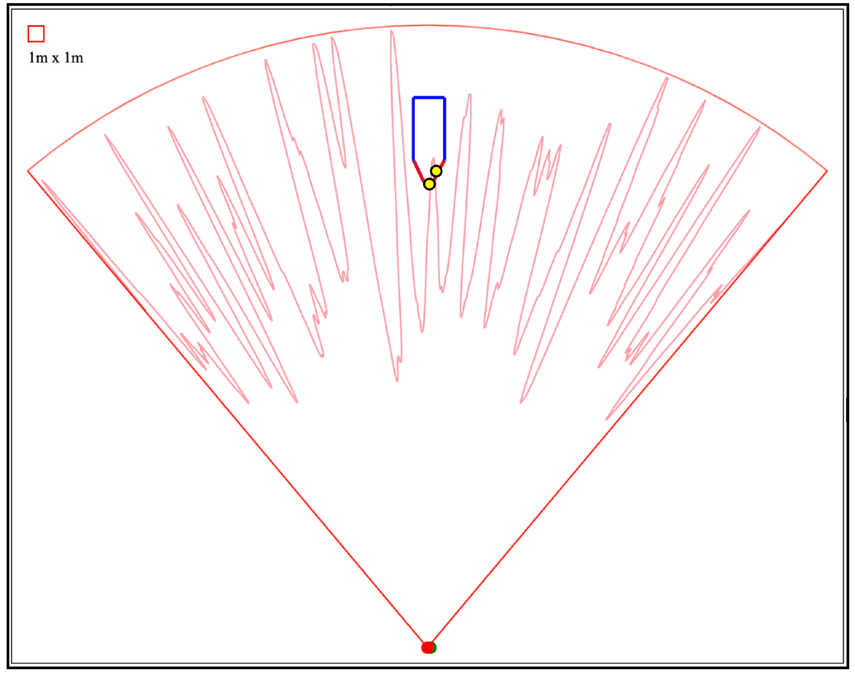
8 curtains



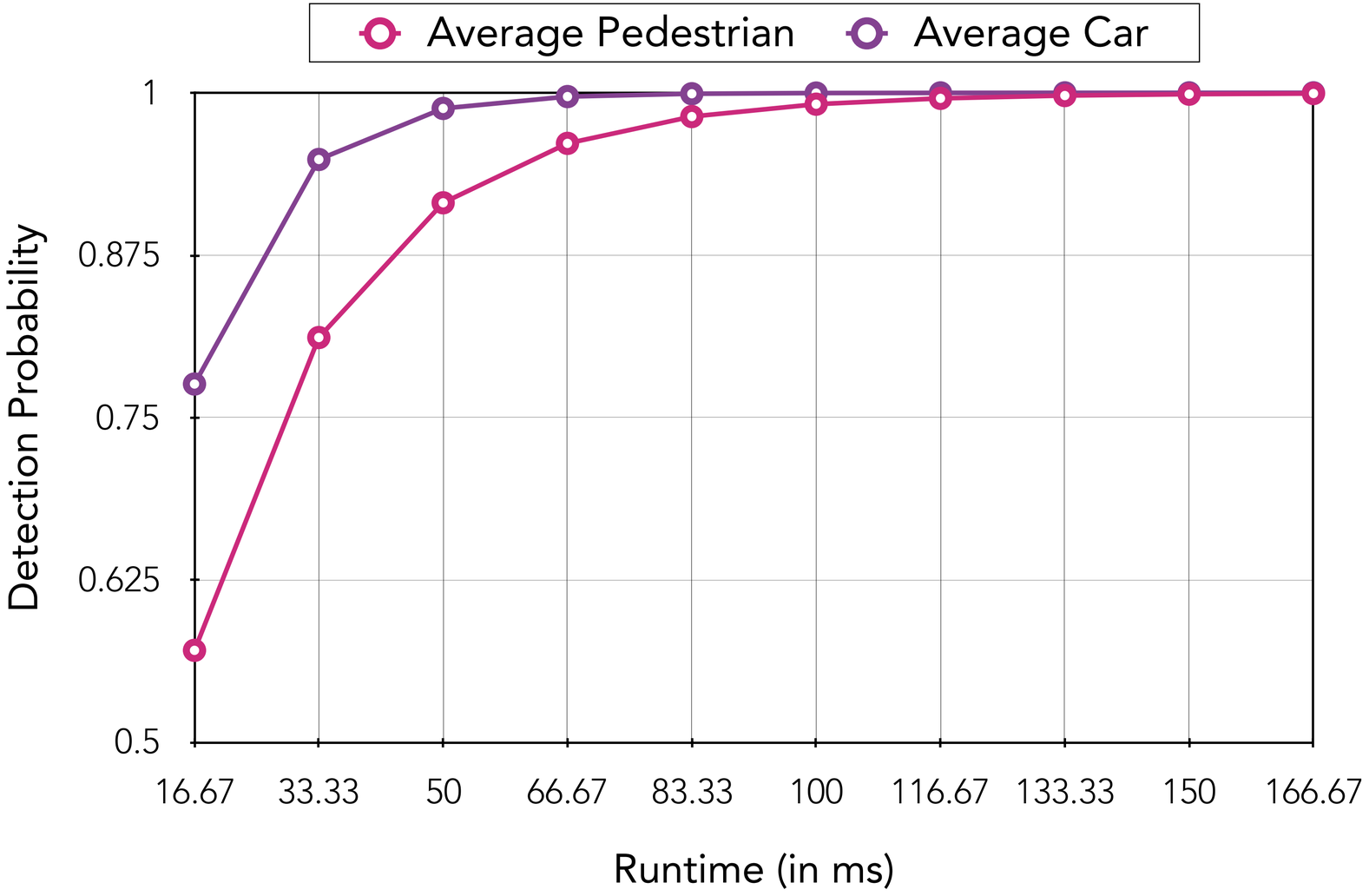
