A Mechanism to Assess the Safety of (Semi-)Autonomous Cars

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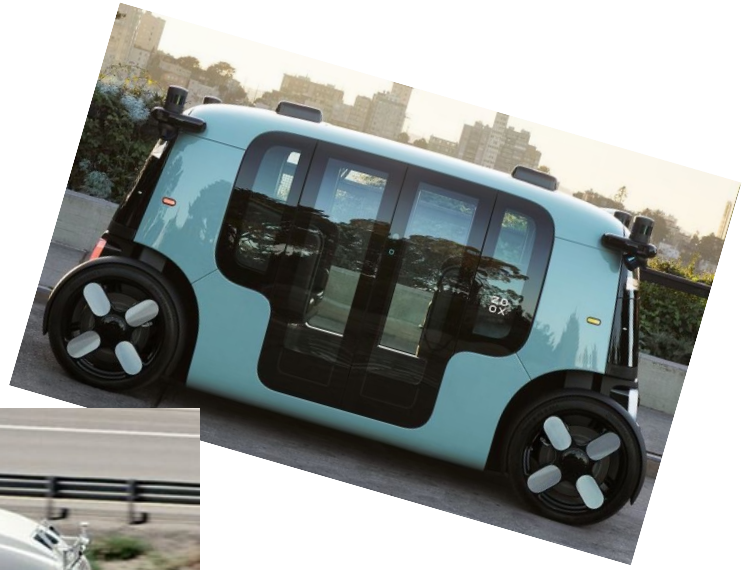
Lots of Work on Autonomous Cars



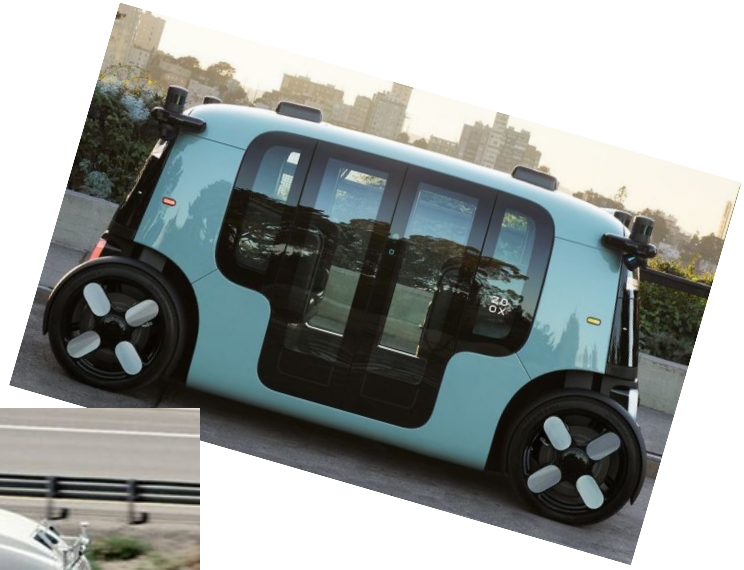
Pictures taken from news release of each car

Lots of Discussions on Safety

- Definitions of safety
- AI (incl. ML) with safety guarantees
- Formal-method based verification
- Finding “bugs” (aka. scenarios that cause accidents)

From and for developers

How about consumers?



