Will the Driver Seat Ever Be Empty?

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1.2 million people die each year in car accidents.

– World Health Org.

Self-driving cars have been able to safely drive many miles.

– (2014)

The natural question: Will the driver seat ever be empty?*

*with widespread public adoption

SAFETY CRITERIA

Main causes of collisions in AVs

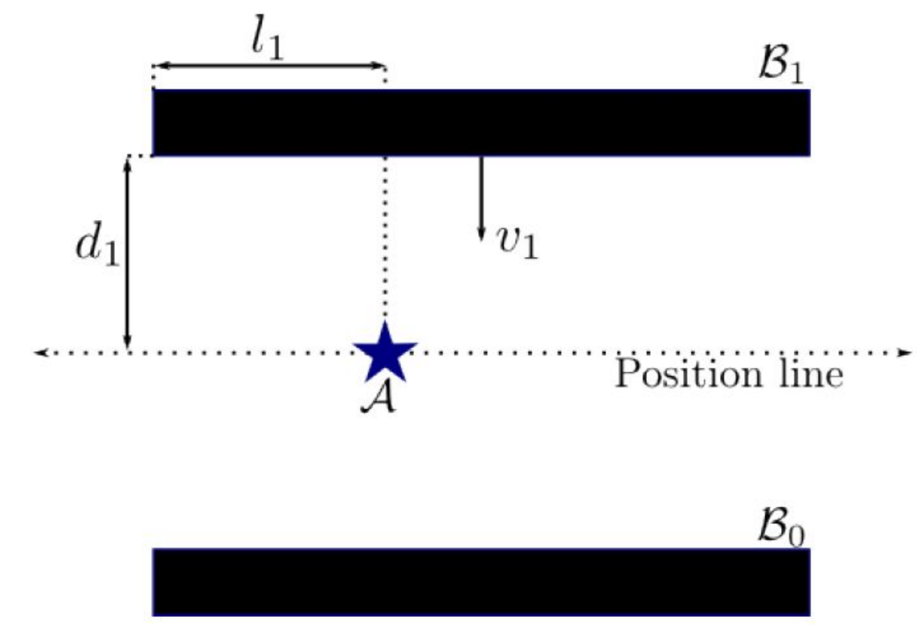
- Hardware failures (e.g. brake failure)
- Software bugs (e.g. float truncation error)
- Perceptual errors (e.g. false negative)
- **Reasoning errors** (e.g. poor strategy)

Motion safety - the ability to avoid collisions

1. Decision time is upper-bounded
2. Reasoning about the future is required
3. Time horizon is lower-bounded
4. Globally considering obstacles is required

CASE STUDY: COMPACTOR SCENARIO

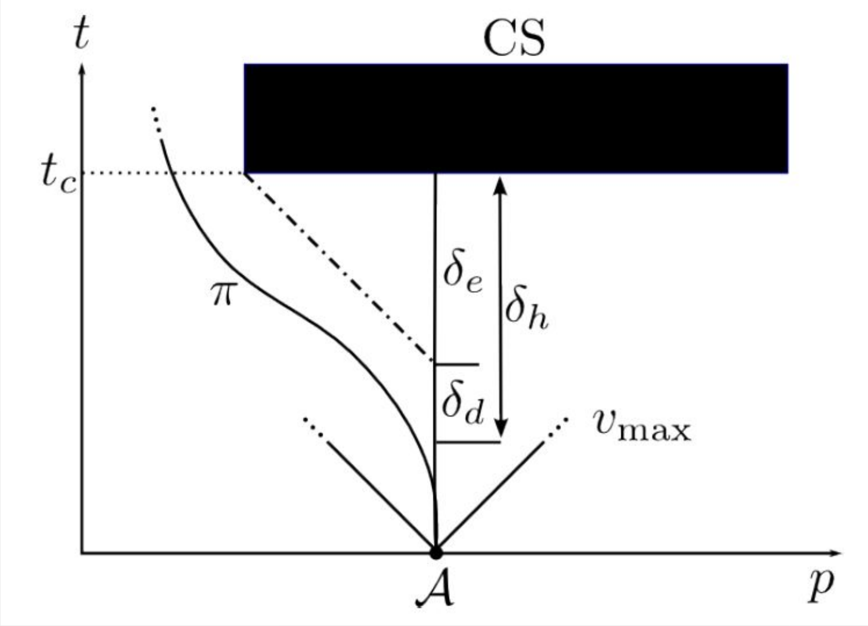
- Toy scenario: two obstacles, B_0 fixed and B_1 moving. AV can move in 1 dimension.
- Looking at just the state space doesn't tell us much.