Example of Random Curtain Analysis



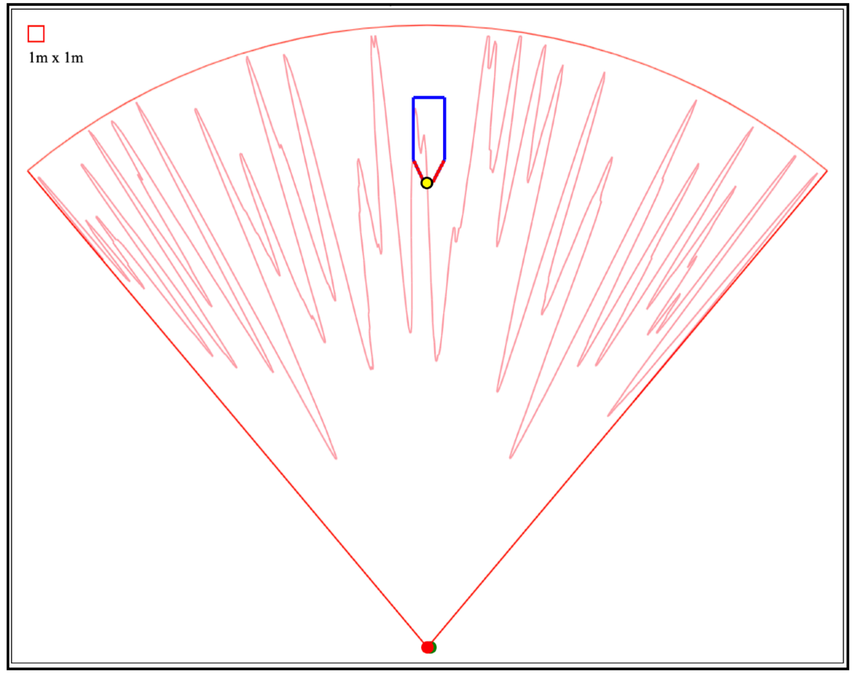
9 curtains



