

American Control Conference 2020

The Colliding Reciprocal Dance Problem

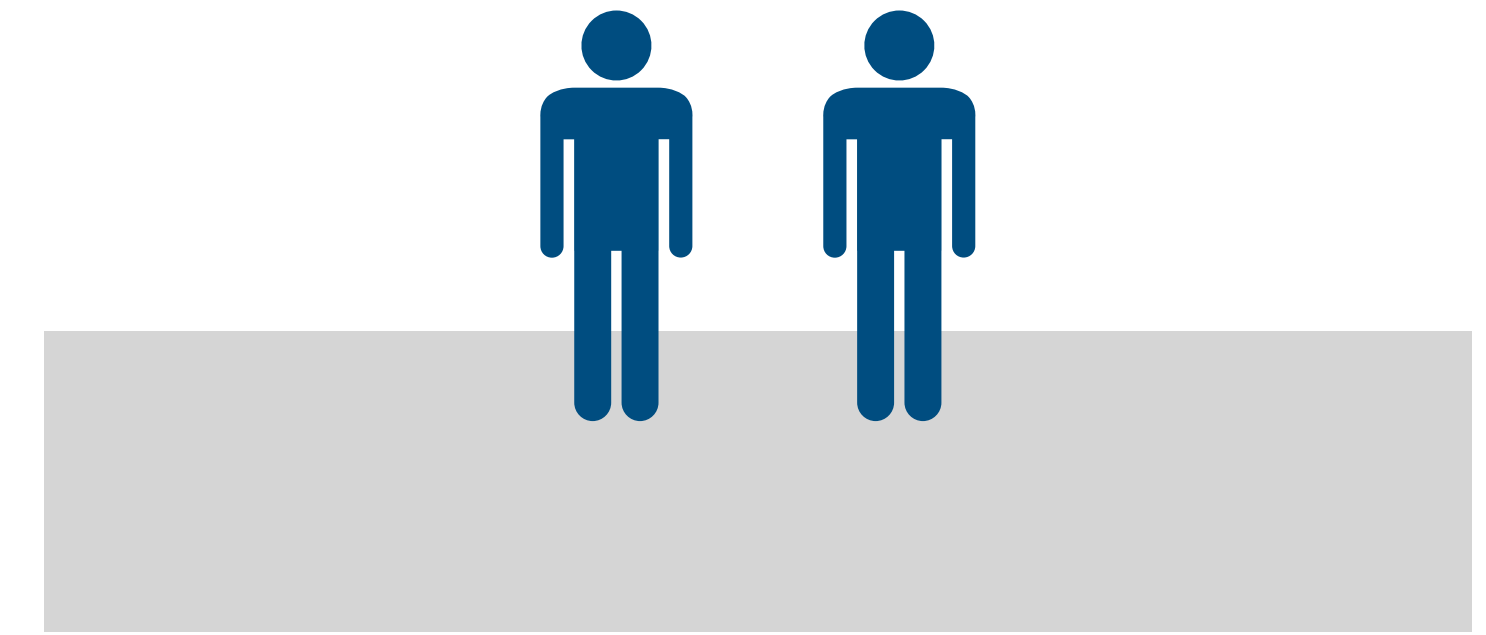
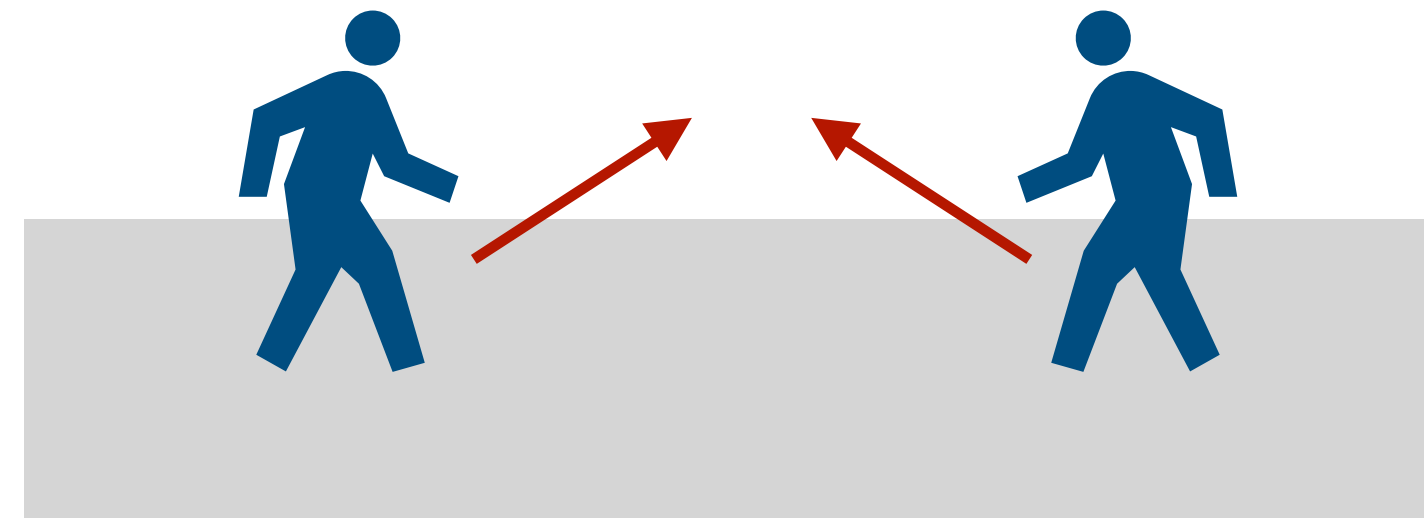
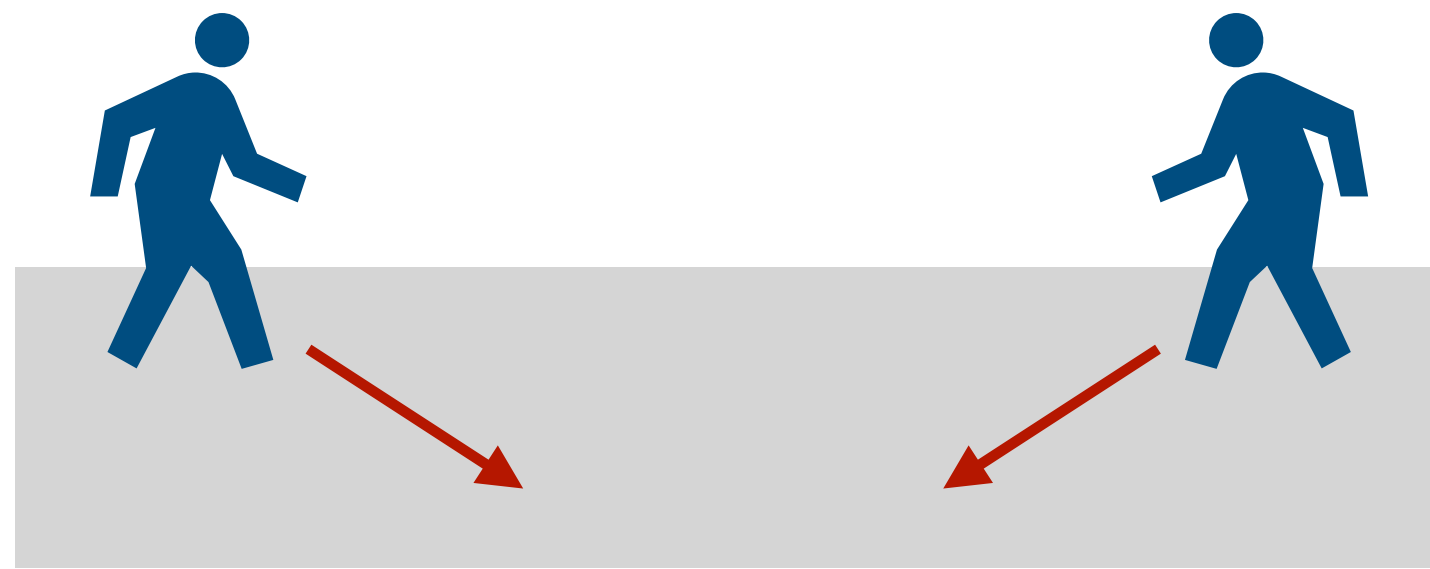
A Mitigation Strategy with Application to Automotive Active Safety Systems