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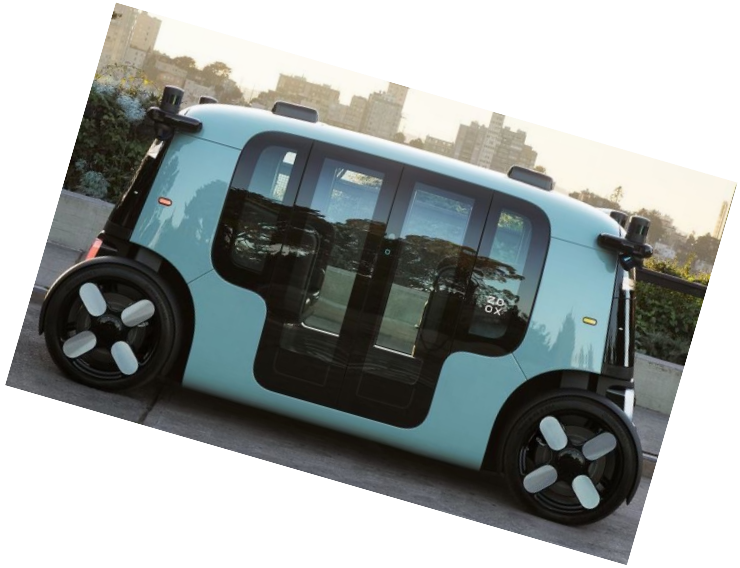
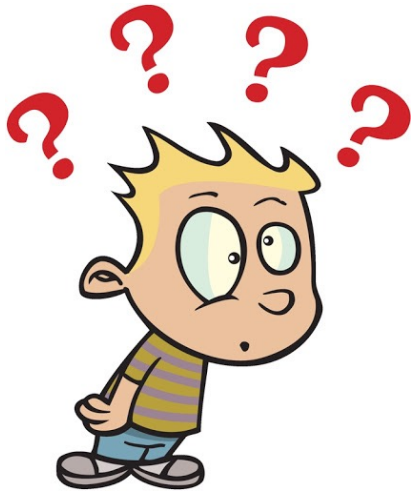
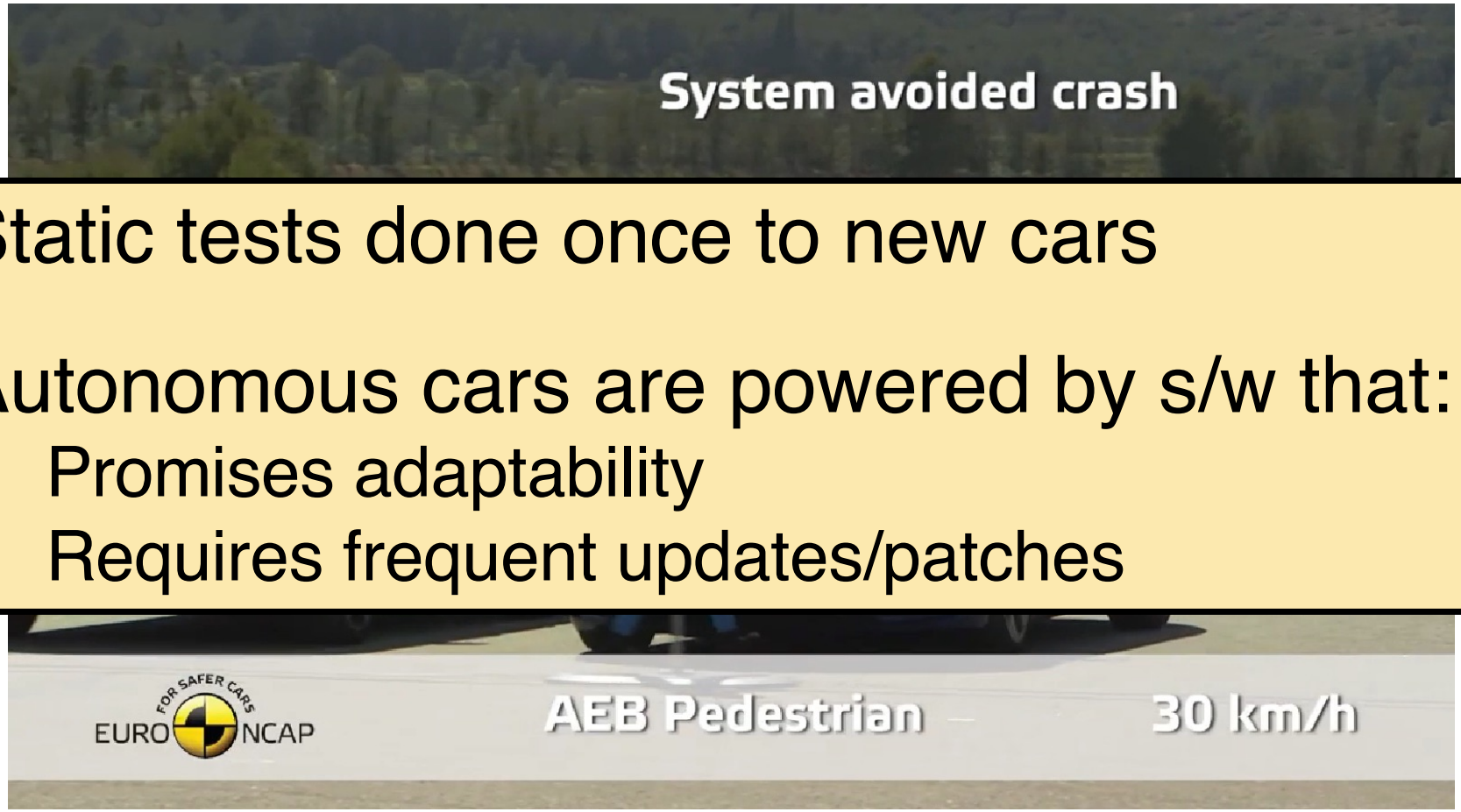