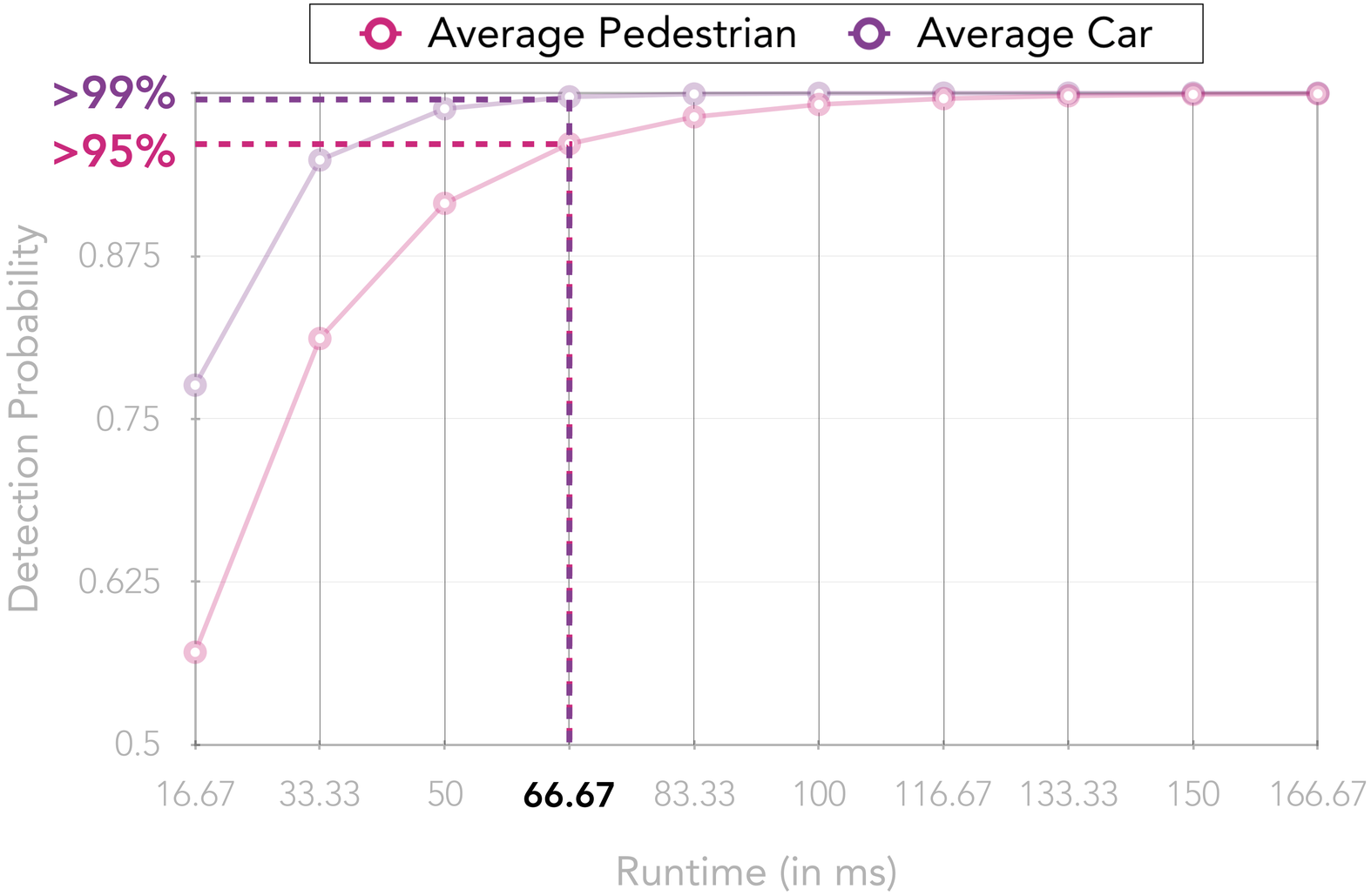
Example of Random Curtain Analysis



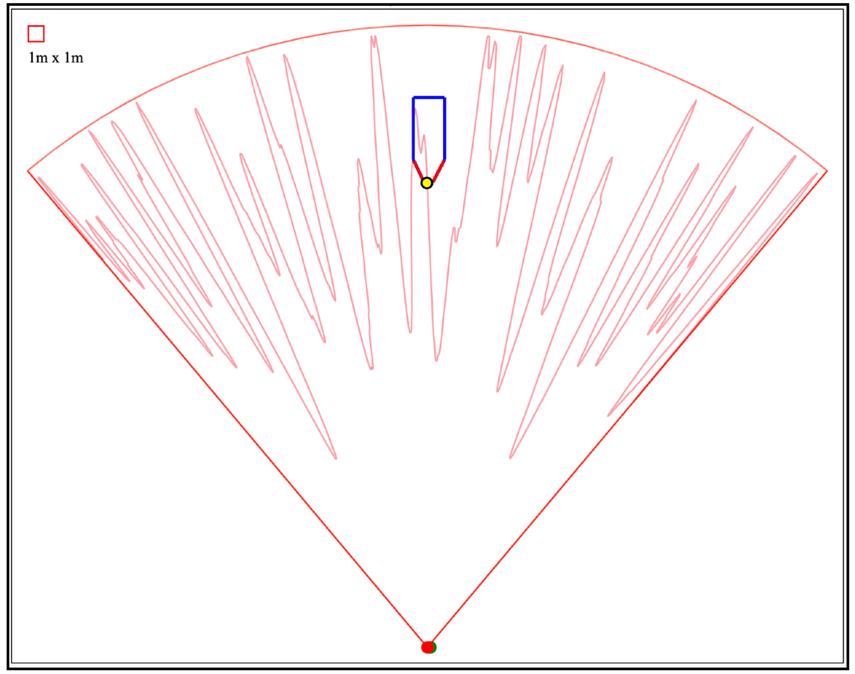
