Principles of Safe Autonomy
ECE 484 Lecture 2: System Safety

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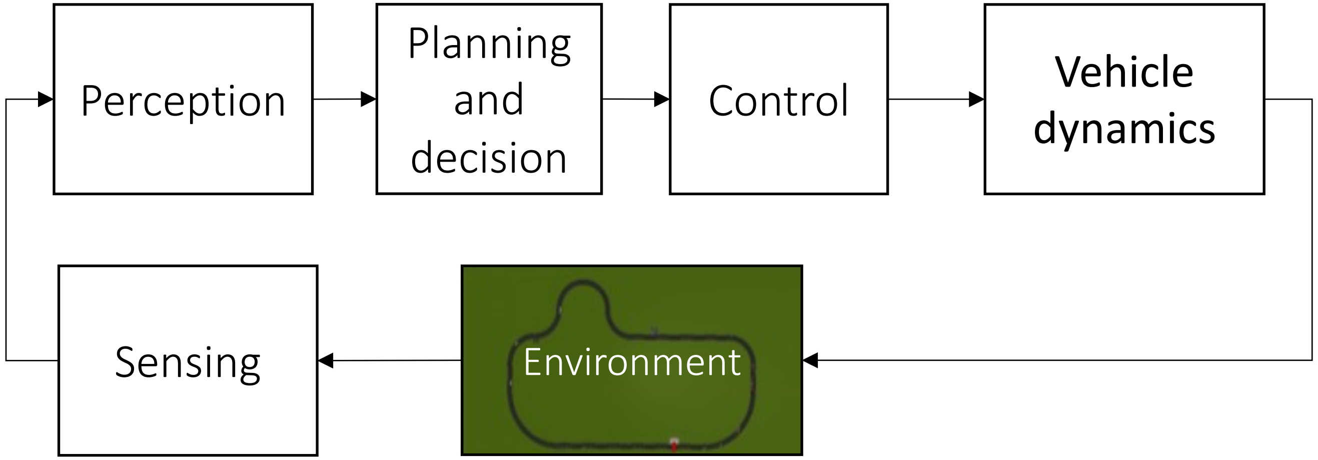
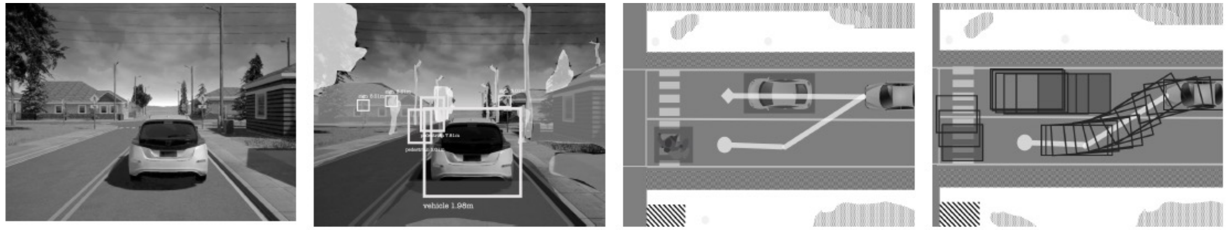
Autonomous GEM vehicle: An example CPS



env: Lidar / vision



Sensing	Perception	Decisions and planning	Control
Physics-based models of cameras, LIDAR, radar, GPS, and so on.	Programs for object tracking, scene understanding, and so on.	Programs and multi-agent models of pedestrians, cars, and so on.	Dynamical models of vehicle engine, powertrain, steering, tires, and so on.

Roadmap

- A general class of models: automata.
- Executions, requirements,
- Safety requirements
- Safety verification problem
- Reachable states
- Invariants

“simple”≠ Easy

A “simple” safety scenario

A car moving down a straight road has to detect any pedestrian in front of it and stop before it collides.

