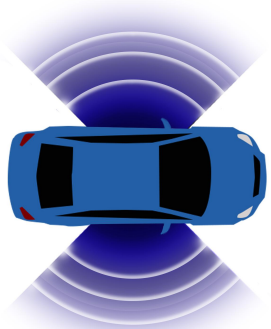


Formal Verification of

V2I aided Autonomous Driving

A hybrid systems approach

Ishan Pardesi
Dhruv Mahajan

The problem

Safety of Autonomous cars is paramount!

It is important to invest in developing formal verification techniques to ensure safety of autonomous vehicles.

Proposed Solution

Formally verify all car maneuvers for safety using differential dynamic logic while designing the system

Use smart road infrastructure to validate all car maneuvers for safety before the maneuver is made in real time

Defining Safety

If a car maintains sufficient distance from other cars such that it can

- brake or
- change lanes

in time to avoid a collision, then it is safe.

Can that be Guaranteed?

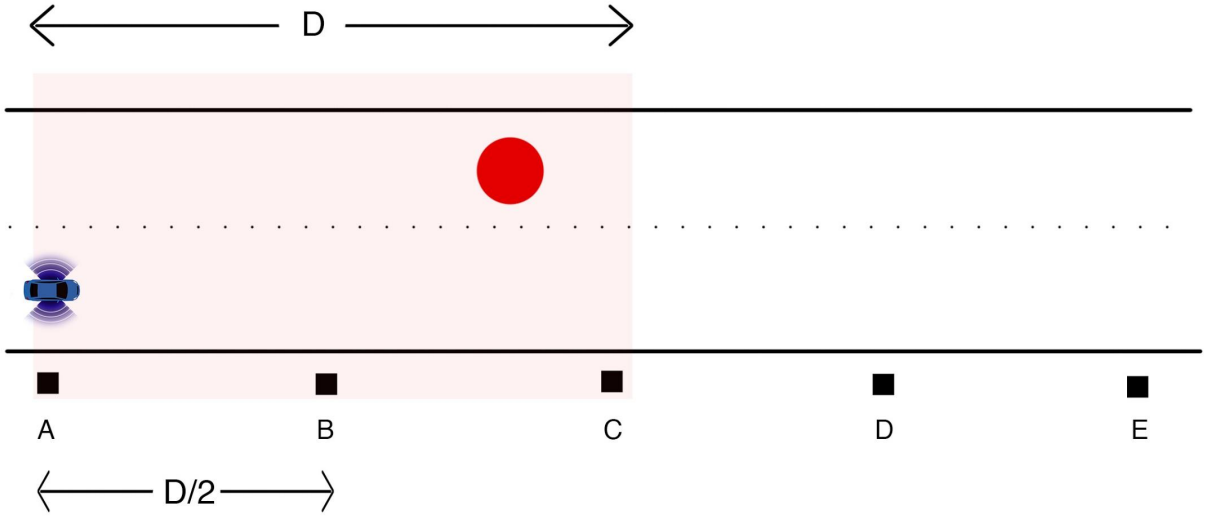
An autonomous car always operates from a limited awareness of its environment.

If only the car new everything about its environment well in advance, there would be no collisions.

Smart Infrastructure as a solution

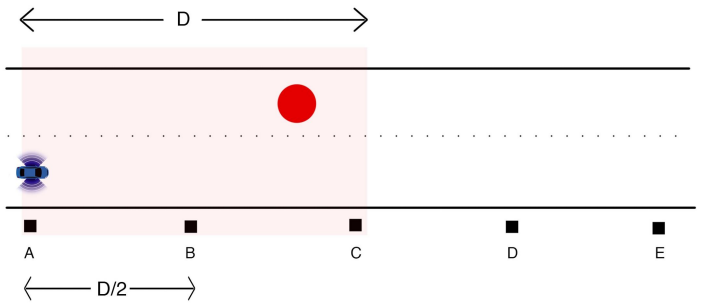
Intelligent nodes at regular distances on the Highway