10 curtains



Example of Random Curtain Analysis

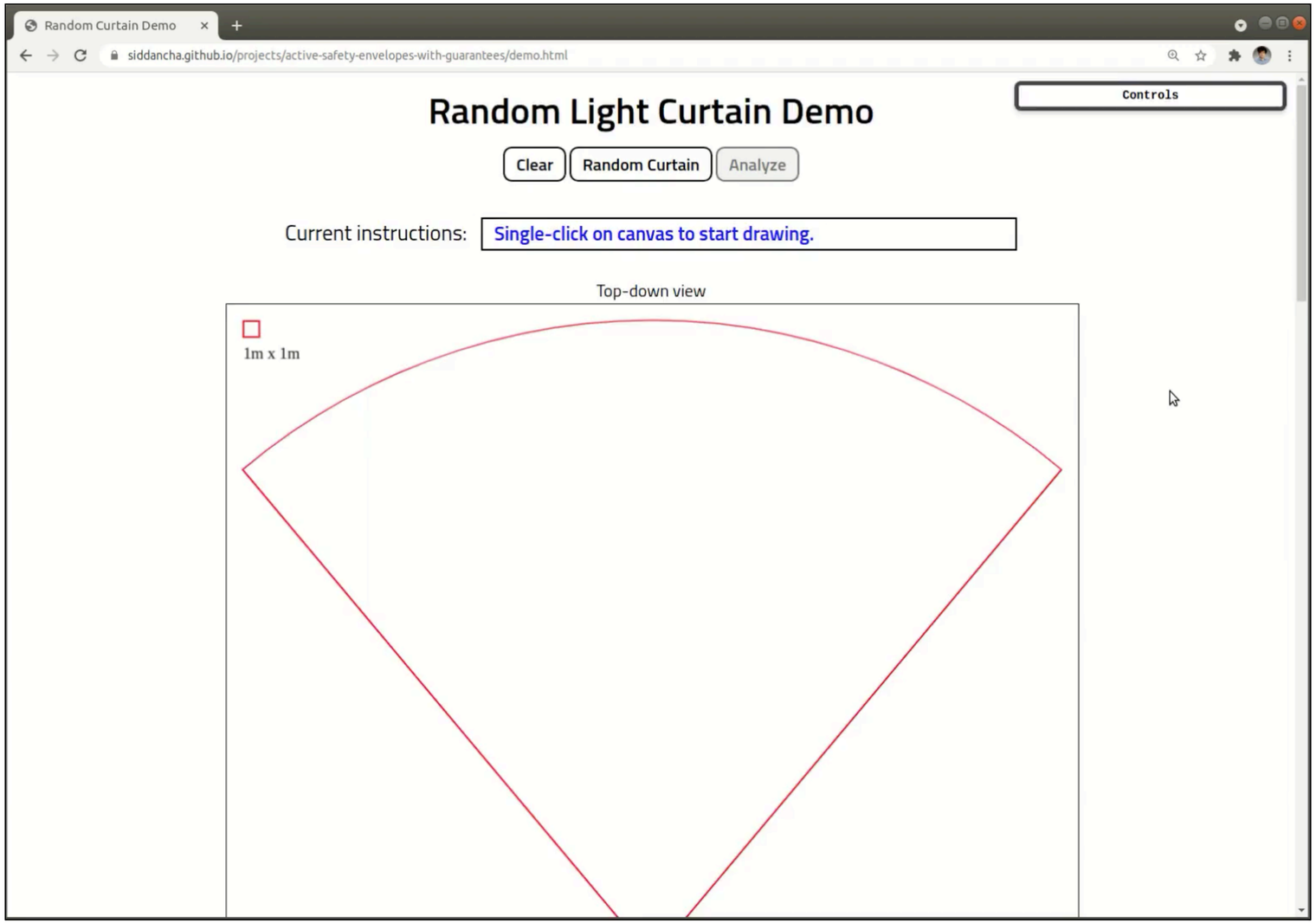