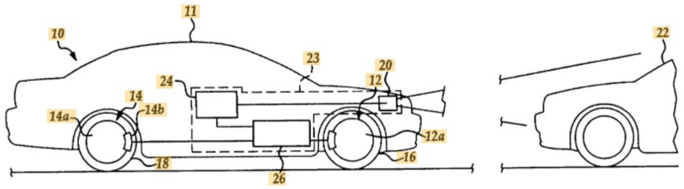
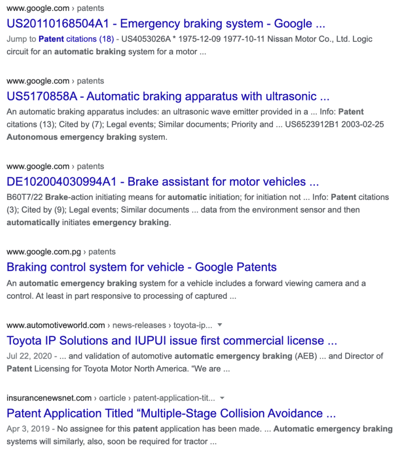


Figure 1

Automatic Emergency Braking



www.google.com › patents
US20110168504A1 - Emergency braking system - Google ...
Jump to **Patent** citations (18) - US4053026A * 1975-12-09 1977-10-11 Nissan Motor Co., Ltd. Logic circuit for an **automatic braking** system for a motor ...

www.google.com › patents
US5170858A - Automatic braking apparatus with ultrasonic ...
An automatic braking apparatus includes: an ultrasonic wave emitter provided in a ... Info: **Patent** citations (13); Cited by (7); Legal events; Similar documents; Priority and ... US6523912B1 2003-02-25 **Autonomous emergency braking** system.

www.google.com › patents
DE102004030994A1 - Brake assistant for motor vehicles ...
B60T7/22 **Brake**-action initiating means for **automatic** initiation; for initiation not ... Info: **Patent** citations (3); Cited by (9); Legal events; Similar documents ... data from the environment sensor and then **automatically** initiates **emergency braking**.

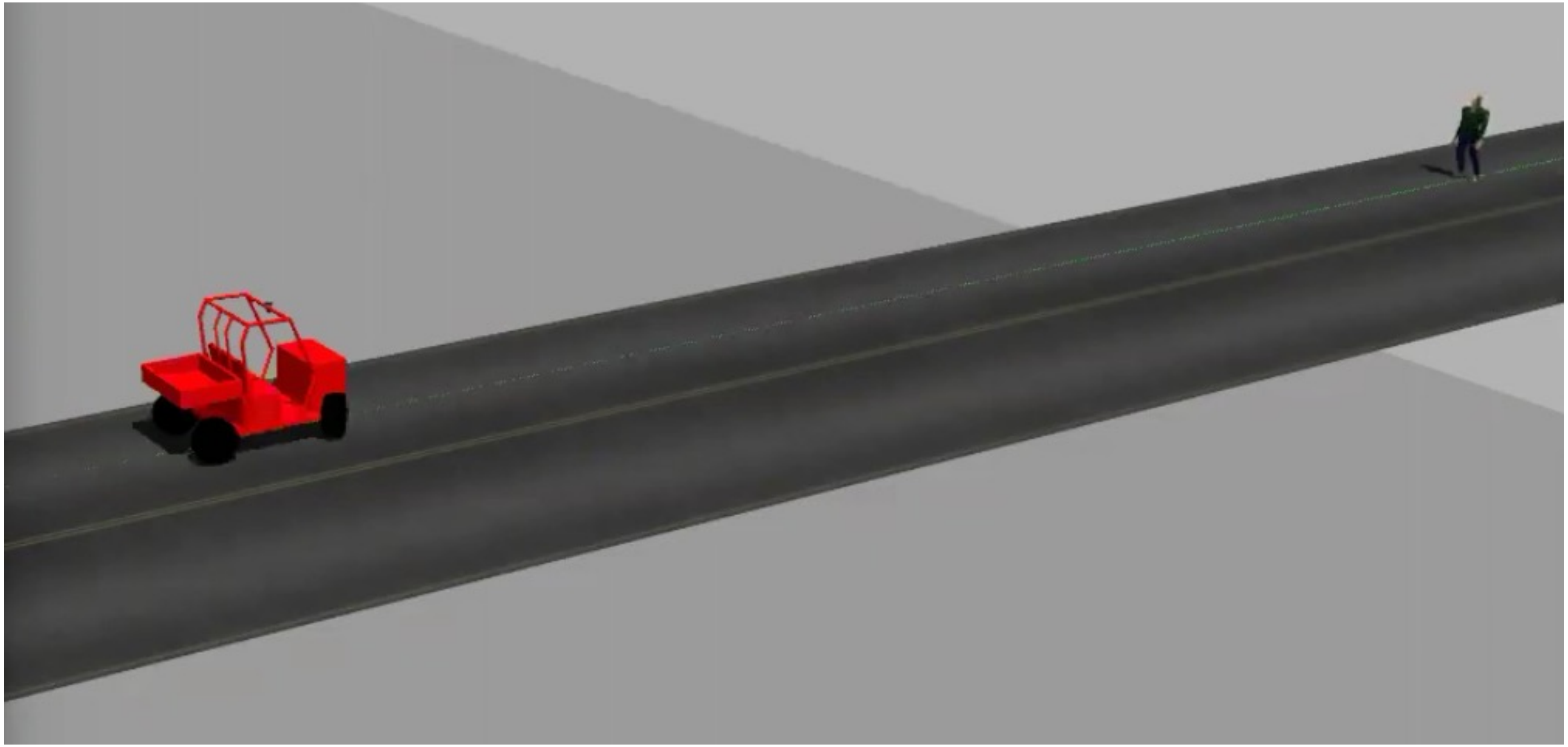
www.google.com.pg › patents
Braking control system for vehicle - Google Patents
An **automatic emergency braking** system for a vehicle includes a forward viewing camera and a control. At least in part responsive to processing of captured ...