- Allows the car to see beyond it's sensing capabilities
- Enforces dynamic regulations, eg. Speed Limits
- Better & accurate control decisions
- Increases safety - more determinism
- Increases efficiency



The Model

Elements of the Model



Highway

A two lane smart highway laid with intelligent nodes at regular distance creating a robust V2I infrastructure

Autonomous Car

Objective is to reach the goal without any collision

Obstacles

Obstructions for the car - static, or moving, introduced one at a time every D/2 distance

General Assumptions - Highway

- Two Lanes
- Highway Speed Limit (V_{SL})- ~ 155 mph
- Inter Node Distance (D/2) = 150 meters (can be higher)
- Range diameter of node - (D) = 300 meters (can be higher)
- Finite Time to change lanes ~ 1-2 seconds
- Next Control Decision - within 1 meter
- Can change lanes within D/2 distance (even at V_{SL})

Modelling overview

(Preconditions) ->

[

(Controller;

differential dynamics)*

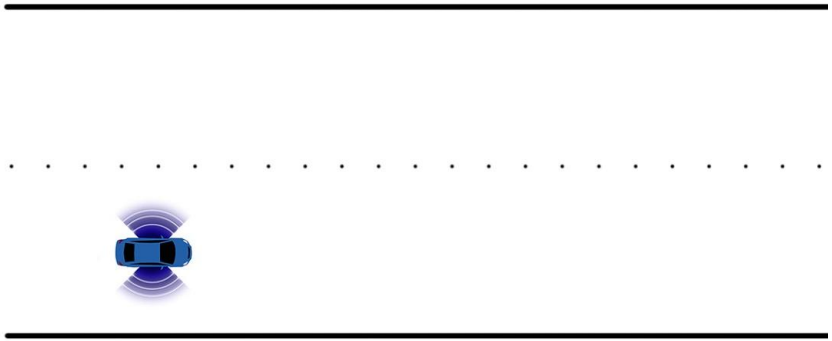
@ invariant

]

(Post Condition)

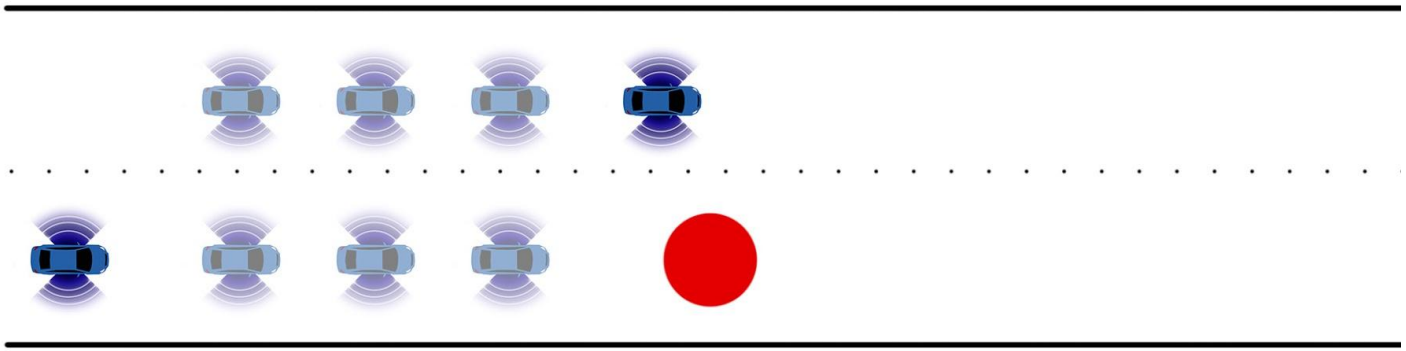
Let’s Build the Models Step by Step

No obstacle on the road



TRIVIAL

Introducing an obstacle



- Constant Velocity
- Car & obstacle in same lane
- Time to change lanes δ = 1 sec
- Single Obstacle