Pictures taken from news release of each car and http://clipart-library.com

In terms of Safety?

- NCAP (New Car Assessment Programme)



Static tests done once to new cars

Autonomous cars are powered by s/w that:

- Promises adaptability
- Requires frequent updates/patches

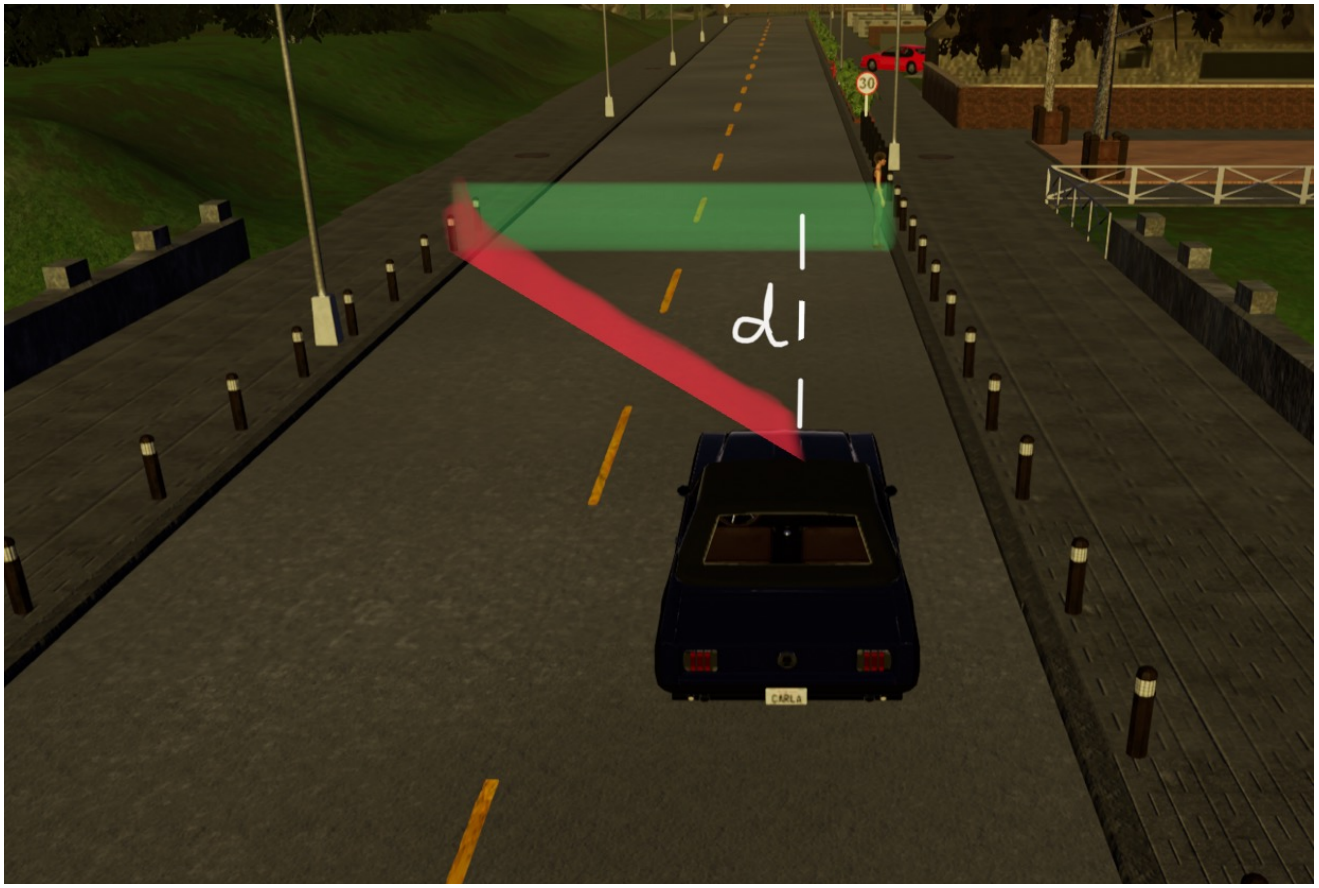
Our Proposal

Picture taken from the facebook page of starcarwash

Desirable Properties

- A simple safety indicator
  - One number, easy to understand by users
- Fast and easy assessment mechanism
  - Assessment can be done frequently (e.g., after every s/w updates, perhaps imposed during registration renewal)