- B_1 moves with constant velocity
- A's velocity is limited by V_{max}

CASE STUDY: COMPACTOR SCENARIO

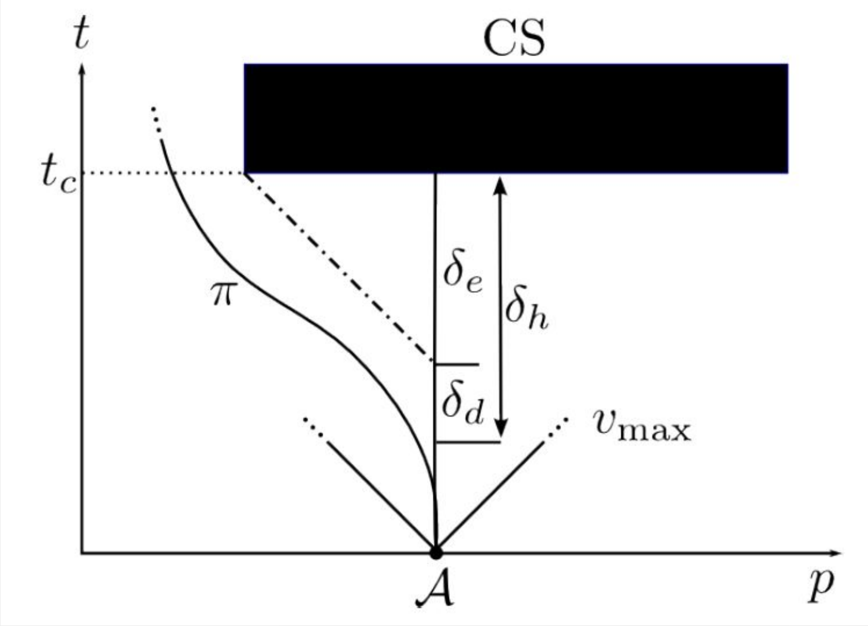
- Look at the problem in the 2D state X time space. Position on X axis, time on Y axis.
- **Motion safety rule #2 : Reasoning about the future is required**



- Not all positions are reachable in the state space due to V_{max}
- π denotes a possible future trajectory of A
- *Collision State (CS): where A collides with obstacle B_1*

CASE STUDY: COMPACTOR SCENARIO

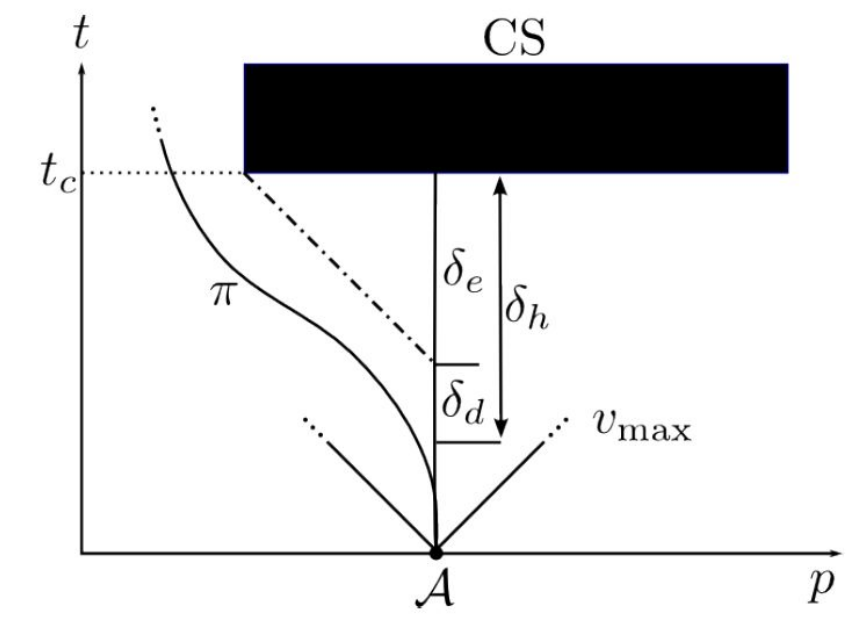
- Look at the problem in the 2D state X time space. Position on X axis, time on Y axis.
- **Motion safety rule #1 : Decision time is upper-bounded**



- δ_e minimum time for A to escape
- A must decide before reaching δ_e
- $\delta_d = t_c - \delta_e$ *maximum* decision time for A to decide future motion