10 curtains

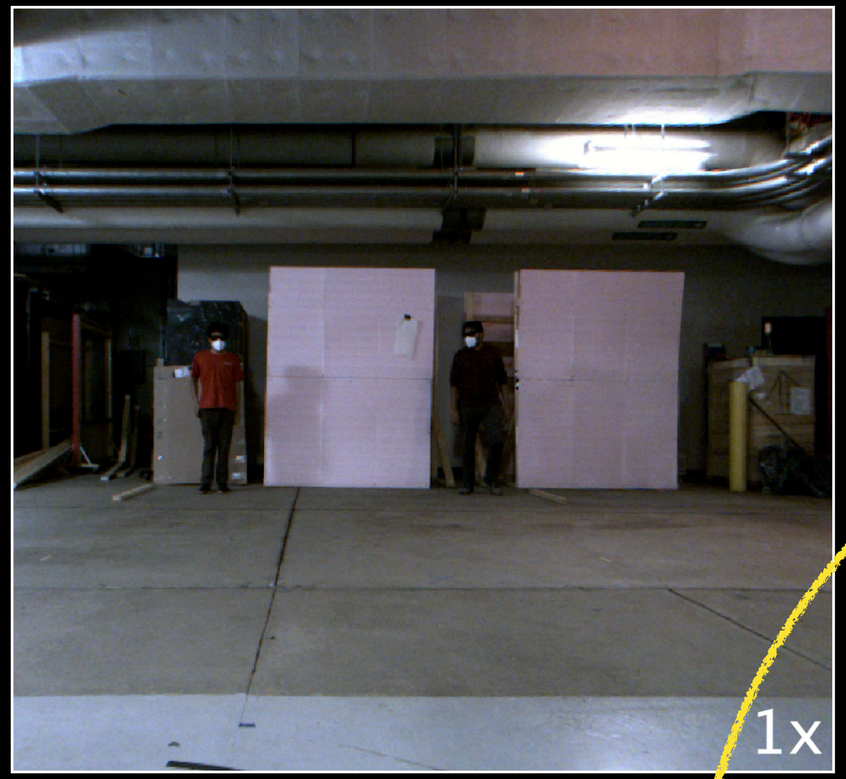


Interactive Web Demo!