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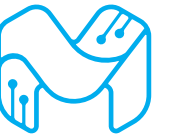




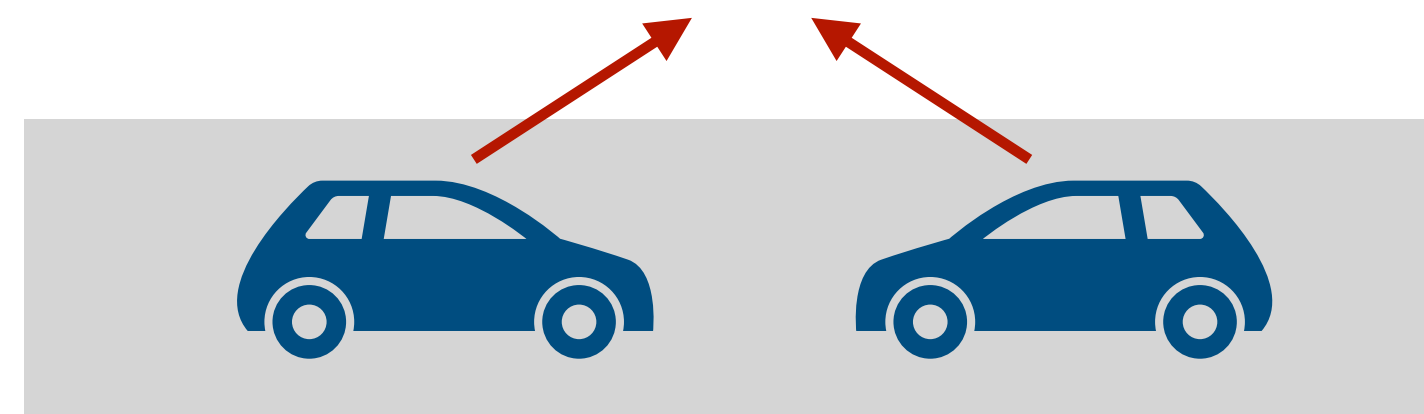
What is a reciprocal dance?



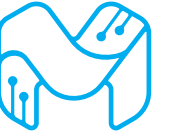
Repeated selection of incompatible actions → *deadlock*



What is a colliding reciprocal dance?