CASE STUDY: COMPACTOR SCENARIO

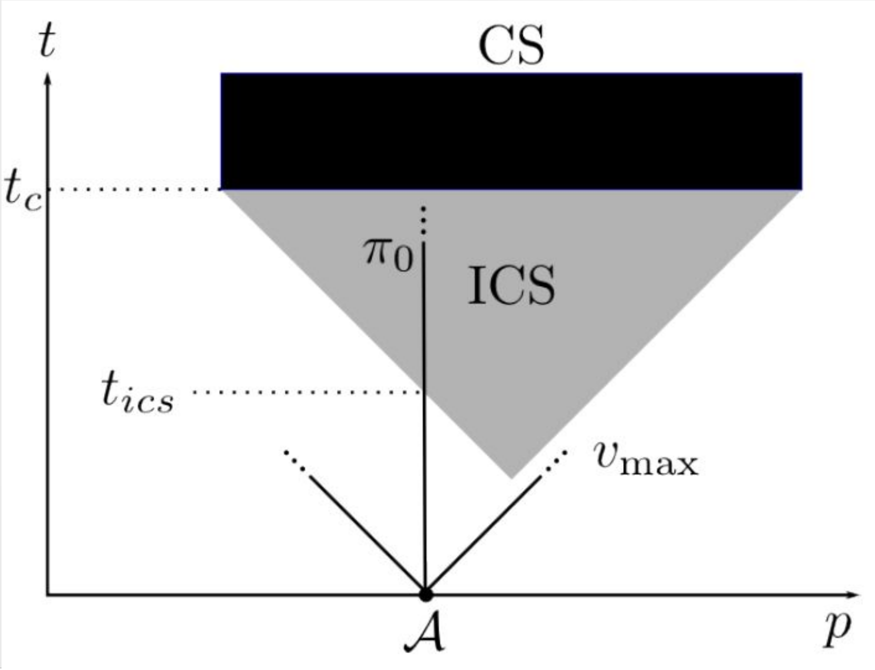
- Look at the problem in the 2D state X time space. Position on X axis, time on Y axis.
- **Motion safety rule #3 : Time horizon is lower-bounded**



- δ_e minimum time for A to escape
- δ_d *maximum* decision time for A to decide future motion
- $\delta_h = \delta_e + \delta_d$ **time horizon:** how far into the future modeling should go
- Must model *at least* δ_d, or else A will not be aware of CS

INEVITABLE COLLISION STATES (ICS)

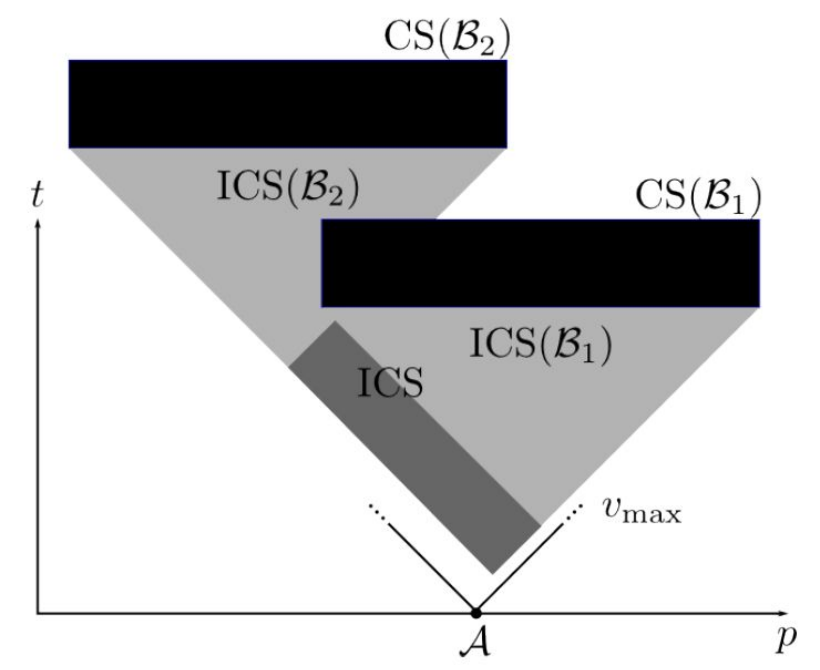
- There is more to instantaneous no-collision. Imagine a car travelling very fast towards a wall, a collision is inevitable, before the crash happens.



- **Inevitable Collision State (ICS)**
  - Gray zone where a crash will happen regardless of any actions taken.

INEVITABLE COLLISION STATES (ICS)

- The total ICS generated by obstacles **is not** the union of each ICS generated independently.
- **Motion safety rule #4 : Globally considering obstacles is required** (instead of individually)



- Total ICS includes
  - + $ICS(B_1)$
  - + $ICS(B_2)$
  - + **Dark gray region**
- If A enters the dark gray region, it will be able to avoid B_1 but will not be able to avoid B_2, even though it is not in $ICS(B_2)$

IN SUMMARY

Motion safety rules. If a rule is violated, a collision is likely to occur. All rules must hold to guarantee absolute motion safety.