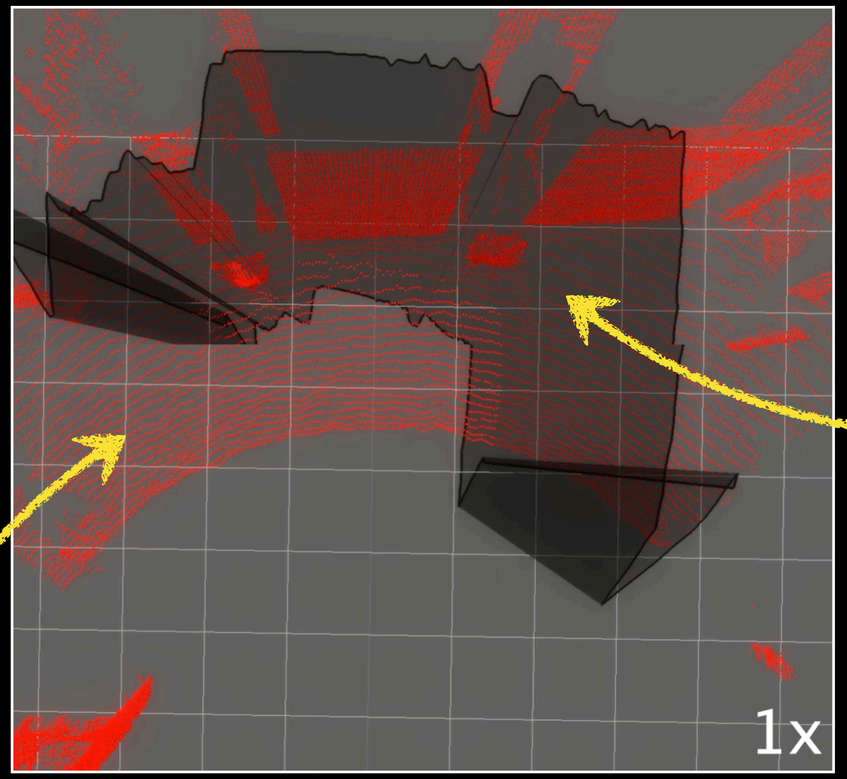
https://siddancha.github.io/projects/active-safety-envelopes-with-guarantees/demo.html



