Defining Safety For Self-Driving Cars

Planning on the Medial Axis for Non-Holonomic Systems

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Problem and Motivation

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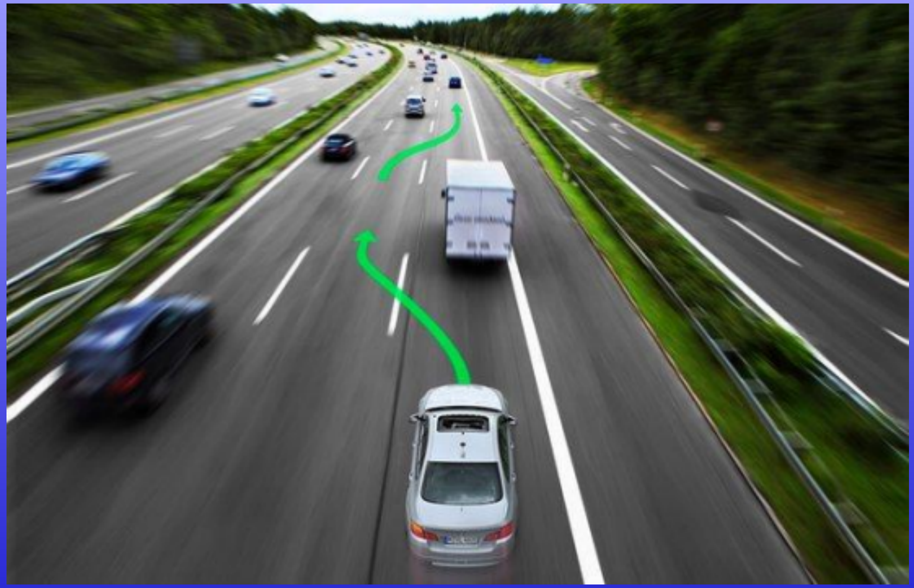
For companies developing self-driving cars,
how can we maximize safety?

We have seen safety prioritized in simple models.

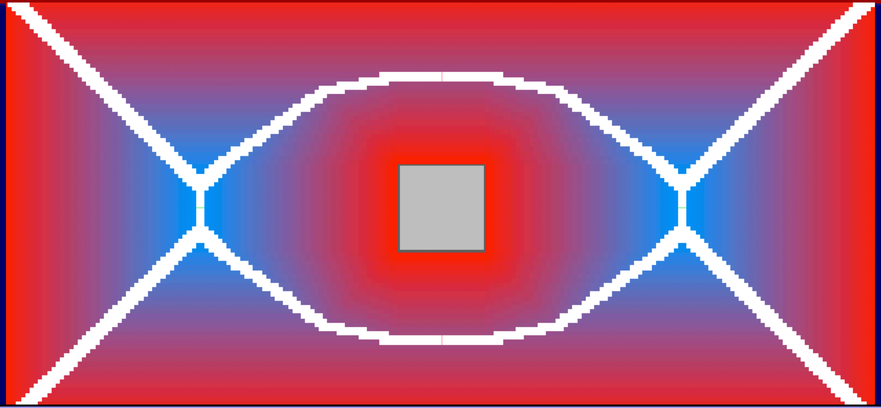
How can we apply that to car-like models?

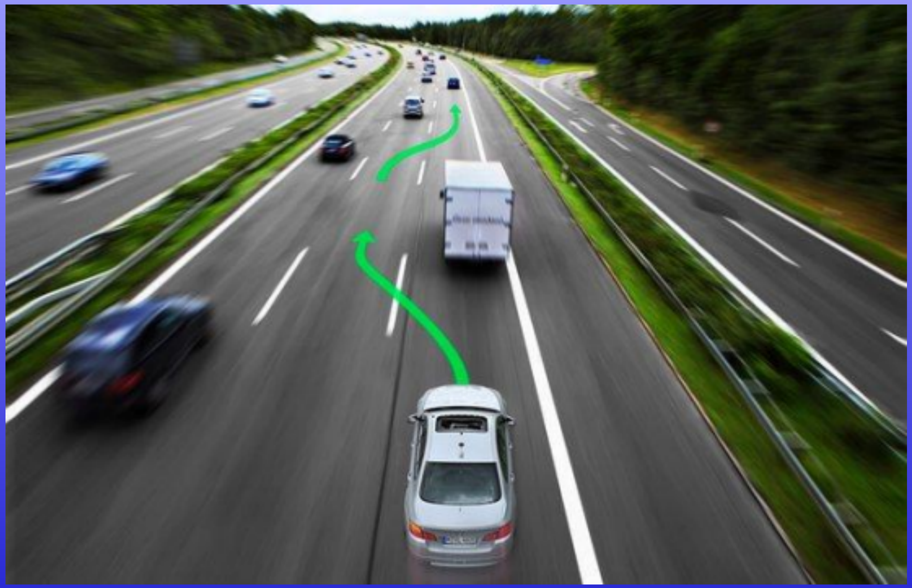


https://towardsdatascience.com/planning-the-path-for-a-self-driving-car-on-a-highway-7134fddd8707

Contributions

- Explored the safest points (**medial axis**) in self-driving car models.
- Proved discontinuity properties in certain settings.
- Developed an algorithm to maximize safety in car-like models using the medial axis.





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Introduction

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Configuration Space and DOFs

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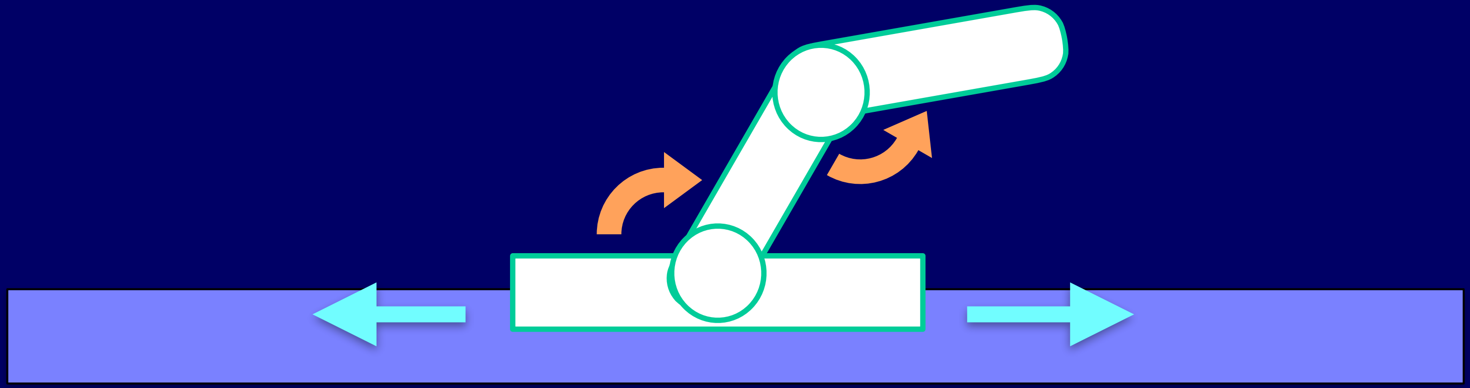
Degrees of Freedom (DOFs): # of independent movements the robot can make

- Number of directions it can translate + Number of angles it can be oriented.