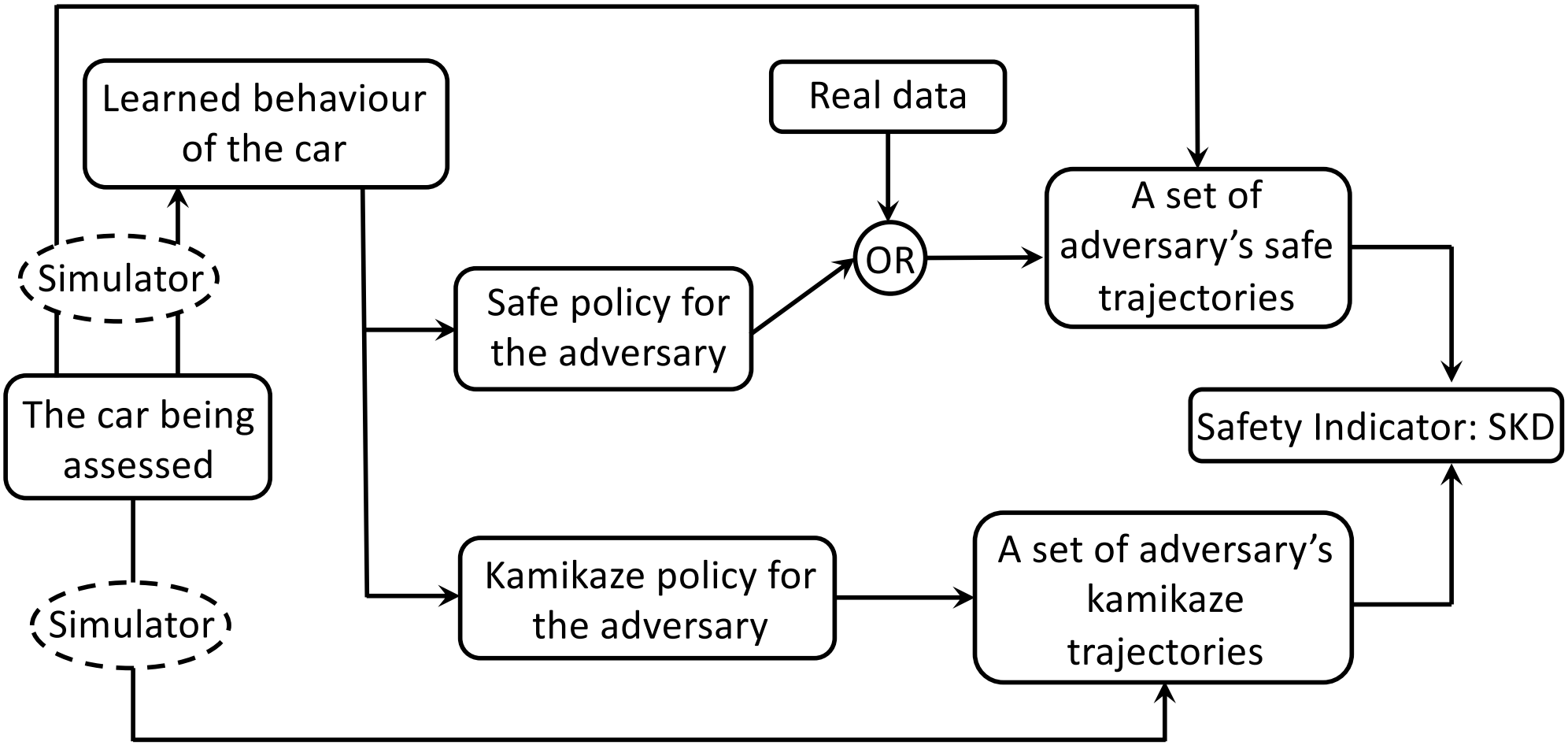
The Hypothesis



The distance between safe and dangerous trajectories of the adversary may serve as a safety indicator.

Distance computation is generally fast!

Proposed Mechanism



Dashed ellipse: May not be used

Safe Trajectories

- Real data
- Provided by regulatory body
- Generate synthetic data
  - Strive for optimal to get to the destination [biological hypothesis, Breed & Moore'15]
  - Account for the car's behaviour, though don't know their exact policy → partially observed
  - Use Partially Observable Markov Decision Process (POMDP)
- A trajectory:
  - A mapping from [0, 1] to position of the adversary in the operating environment (in this case, a bounded R^2)
  - Can be approximated by a polygonal chain (a sequence of line segments)

Kamikaze Trajectories

- Given a safe adversary's trajectory ϕ
- Find a sampled set of adversary's trajectories closest to ϕ that causes collision with the car being tested
  - The exact policy of the car is not known in advance and need to be learned → car's behaviour is partially observed