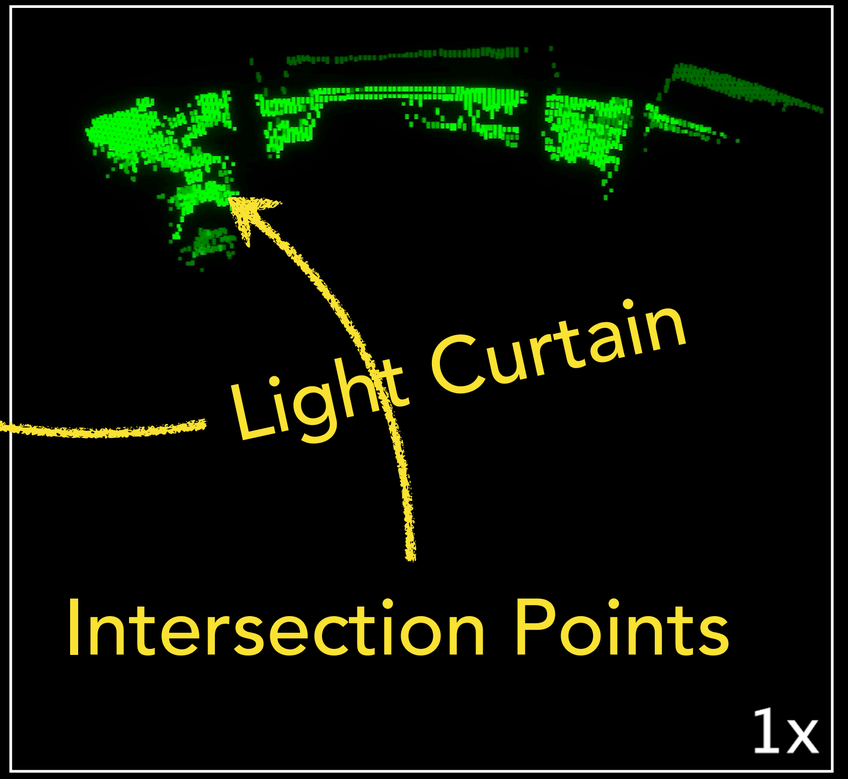
Active Pedestrian Envelope Tracking



RGB Scene Video



Top-down view with LiDAR points

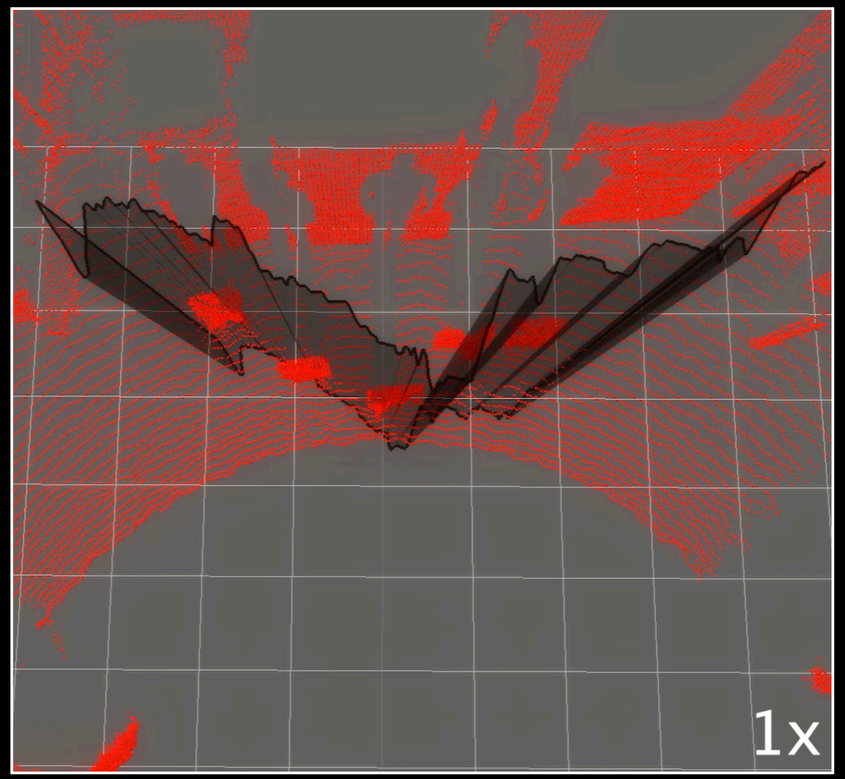


Top-down view of intersection points

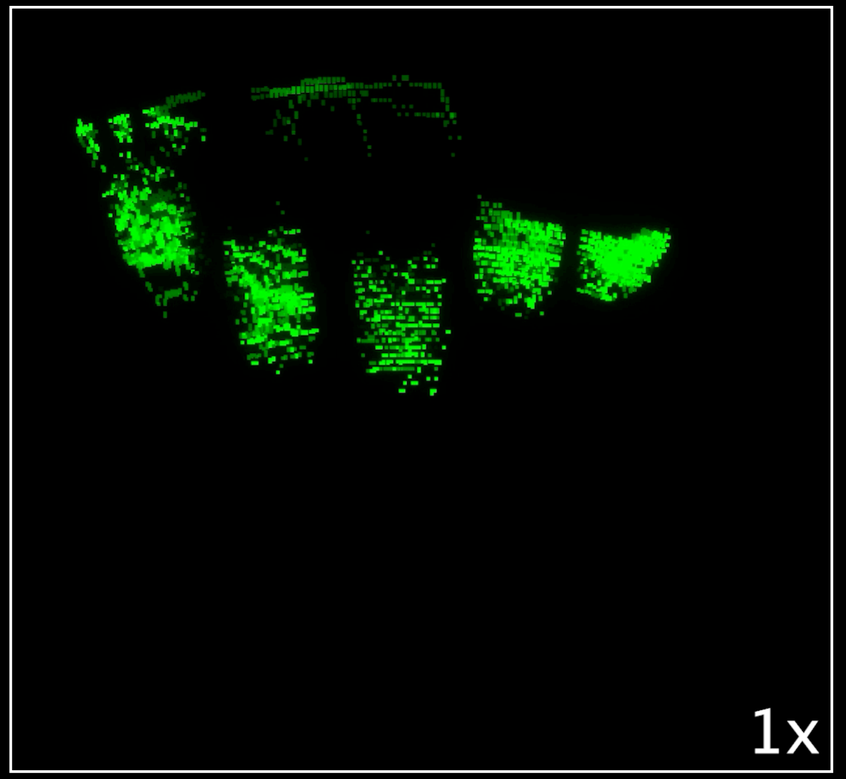
LiDAR Point Cloud

Many Obstacles

RGB Scene Video



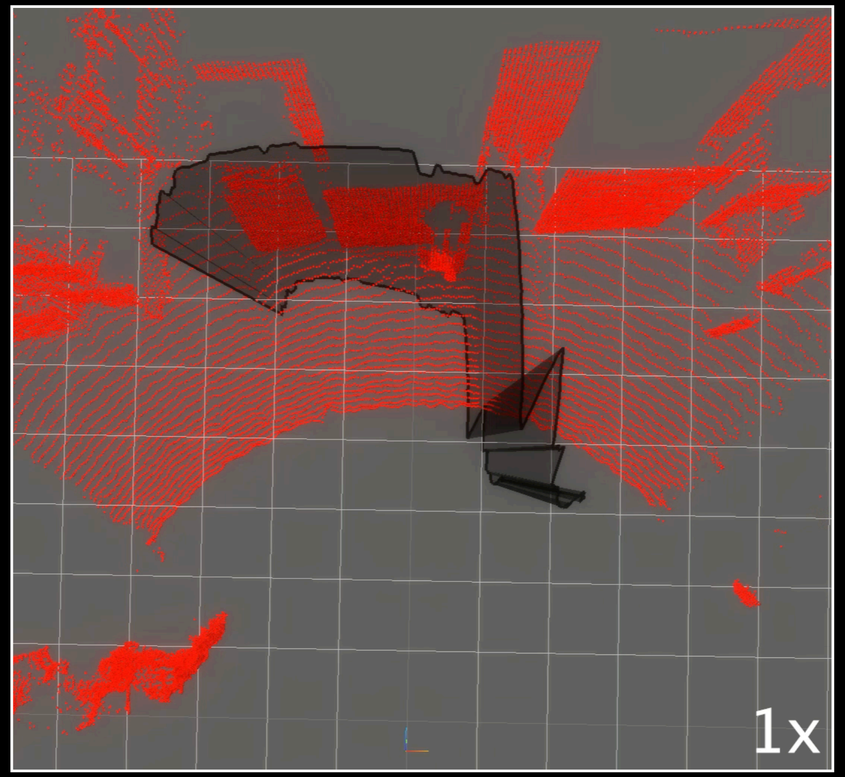
Top-down view with LiDAR points