Inertial constraints prevent deadlock from occurring prior to collision



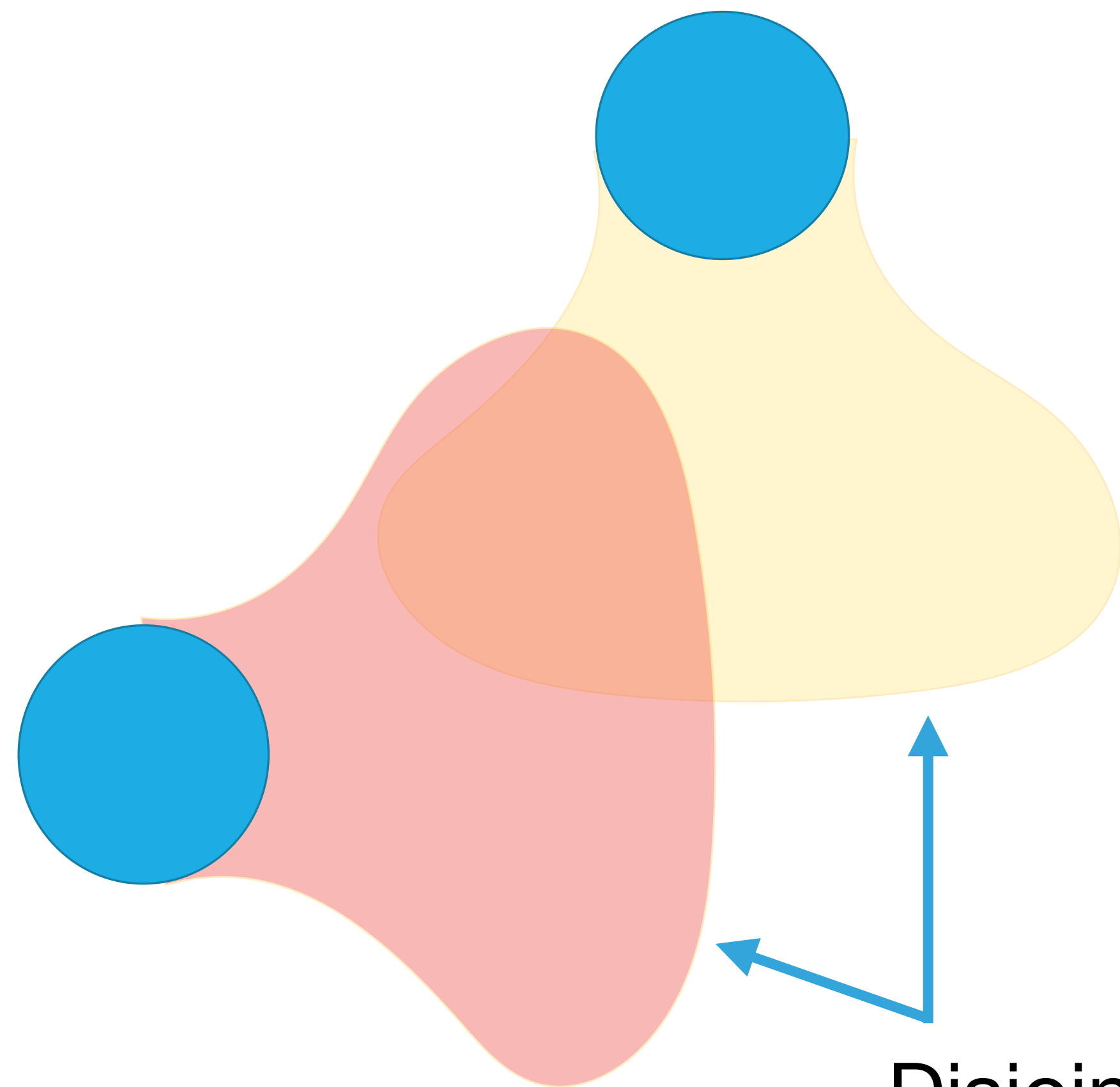
What problem is being solved?

- The dance cannot always be avoided
- In an imperfect world, collision cannot always be avoided
- Just “being conservative” often means unacceptable loss of permissiveness

How to reduce an existing control system's collision likelihood without sacrificing permissiveness?