Model Explained

Car is safe initially ->

[

{ {If sufficient distance to change lanes after 1 control cycle

=> Continue or change lanes

Else

Change lanes NOW};

{Differential dynamics} }

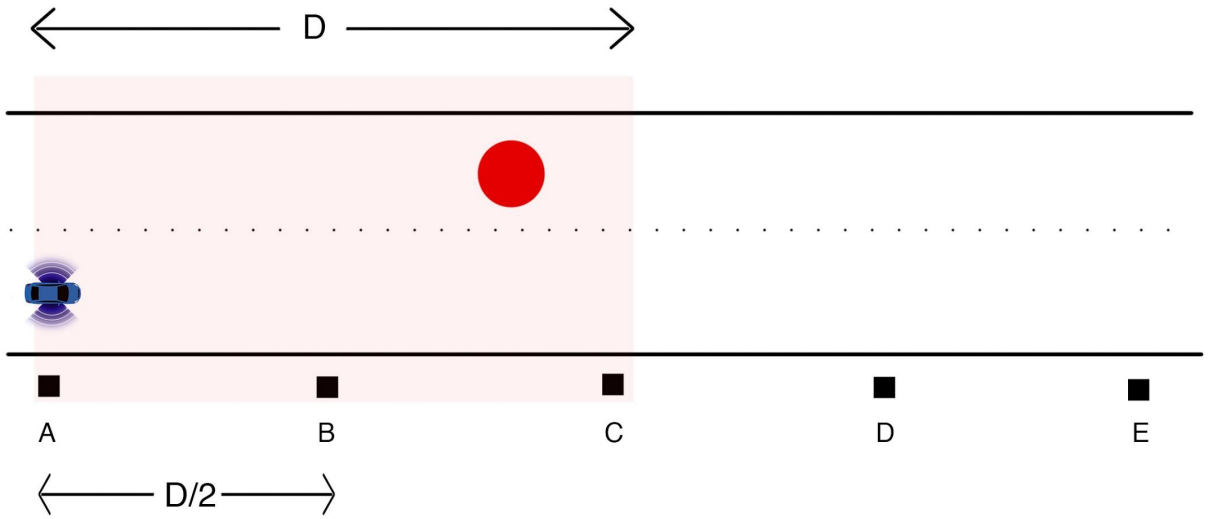
@ {If lane changing =>must complete without collision

OR it must be safe to change lanes}

]

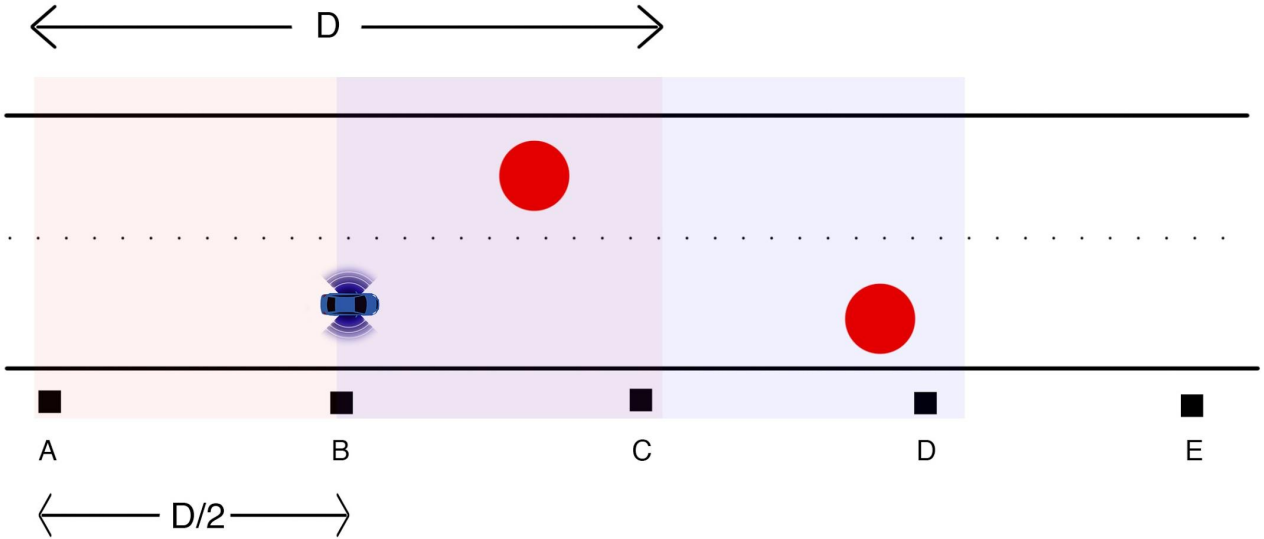
(No collision - Safety Condition)