Configuration (Cfg): Specification of a robots **DOFs**

Configuration Space (C-Space, $\mathscr{C}$): All possible **Cfgs** of a robot

- Robot is a point in C-Space
- **DOFs** $= \dim(\mathscr{C})$

Workspace vs. C-Space

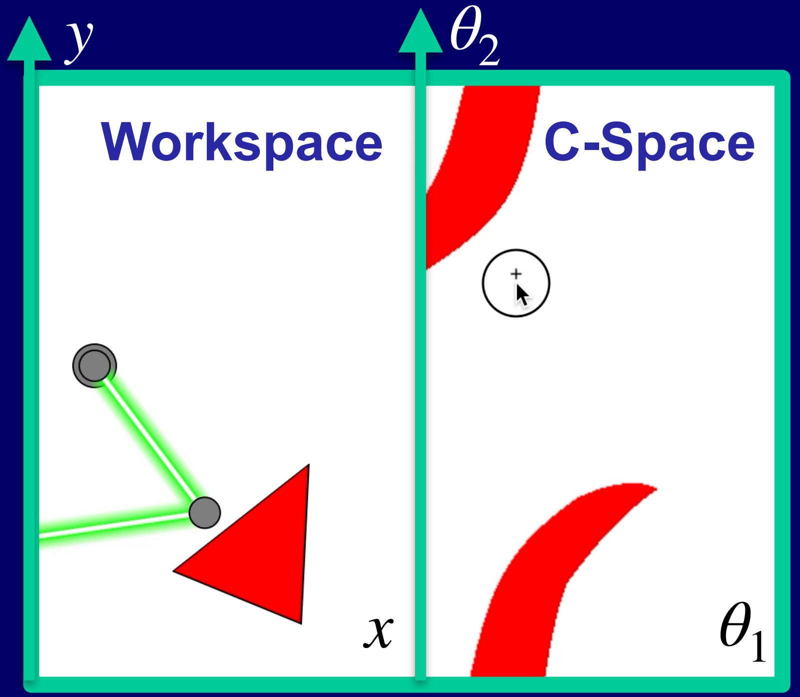
Workspace: Actual 2D or 3D space in which the robot is moving.

Configuration Space: Parameterization of robot, N-Dimensional

$\mathcal{C}$: **All configurations**

$\mathcal{C}_{obst}$: All configurations **in collision**

$\mathcal{C}_{free}$: All configurations **not in collision**



https://www.cs.unc.edu/~jeffi/c-space/robot.xhtml

Non-Holonomic Systems & State Space

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In real systems, constraints on position, velocity, acceleration, .etc limit movement.

(Holonomic) (Non-Holonomic)

State Space: What states can the robot be in?

> Configuration + Time Derivatives

Control Space: What actions can the robot take?

> Turn left, turn on radius, turn joint, etc.

What Does "Safe" Mean

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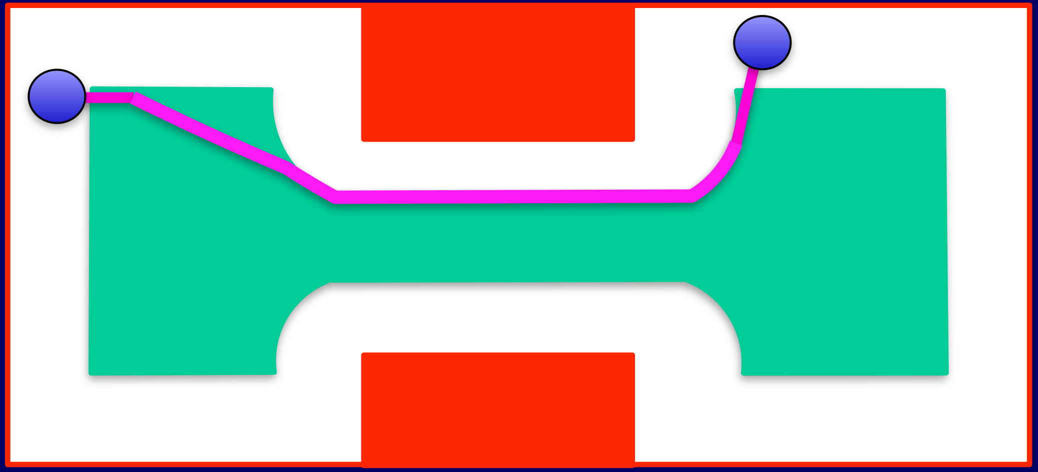
Minimally safe or *maximally safe*?

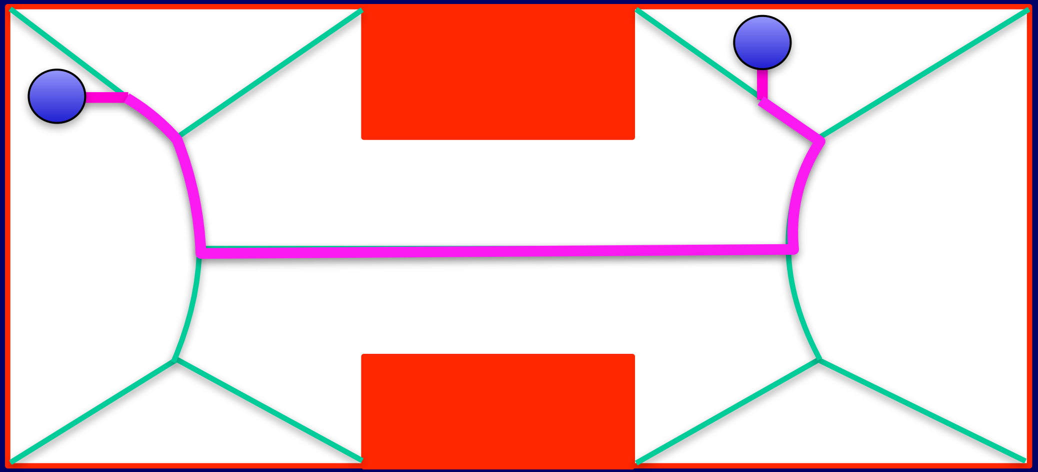
Medial Axis - Set of **maximally safe** points.