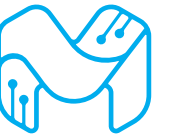


Formalizing the problem

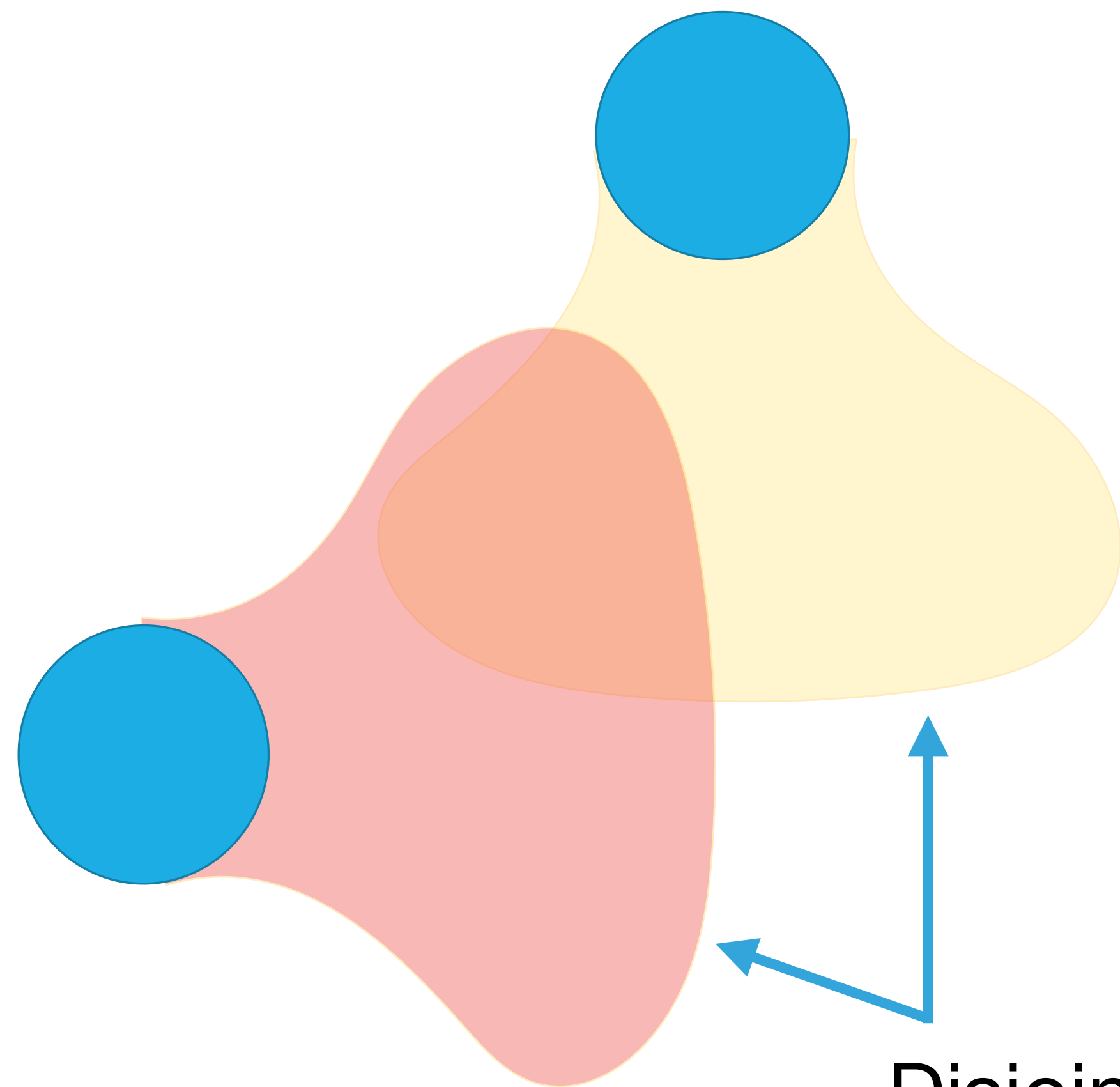


- Compute intersection
- If non-empty, contingency available
- Collision can be avoided

Disjoint contingencies exist

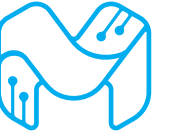


Formalizing the problem



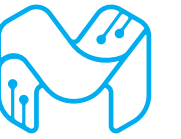
- But any noise or assumption violation can corrupt this result

Disjoint contingencies exist



Methods to mitigate incorrectness

- **None:** Do not mitigate, trust the system
 - *Highest* permissiveness, *highest* risk
- **Conservative:** Globally overestimate stopping time
 - *Lowest* permissiveness, *lower* risk
- **Constraint tightening:** Adaptively dampen controls
 - *Moderate* permissiveness, *lowest* risk



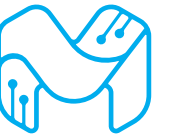
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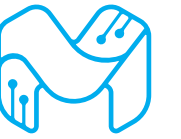


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Constraint tightening overview

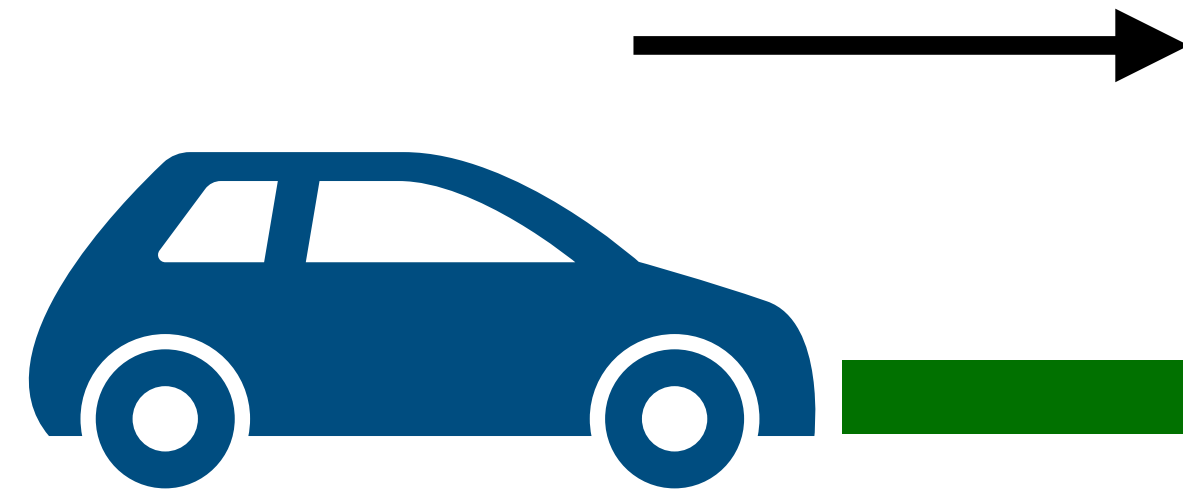
Perfect world example



accel
range (m/s^2)