Limited Sensing Capability



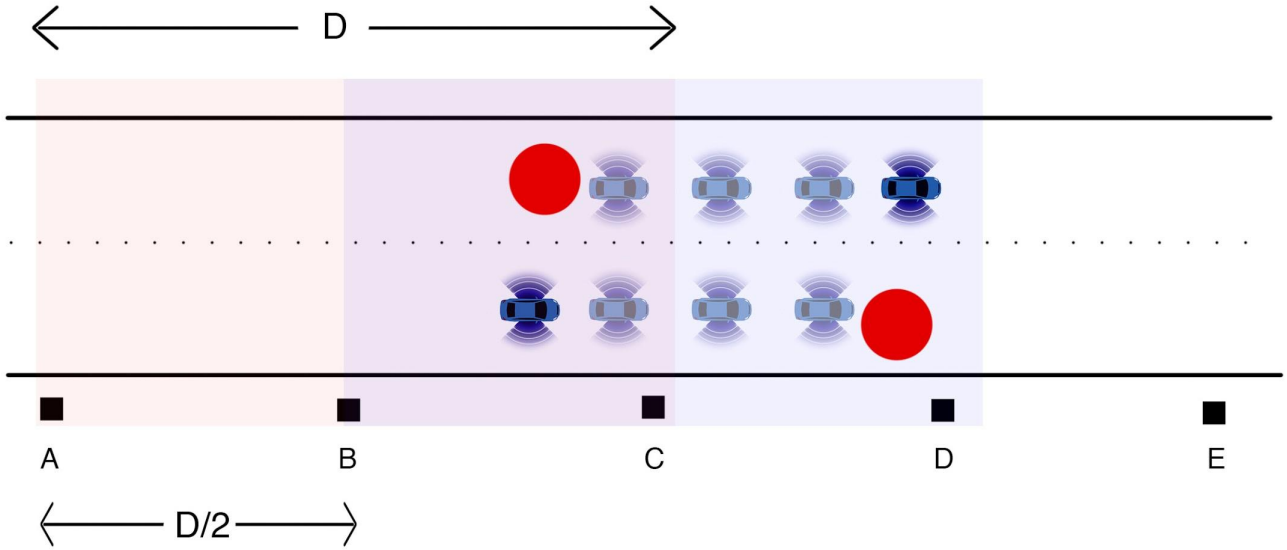
- Upto 80-100 meters
- Can't see beyond 1-2 vehicles
- Nodes allow to see beyond
- Allows better control decisions

Model explained



- Constant Velocity
- Multiple obstacles on road
- New obstacle in next D/2 block of road
- New information available after each node

Model explained



Model explained

Car is safe initially ->

[

] (No collision)

Model explained

Car is safe initially ->

[

{Crosses Node and gets info about next D distance}

{ {If sufficient distance to change lanes after 1 control cycle

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Else

Change lanes NOW};

] (No collision)

Model explained

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Proof strategy intuition

Consider all cases in the model. For example

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If lane change just completed

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If lane change just completed

If the car just crossed a node

Proof strategy intuition

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If there is a node ahead in the same lane

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Begin the lane change procedure immediately.