Maximize **clearance** during travel

Clearance:

Travel distance from cfg to closest $\mathcal{C}_{obst}$

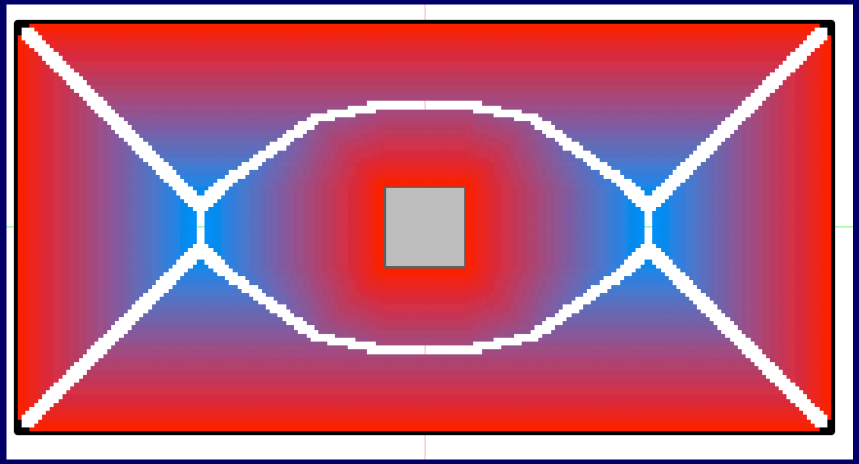




Theory

The Medial Axis

- **Medial Axis:** The "safe points" subset of C-space that follows one of:
  - **2-Points:** Equidistant from 2 or more nearest obstacle points
  - **Singularity Set:** Singularities (ridges) in the distance function
  - …



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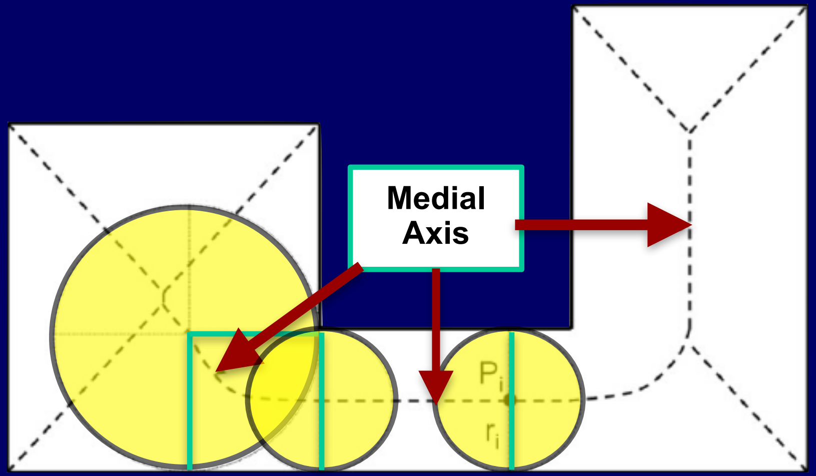
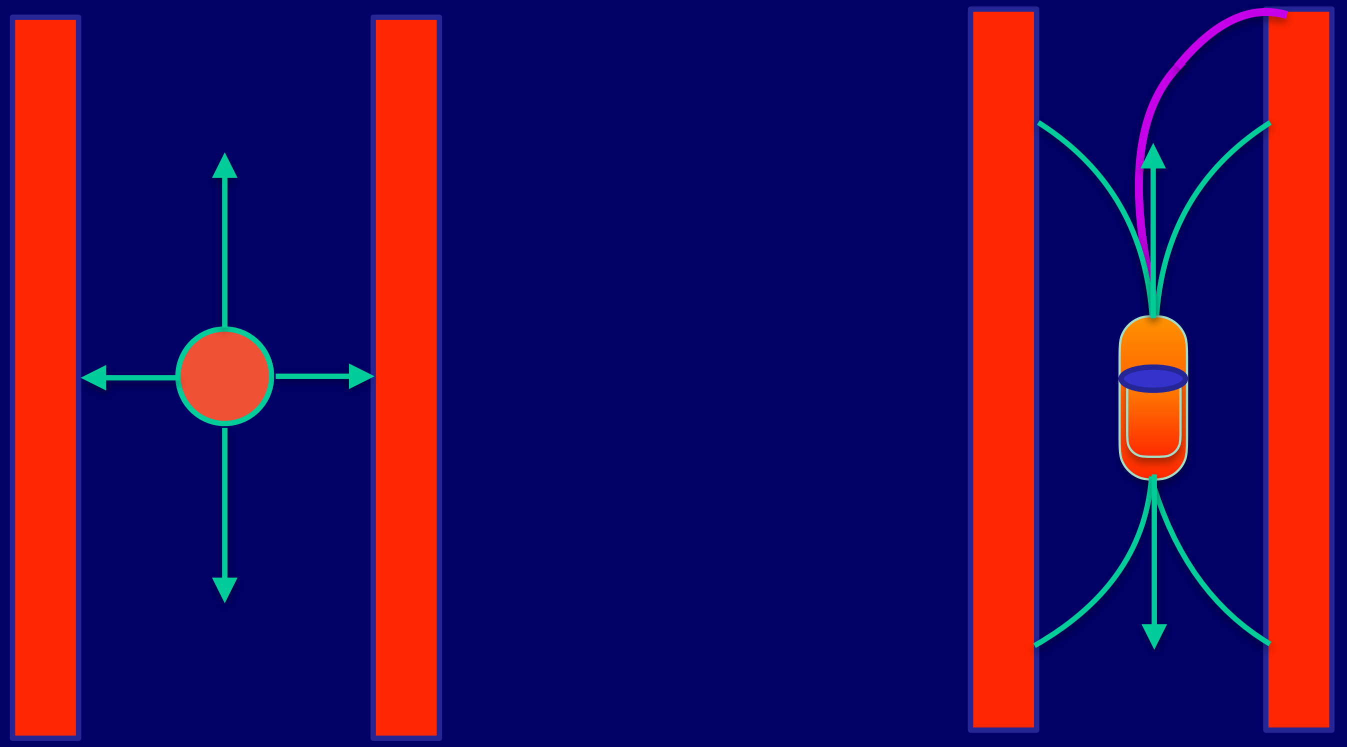