1. Decision time is upper-bounded
2. Reasoning about the future is required
3. Time horizon is lower-bounded
4. Globally considering obstacles is required

In a dynamic environment, one has a **limited time** only to make a motion decision. One has to **globally reason about the future** evolution of the environment and do so with an **appropriate time horizon**.

HOW DOES THESE RULES HOLD IN THE REAL WORLD?

- In the real world, complete information about the environment and future is not known beforehand.
- Therefore, the model must use some method to determine the future.

Basic

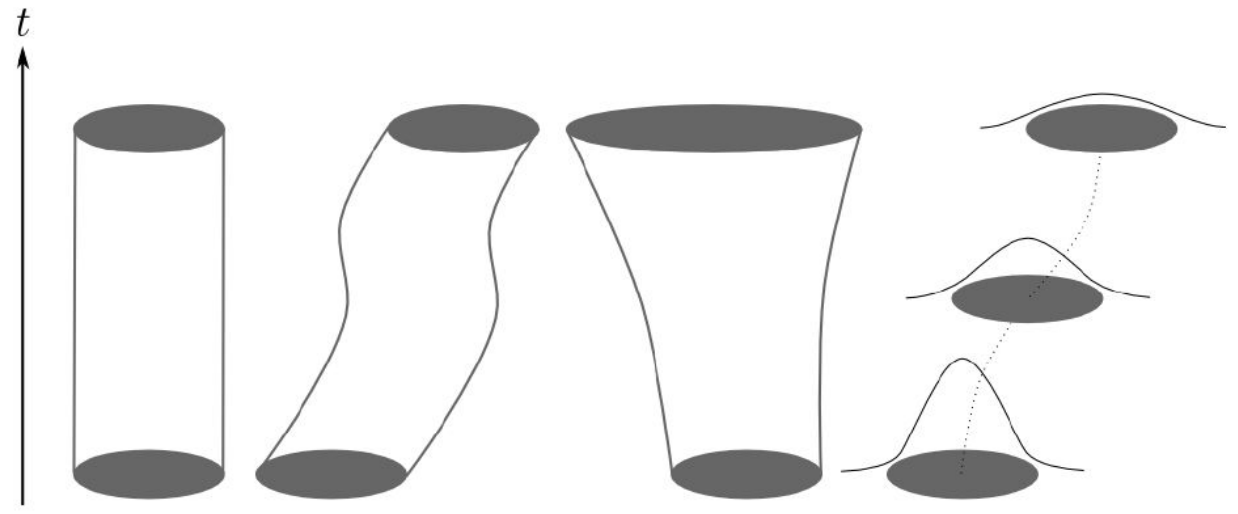


Figure 5: How to model the future? From left to right: deterministic (fixed, moving), conservative and probabilistic models for a disk obstacle.

Advanced

PROBABILISTIC MODELS

- Probabilistic models
  - Kalman filters
  - Hidden Markov Models
  - Monte Carlo Simulations
- **Probabilistic models do not provide strict motion safety guarantees**
  - **Can only minimize the risk of collision**

- So if we can't enforce strict motion safety guarantees, what can we do?
  - Weaker safety: ***passive motion safety***, ensures that if a collision does take place, the vehicle will be at rest, and the colliding obstacle would have time/be able to avoid the collision (if it wanted to)

CONCLUSION

Will the driver seat ever be empty?

- **Not a yes/no answer.**
- Derived 4 basic safety rules and dealing with real-world data…
  - **No strict absolute motion safety guarantees**
  - **Best we can do is advocate for weaker safety guarantees**
    - **passive friendly motion safety**

Questions?

DISCUSSION

- Passive safety guarantee: if a collision must take place, the AV will be at rest and the colliding agent will have time to avoid the collision (if it wanted to).
    - Is that enough of a guarantee to trust in this system? Would you rely on other driver's to keep you safe?
- This paper rules out the possibility of guaranteeing absolute motion safety. What direction do you think the automotive industry will head? And do you think they will be successful (see mass public adoption)?
    1. Full driverless taxis (i.e. no steering wheel) Or
    2. Focus on driving assistive technology (i.e. require a human driver)

CLOSING THOUGHTS

Accept

- Interesting question and thought experiment, although we never get a yes/no answer.
- Although I expected an analysis of existing self driving systems,
    - Author had a satisfactory approach to the question using a theoretical perspective.
- Elegant to use a simple case study of compactor scenario to derive foundational rules of motion safety that future work can build on.