  - Closest: Current practice, within certain distance away from ϕ
  - Use Partially Observable Markov Decision Process (POMDP)

The Safety Indicator: SKD

- Given:
  - A set of safe trajectories Φ
  - A set of kamikaze trajectories $\Psi(\phi)$ for each safe trajectory $\phi \in \Phi$
- Suppose $\Psi = \bigcup_{\phi \in \Phi} \Psi(\phi)$, then

$$SKD(\Phi, \Psi) = \frac{1}{|\Psi|} \sum_{\phi \in \Phi} \sum_{\psi \in \Psi(\phi)} d(\phi, \psi)$$

SKD = Safe-Kamikaze Distance

$d(\phi, \psi) = inf_{\alpha,\beta}\, max_{t \in [0,1]} \left\| \phi\big(\alpha(t)\big) - \psi(\beta(t)) \right\|$

Also known as Fréchet distance

Turns out …

If $SKD(\Phi, \Psi) = \delta$ and we have sufficiently many samples, then

$$Prob(d(\phi', \psi') < \eta) \leq 2\left(\frac{\eta}{\delta^2} + \frac{\eta}{\delta}\right)$$

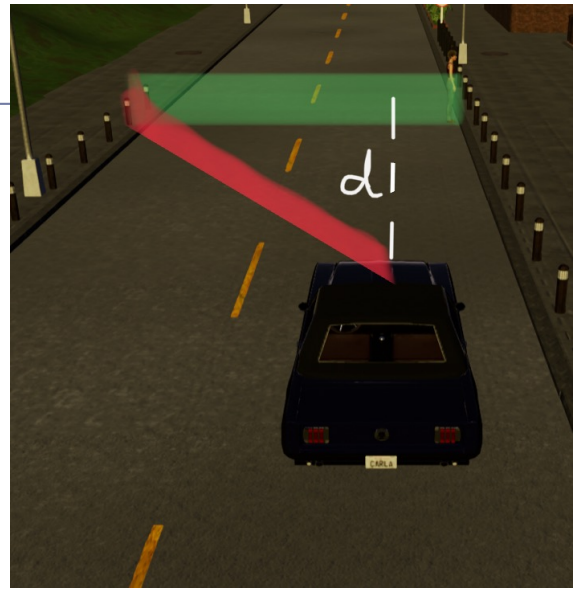
for small $\eta \in (0, \delta)$ and any safe trajectory ϕ' and corresponding dangerous trajectory ψ' sampled from the same distribution as the one used to generate Φ and Ψ