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Consider all cases in the model. For example

If lane change just completed

If the car just crossed a node

If there is a node ahead in the same lane

If the car will not have time to change lanes after the next time cycle T

Begin the lane change procedure immediately.

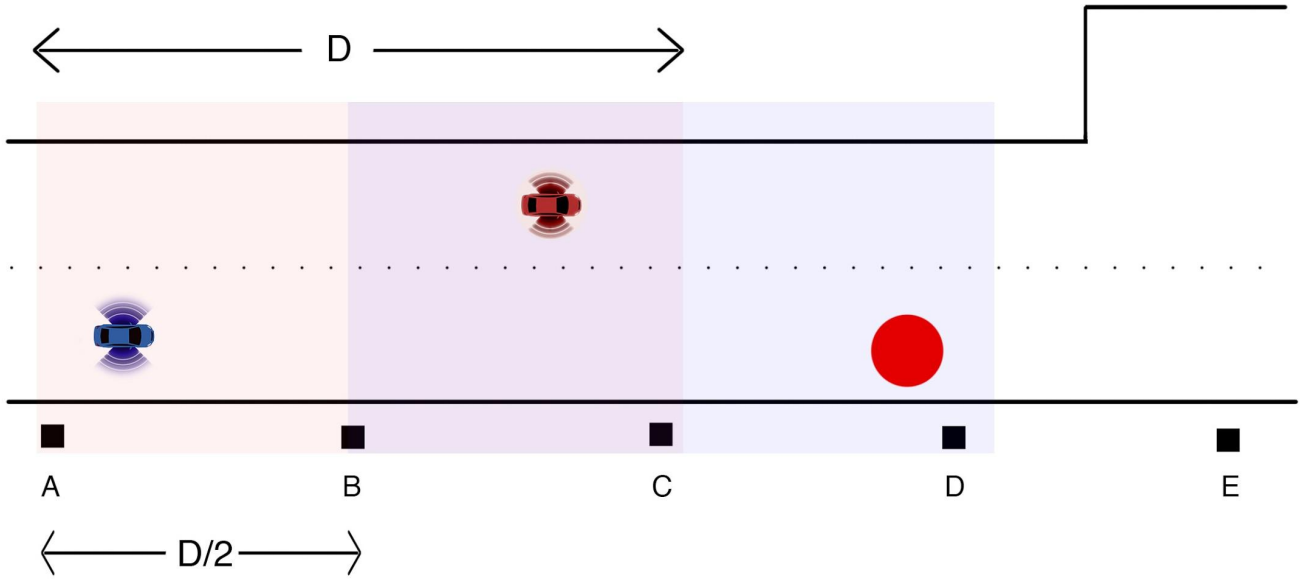
Solve the ODE and check if the car is safe or not

Subsequent Models

In the subsequent models, we allow the following capabilities while ensuring safety-

- Accelerate
- Decelerate
- Lane changing (even when not necessary)

Future Work



- Moving Obstacles
- Dynamic change in # of lanes
- Combining all into one
- Hybrid Games (dGL) Approach

Implications of the approach

Policy Implications

Ownership of accident responsibility

Infrastructure ensured safe driving - more freedom to automakers.

Ensuring strict enforcement of road laws

Technology Implications

Brings determinism and safety guarantees in autonomous driving

High driving efficiency by increased road awareness

Allows better transport planning and traffic optimization.

Acknowledgements

- Professor André Platzer
- Yong Kiam Tan (TA)
- Mengze Li (TA)

References

- Original reference of Image on slide 6 (largely modified) -https://bit.ly/2LaorIi
- Presentation template by SlidesCarnival

THANKS!

Questions?