www.automotiveworld.com › news-releases › toyota-ip...
Toyota IP Solutions and IUPUI issue first commercial license ...
Jul 22, 2020 - ... and validation of automotive **automatic emergency braking** (AEB) ... and Director of **Patent** Licensing for Toyota Motor North America. “We are ...

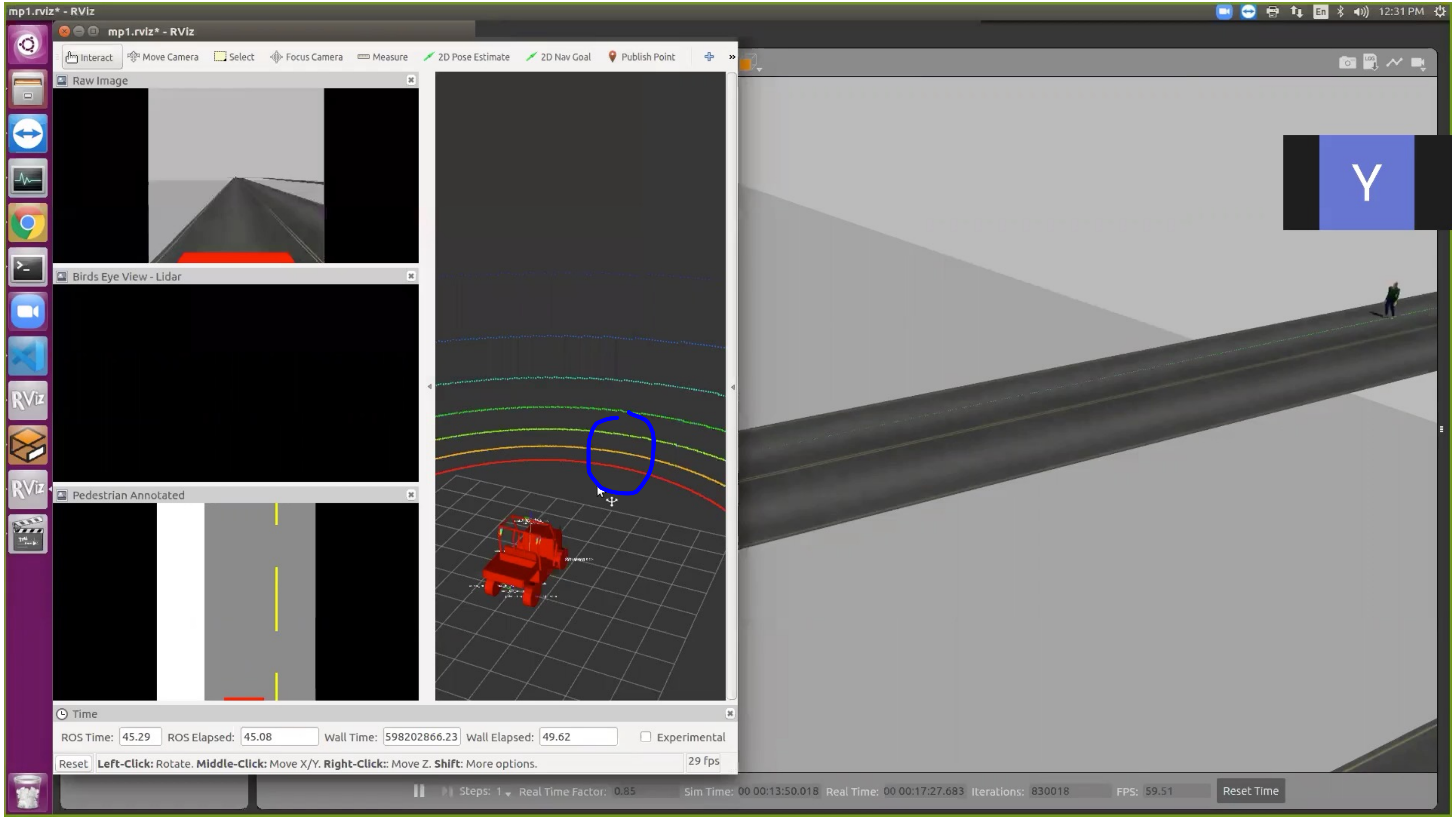
insurancenewsnet.com › oarticle › patent-application-tit...
Patent Application Titled “Multiple-Stage Collision Avoidance ...
Apr 3, 2019 - No assignee for this **patent** application has been made. ... **Automatic emergency braking** systems will similarly, also, soon be required for tractor ...