Voxel-Based Thickness Analysis of Intricate Objects: Karupppasamy Subburaj

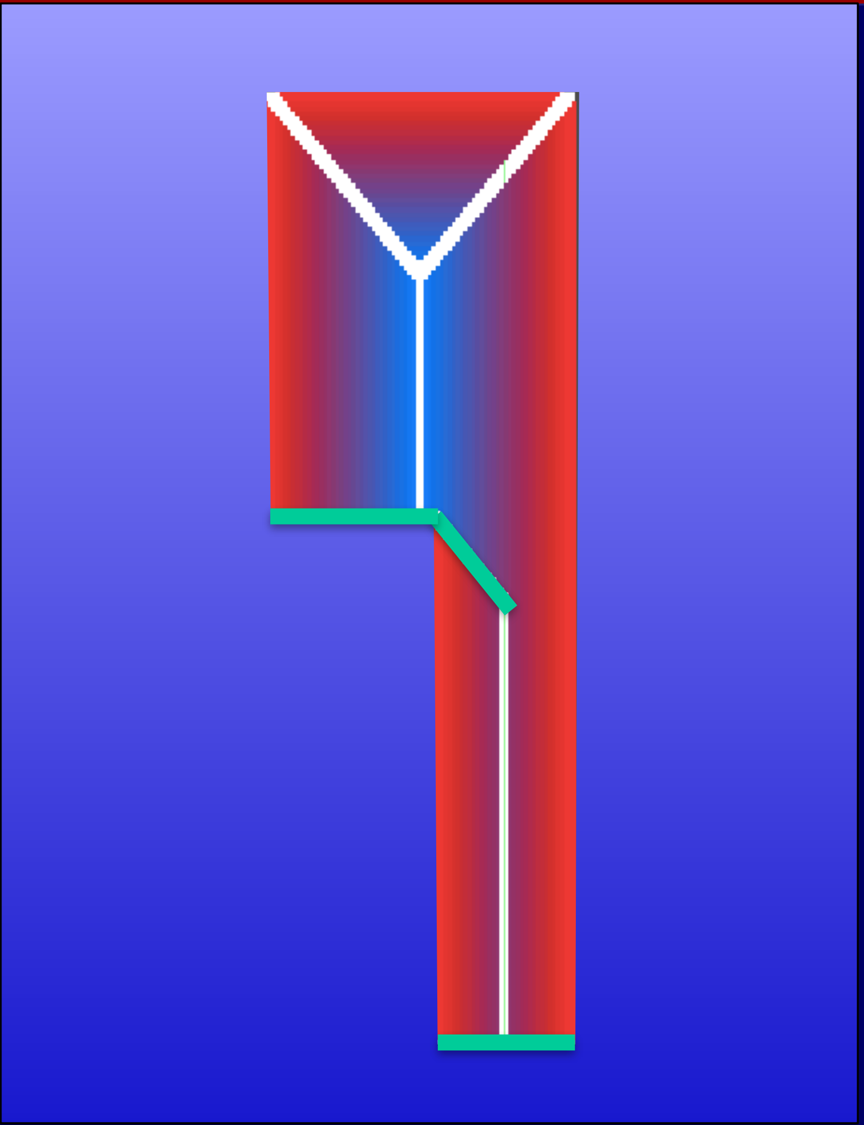
Distance & Clearance

- How do we define **clearance** in non-holonomic models?



holonomic non-holonomic

Basic Model Example



Galaga Model:

- **State:** $x_0, y_0, \dot{y}$
- **Control:** $\dot{x}$

Chooses translation in the x direction within limits, but moves at a constant speed in the y direction (drift).

New!!!

2-points vs singularity set?

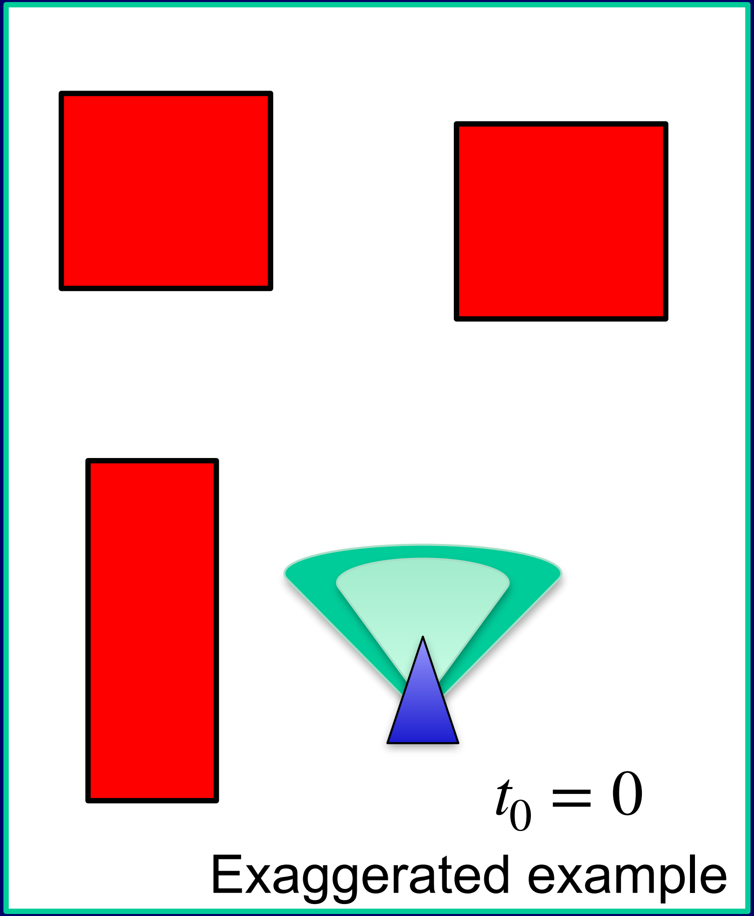
Clearance Function is discontinuous in certain non-holonomic models!