computed

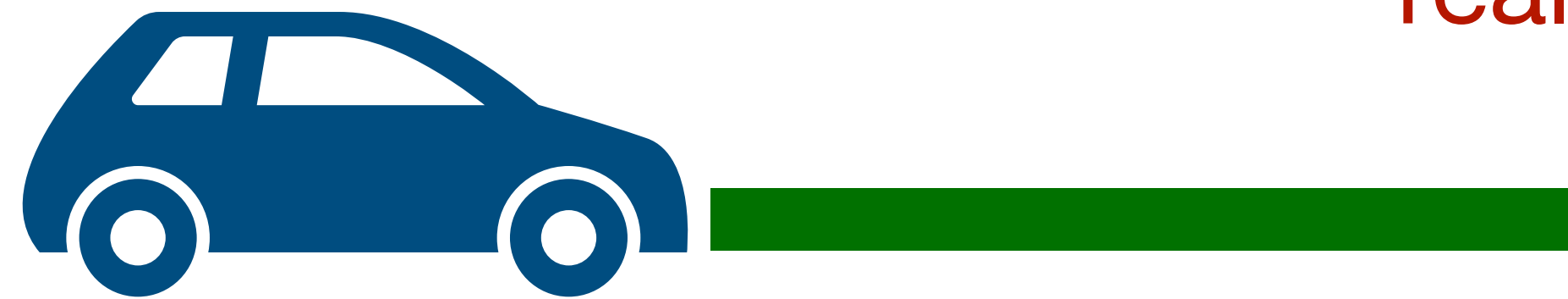
real



$[-5, 5]$

computed

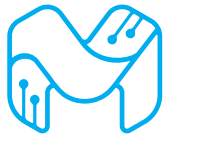
real



$[-5, -5]$



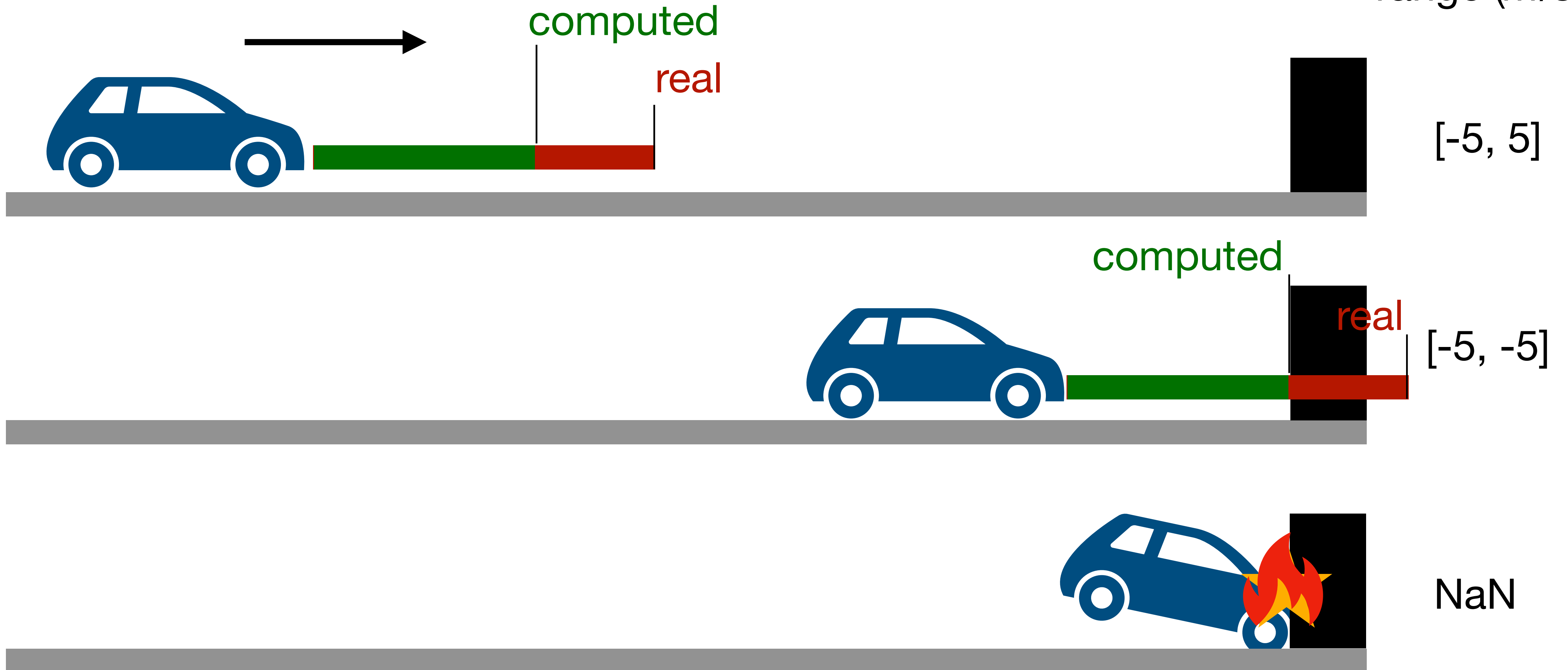
$[-5, 0]$

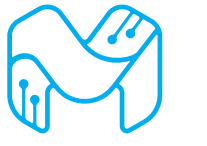


Constraint tightening overview

Contingency insufficient

accel
range (m/s^2)