The probability that a small deformation changes a safe adversary's trajectory into a dangerous one is upper bounded by a value inversely proportional to SKD

So…

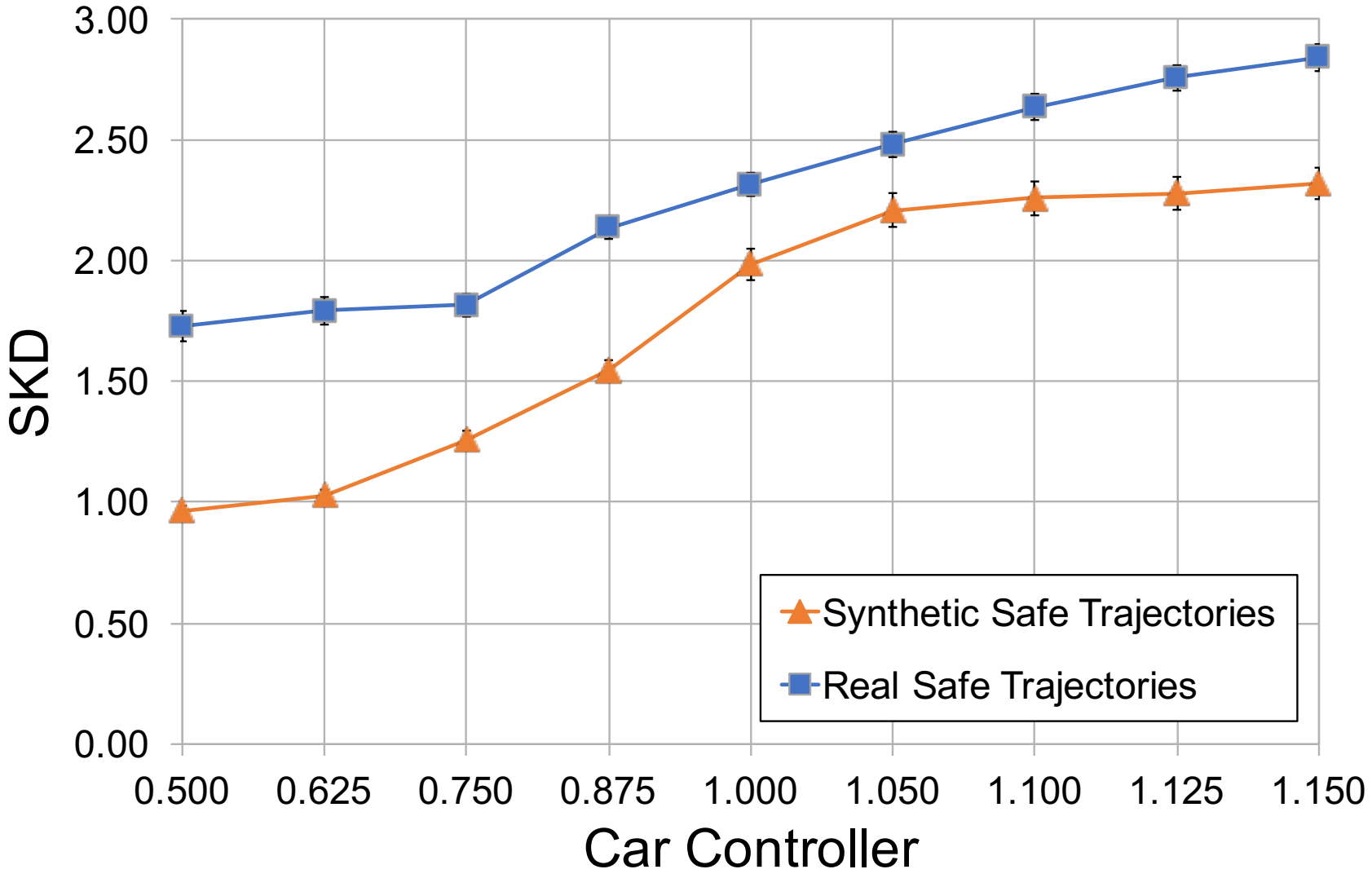
- Large SKD is a possible sufficient condition for an autonomous car to be safe. Meaning:
  - If SKD is large, the car is likely to be safe
  - If SKD is small, unfortunately, we can’t say much!!!