Method

Algorithm 1: Clearance Computation

Input: Starting state x_0 and number of trajectories r.

Output: Clearance of the shortest path from state.

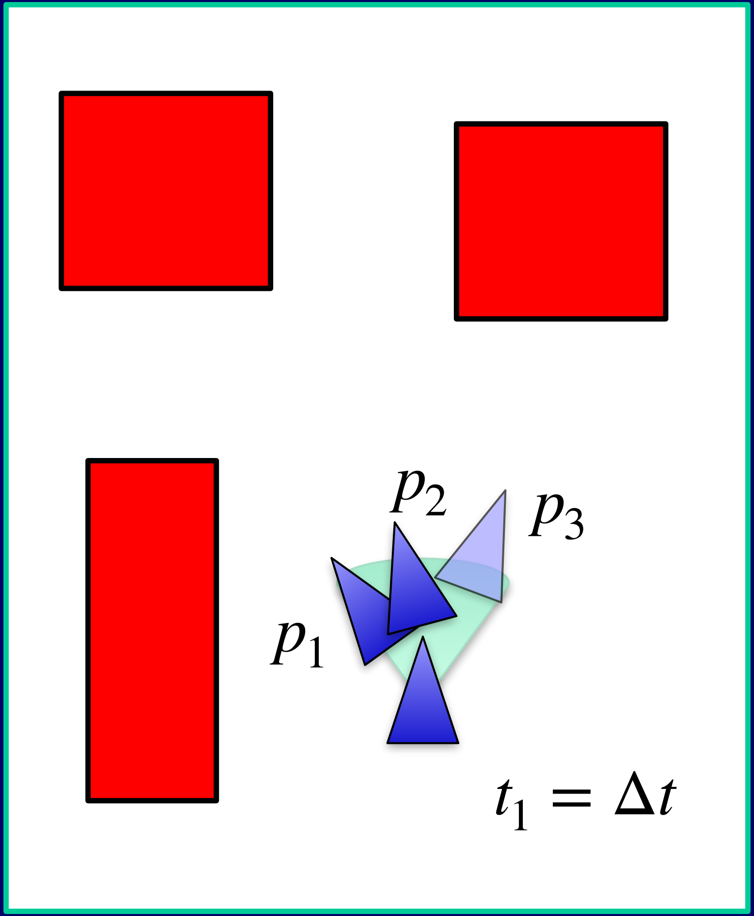


Algorithm 1: Clearance Computation

Input: Starting state x_0 and number of trajectories r.

Output: Clearance of the shortest path from state.

1. Send out r trajectories w/ random controls.



Algorithm 1: Clearance Computation

Input: Starting state x_0 and number of trajectories r.

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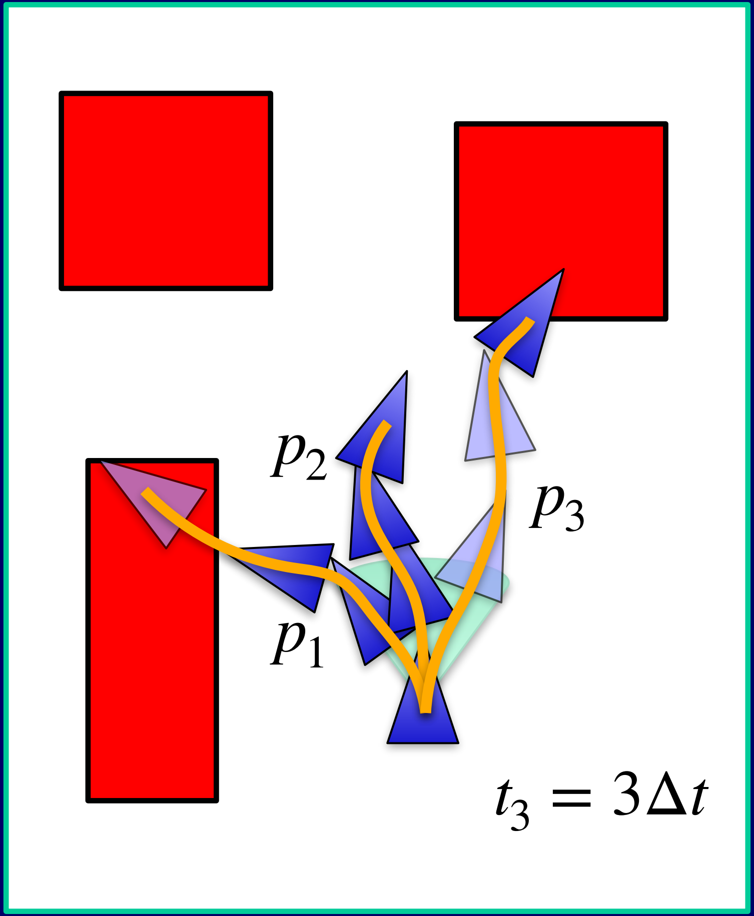
1. Send out r trajectories w/ random controls.
2. Advance trajectories until *first one* hits.