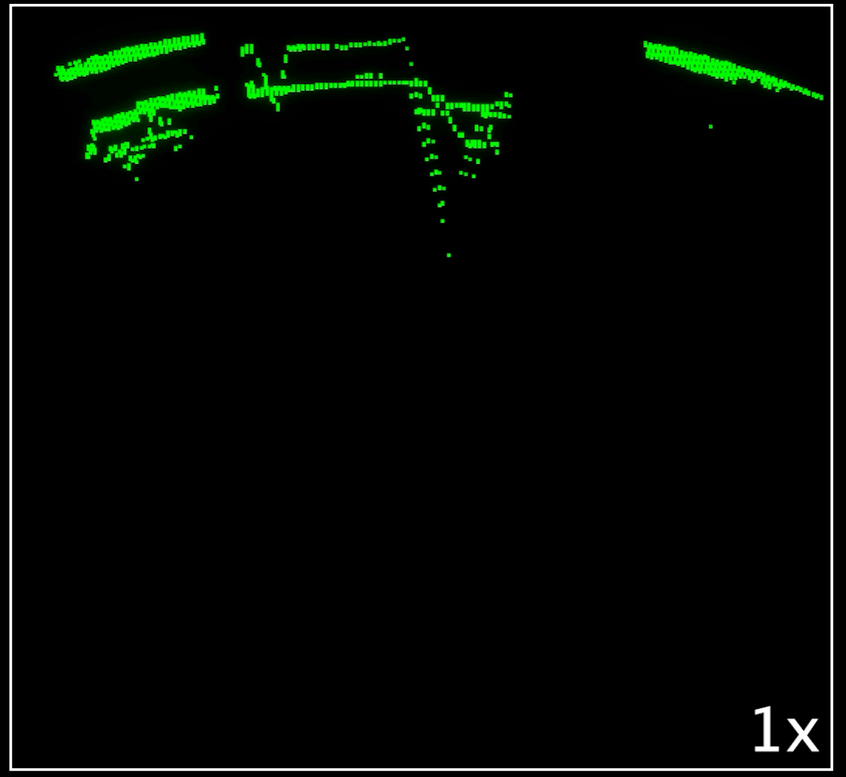
Top-down view of intersection points

Fast Motion

RGB Scene Video



Top-down view with LiDAR points



Top-down view of intersection points

Active Safety Envelopes using Light Curtains with Probabilistic Guarantees

Webpage

https://siddancha.github.io/projects/active-safety-envelopes-with-guarantees

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