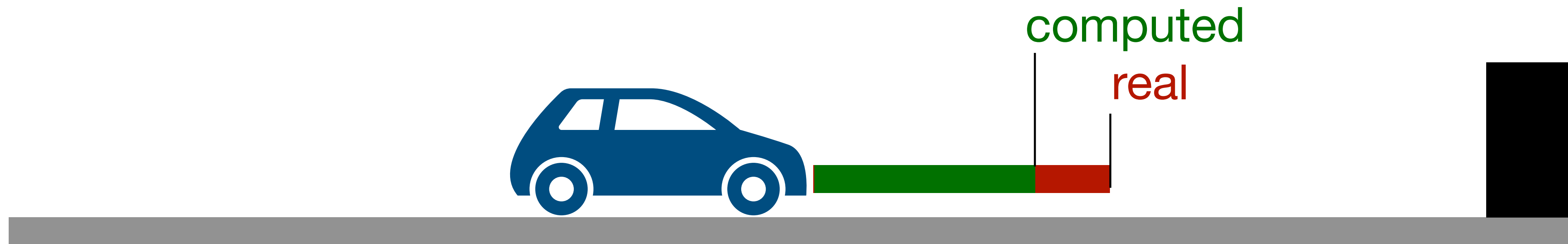
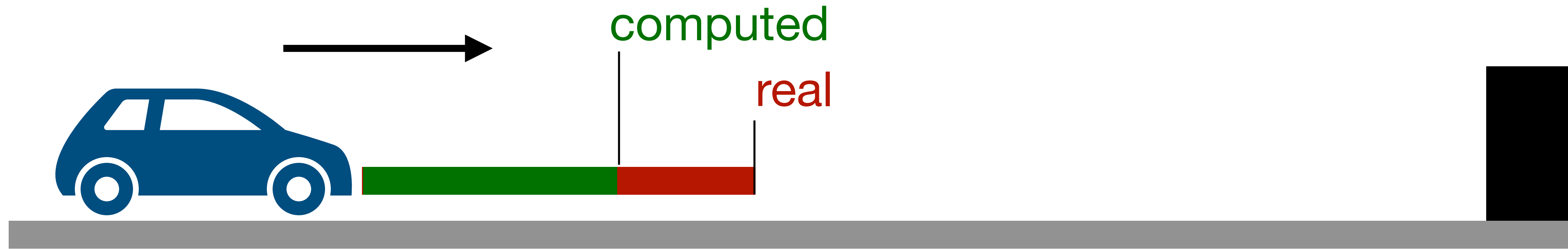


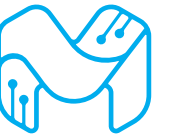


Constraint tightening overview

Contingency insufficient but mitigated

accel
range (m/s^2)





Mitigation through constraint tightening

- Scale the bounds of available controls toward contingency controls

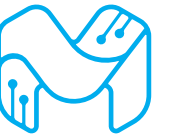