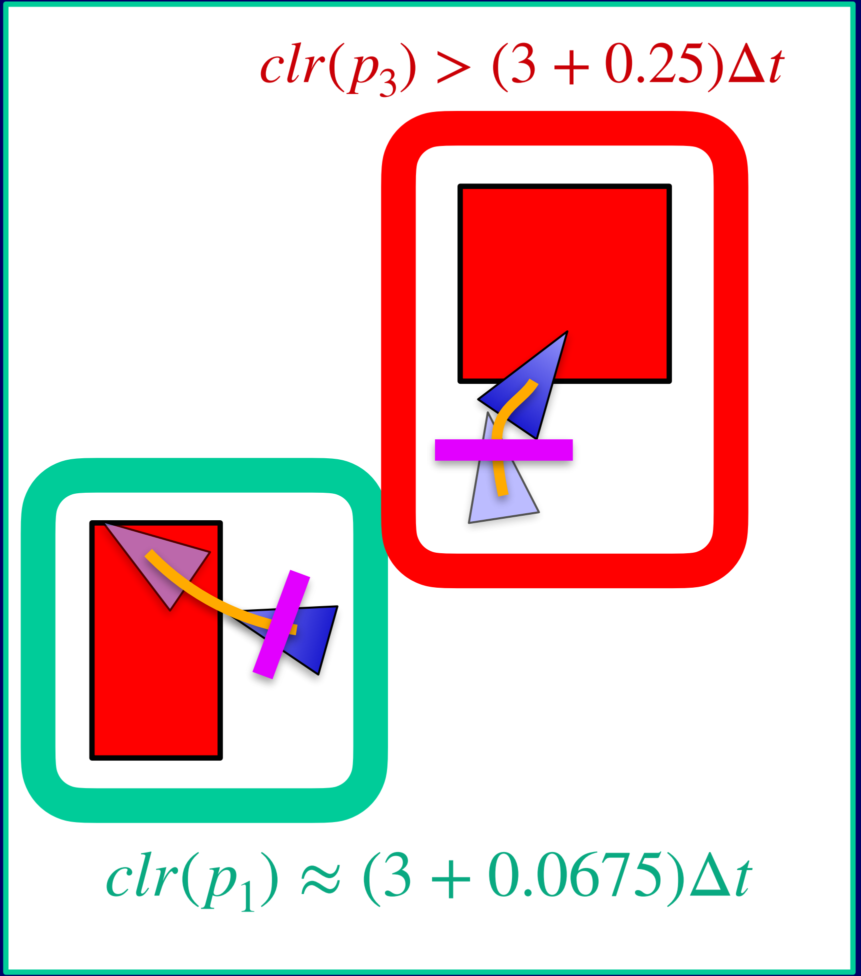


Algorithm 1: Clearance Computation

Input: Starting state x_0 and number of trajectories r.

Output: Clearance of the shortest path from state.

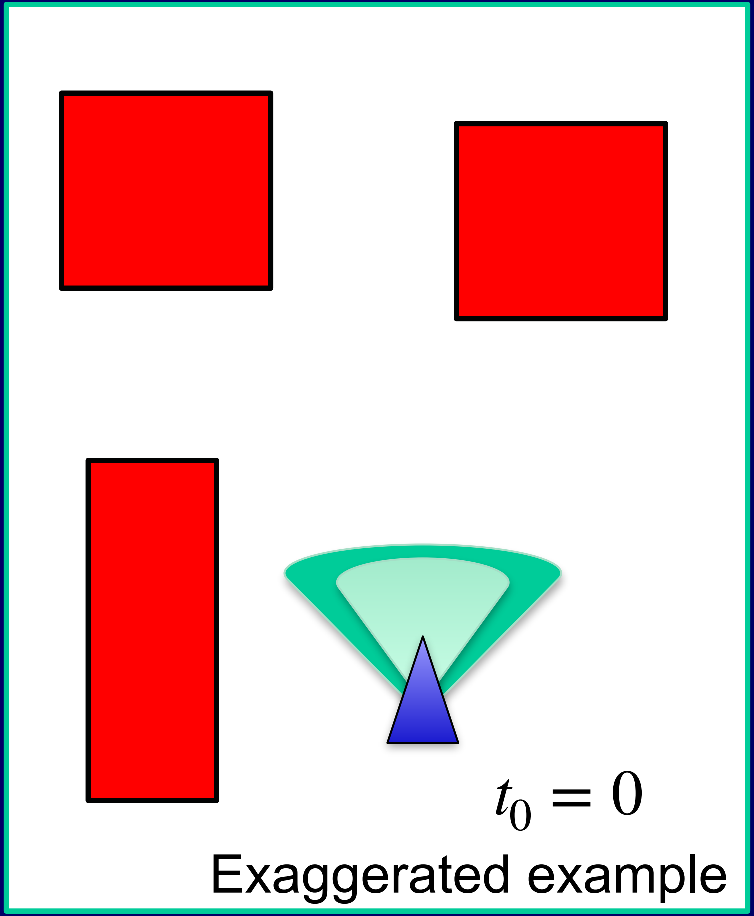
1. Send out r trajectories w/ random controls.
2. Advance trajectories until first one hits.
3. Find closest cfg to collision & use distance metric.



Algorithm 2: NH Medial Axis Sampler

Input: A starting state x_0.

Output: Sample of states approximately on the MA.



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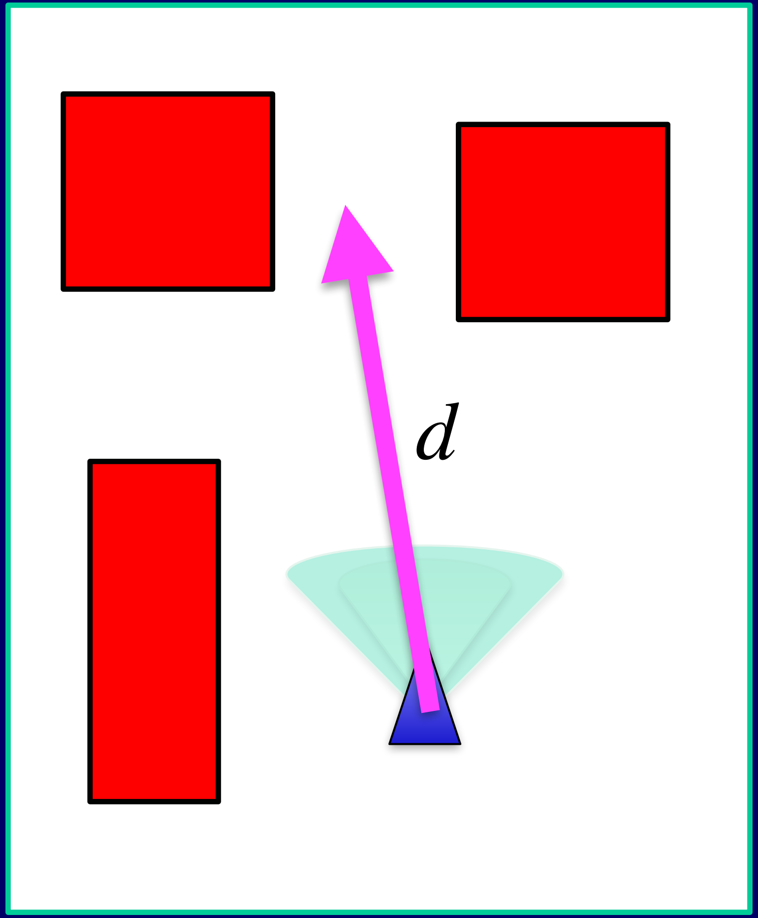
1. Pick a ray in the workspace.