Systematic Test



- Scenario: Euro-NCAP Vulnerable Road User test on Autonomous Emergency Breaking
- A pedestrian crossing a road in front of the car moving on a single lane
- The car:
  - Has a maximum velocity & fixed acceleration/deceleration
  - Safe stopping distance κ: The distance to move from maximum velocity to 0 with maximum deceleration
  - Where the car starts to decelerate: $C.\kappa$ distance away from the pedestrian
    - C: Multiplier, larger means safer

Simulation Results



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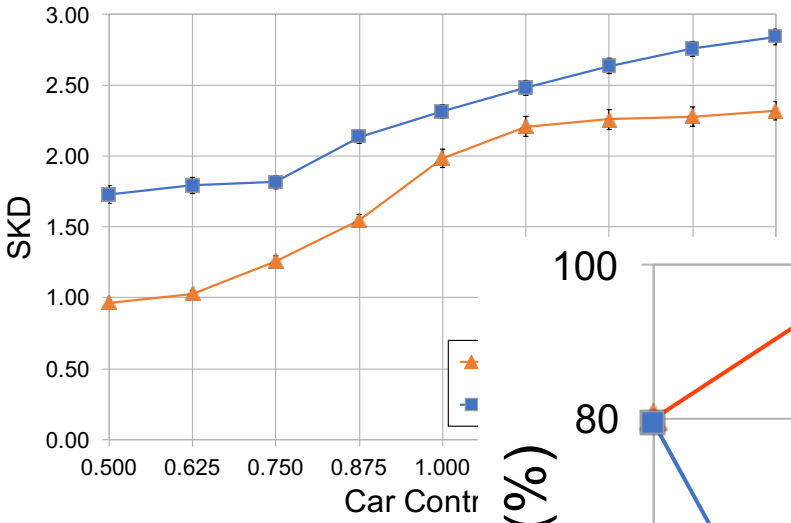
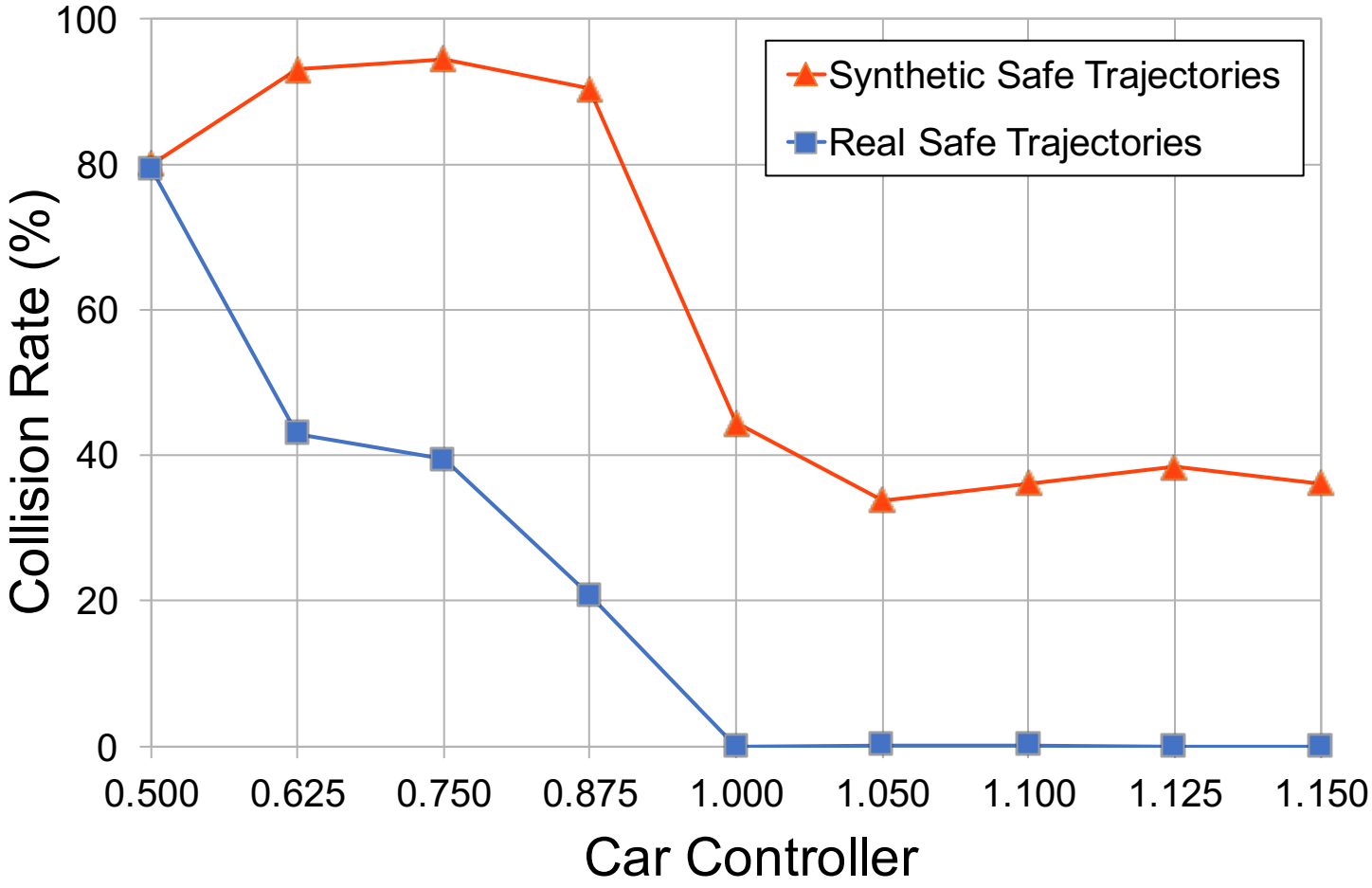
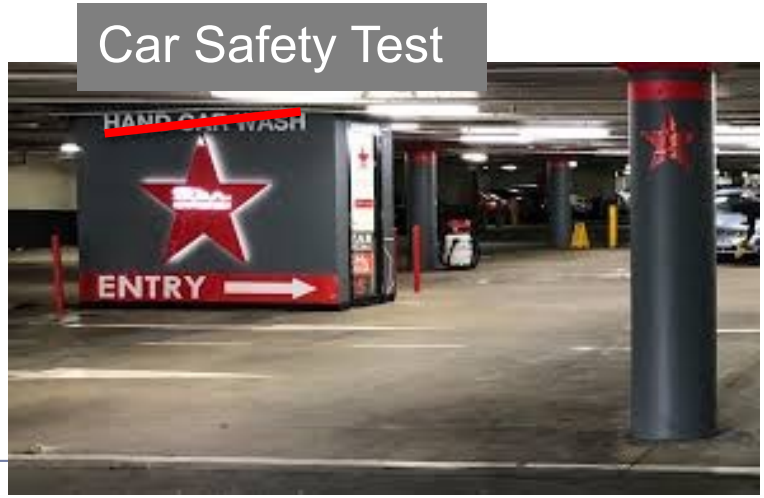


Average time to generate trajectories + computing SKD < 10s per run



Summary

- The safety indicator SKD can be used to upper bound the probability that a small deformation changes a safe adversary's trajectory into a dangerous one
- SKD with sufficient statistical confidence can be computed in under 30 minutes using a typical desktop (i7 quad-core)



Thank you

Q&A