mitigated control bound

scaling factor

nominal control bound

$$c^* = (1 - \gamma)c^c + \gamma c^n$$

contingency control bound



Mitigation through constraint tightening

- Scale the bounds of available controls toward contingency controls

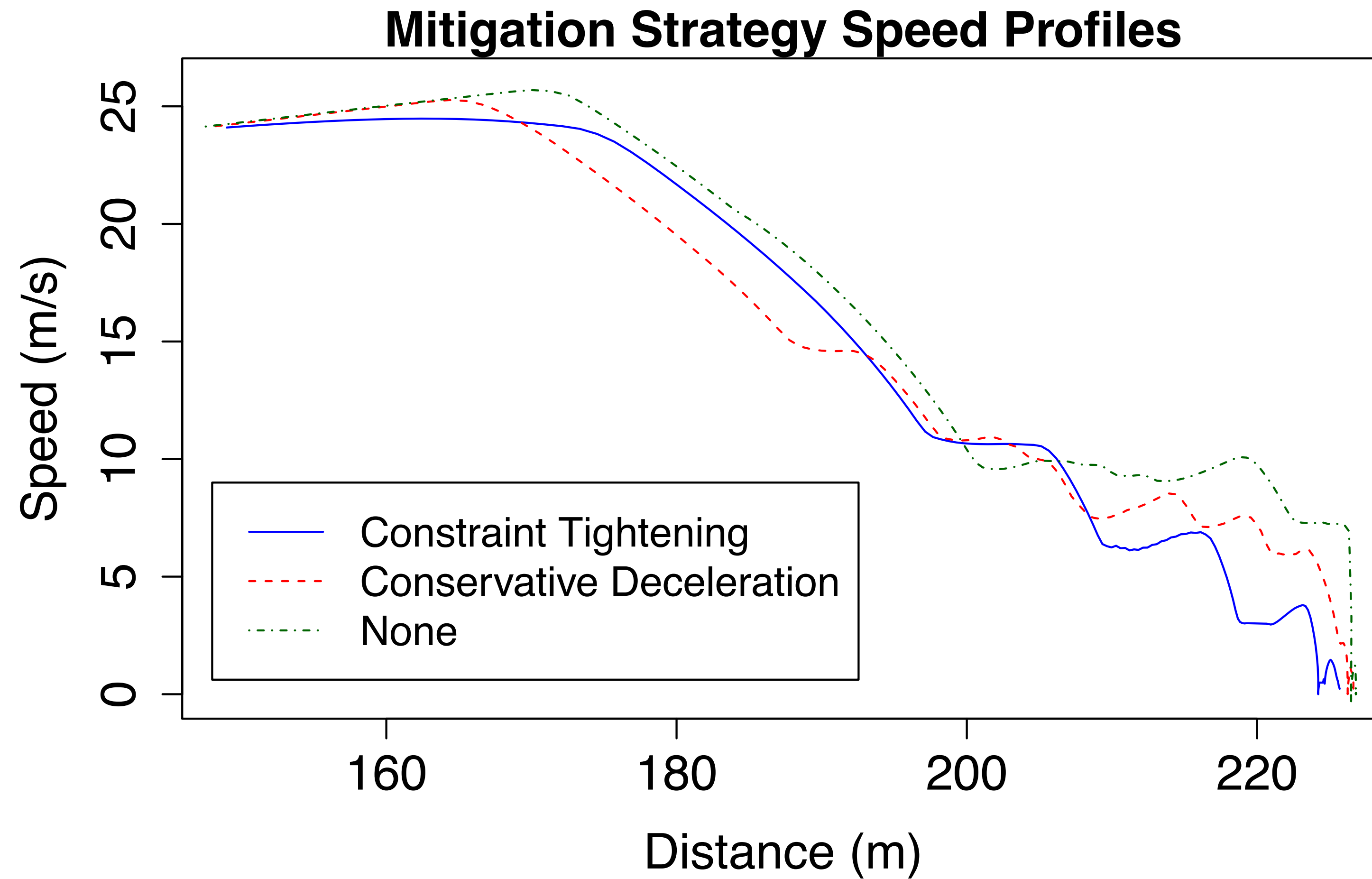
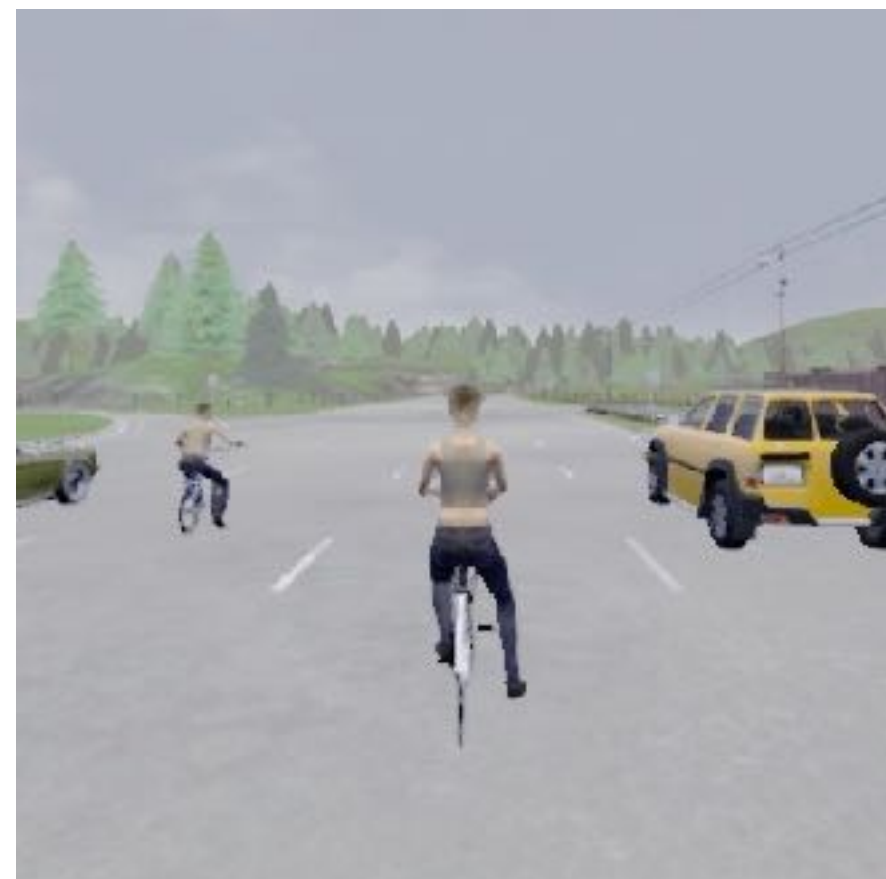
generalized sigmoid