Algorithm 2: NH Medial Axis Sampler

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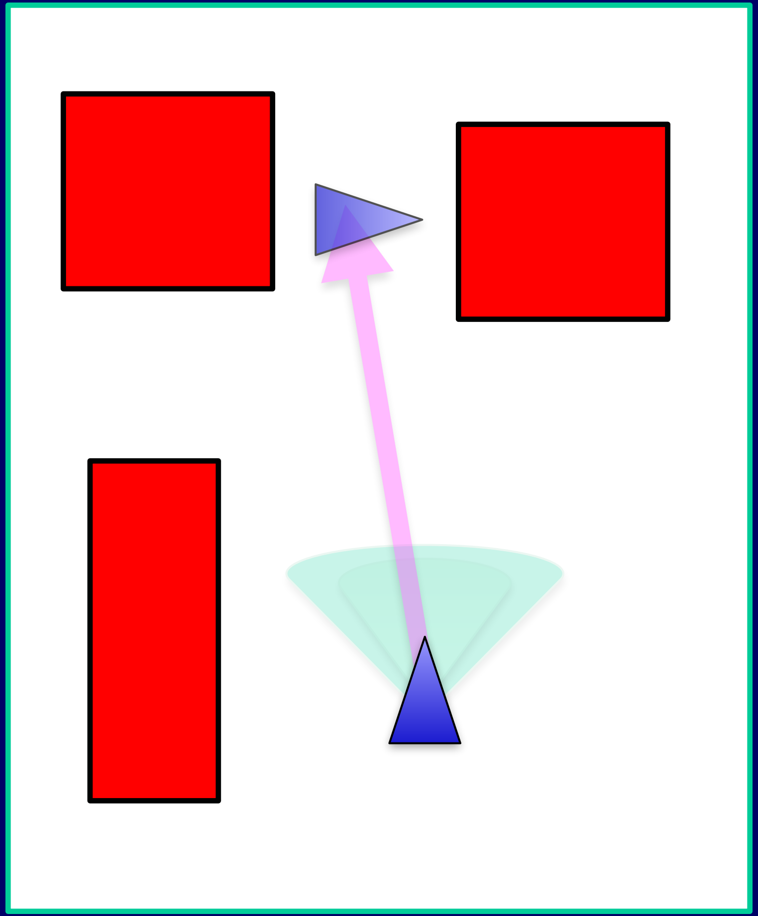
Input: A starting state x_0.

Output: Sample of states approximately on the MA.

1. Pick a ray in the workspace.
2. Get a new state at the tip of the ray.

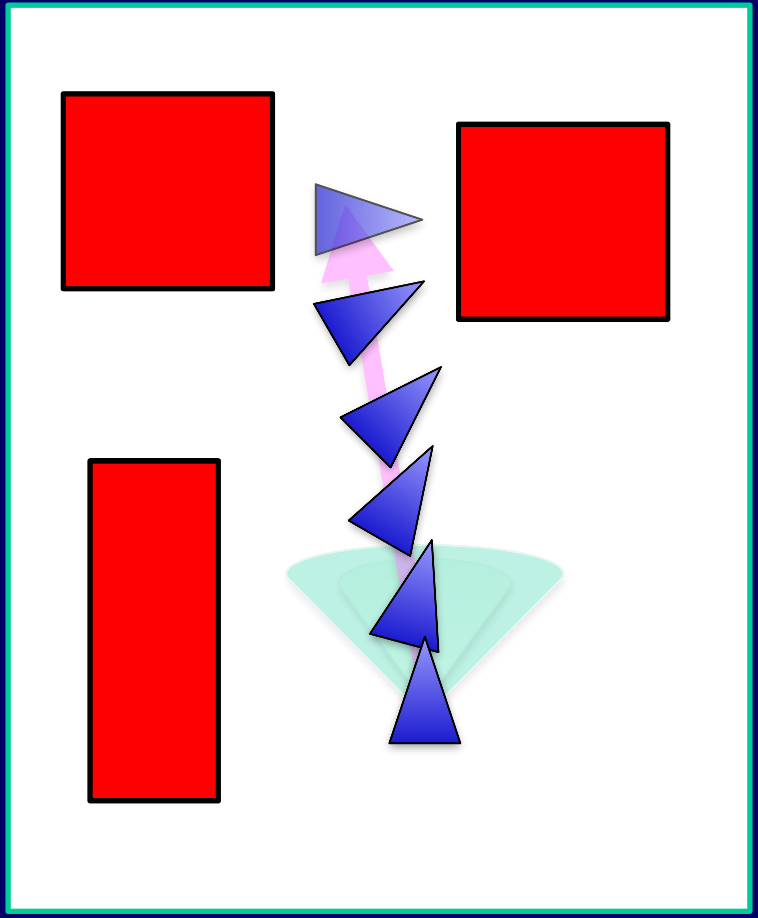


Algorithm 2: NH Medial Axis Sampler

Input: A starting state x_0.

Output: Sample of states approximately on the MA.

1. Pick a ray in the workspace.
2. Get a new state at the tip of the ray.
3. Interpolate along ray.



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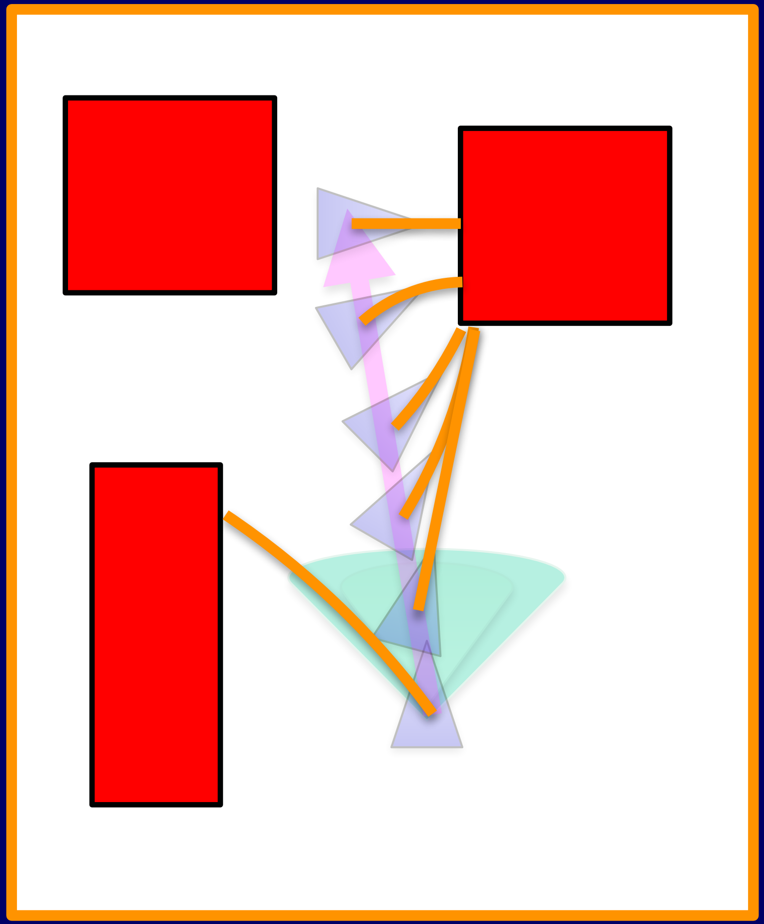
4. Get clearance for each in-between state.



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1. Pick a ray in the workspace.
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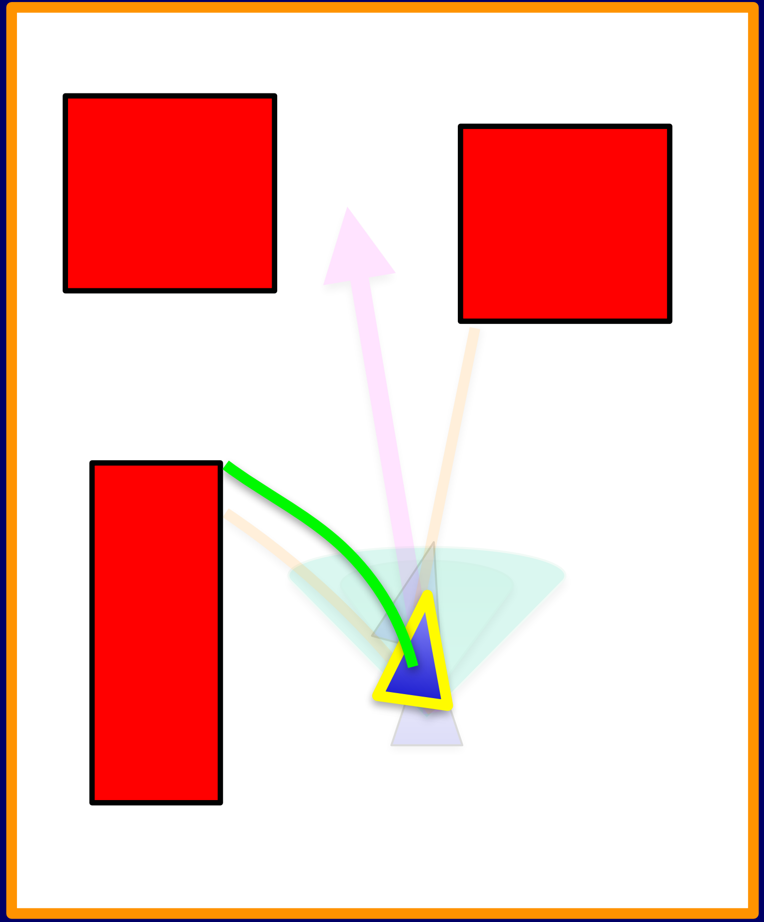
4. Get clearance for each in-between state.
5. Find local maxima (binary search).



Conclusion

Conclusion and Future Work

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Safer Driving with Self-Driving Cars

New algorithm for sampling on MA of non-holonomic state space.

Helps define safety for non-holonomic models.

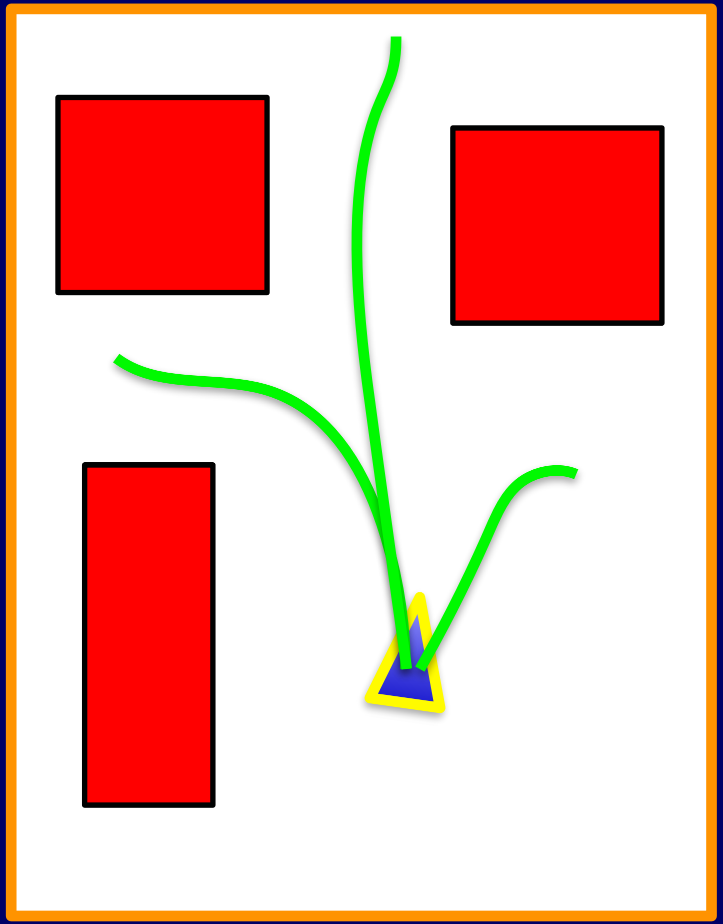
Aid the development of autonomous vehicles.

Future

Improve efficiency and accuracy of algorithm.

Develop algorithms to compute the singularity set explicitly.

Use MA to solve different problems in real NH systems.



https://giphy.com/gifs/loop-kbUq8z1MEYQ7u

Thank you!

Questions?

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