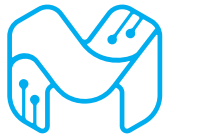
$$\gamma(t^c) = \begin{cases} 0 & t^c \leq 0 \\ \max(0, R(t^c)) & t^c > 0 \end{cases}$$

time to expected contingency invocation

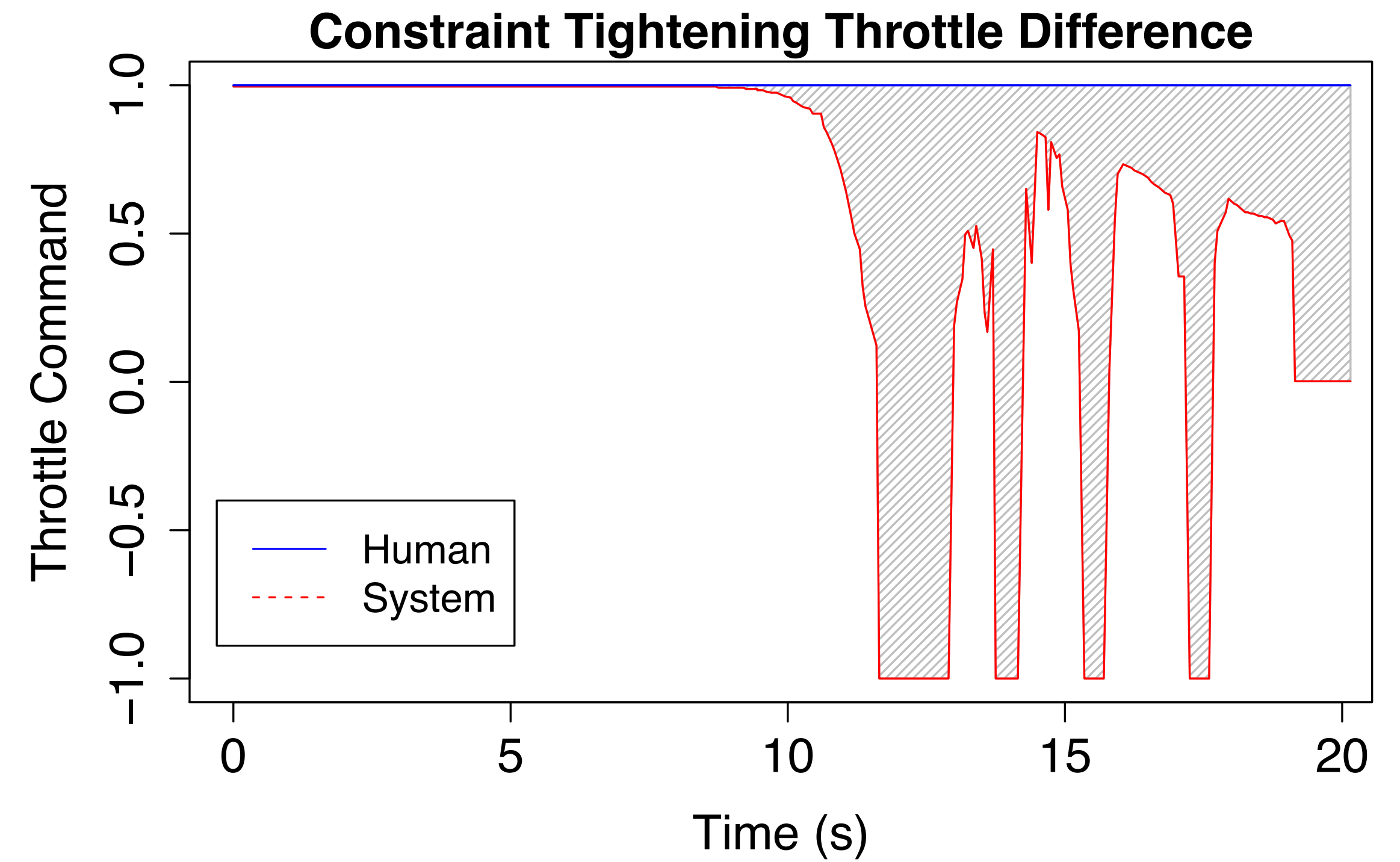
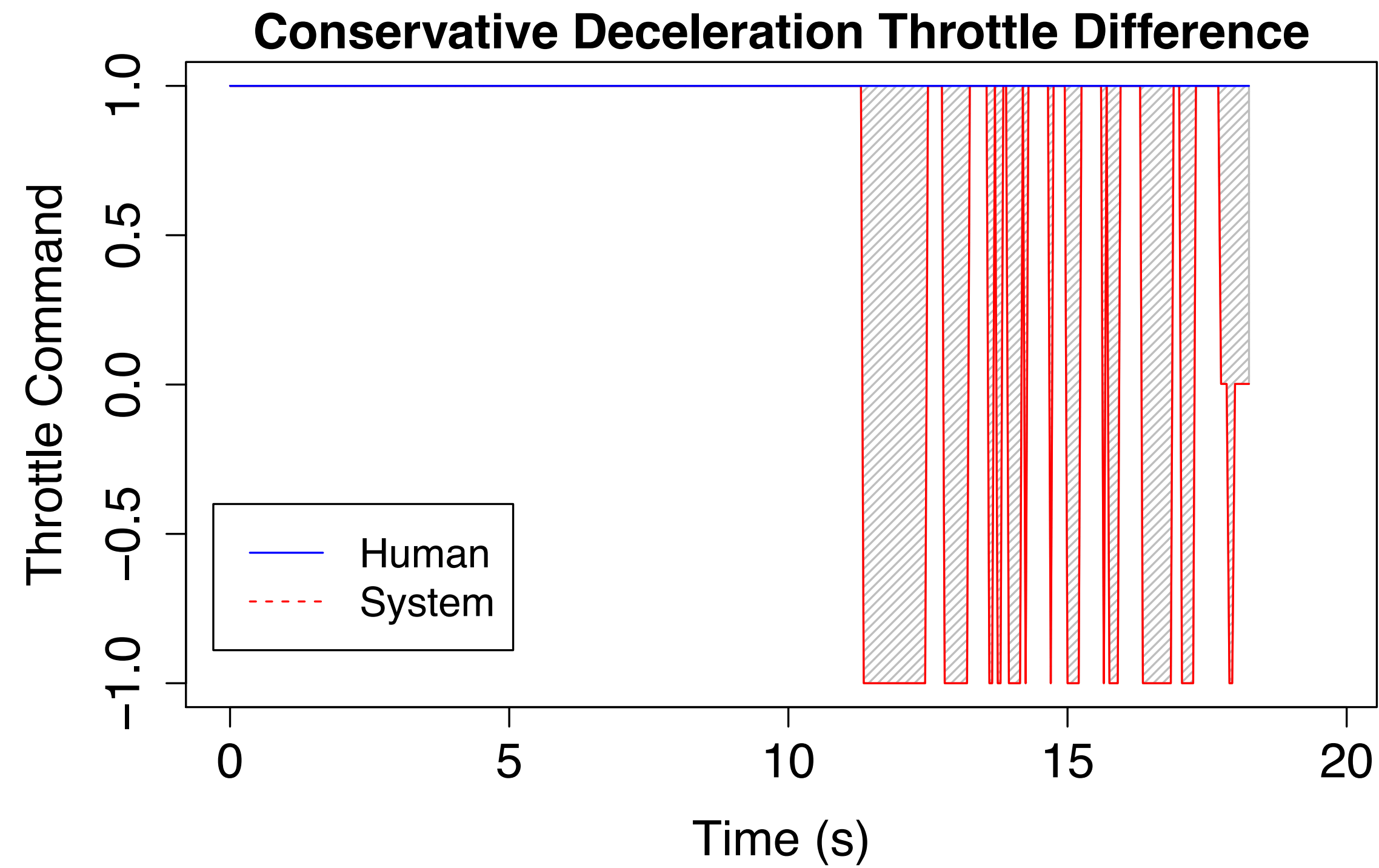


Experiment: Longitudinal active safety





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Summary + Open topics

- Increased robustness without significant loss of permissiveness
- Relatively simple to implement
- Linear scaling may not always be valid scaling mechanism
- Examine how methods like this can augment safety case argumentation