Not a trivial requirement

A Safety Scenario



MP0: Simulate model for testing



“All models are wrong, some are useful.”

Wrong and useless models

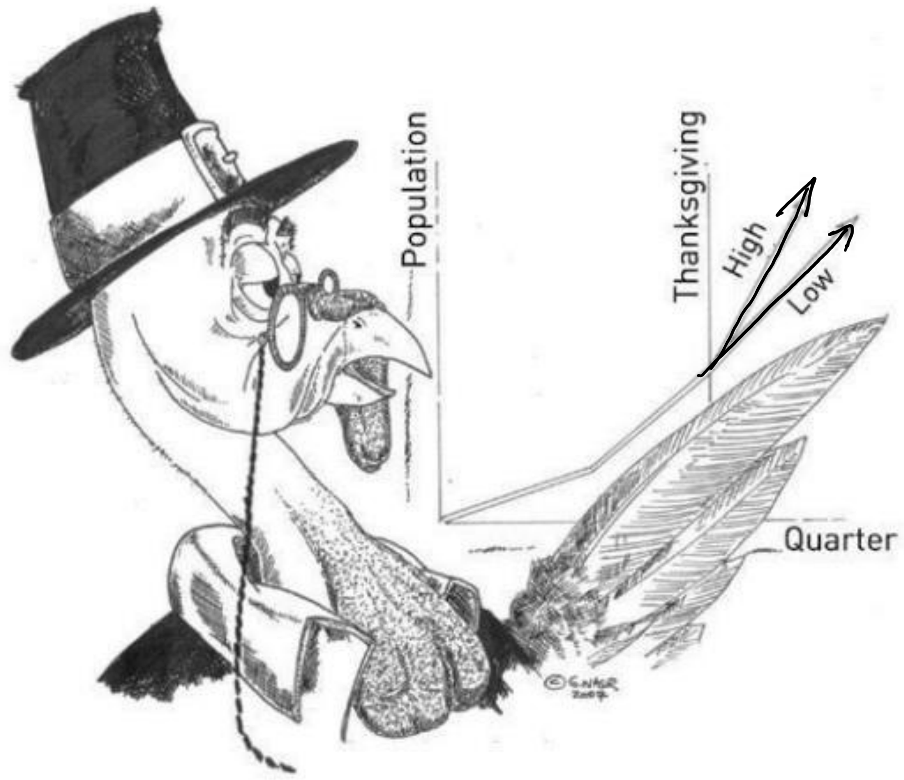
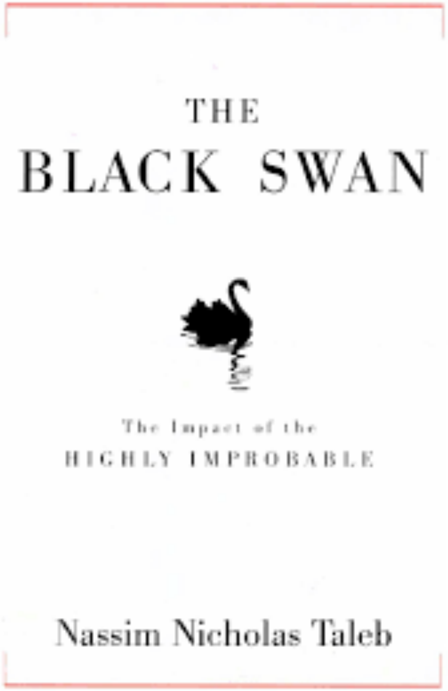
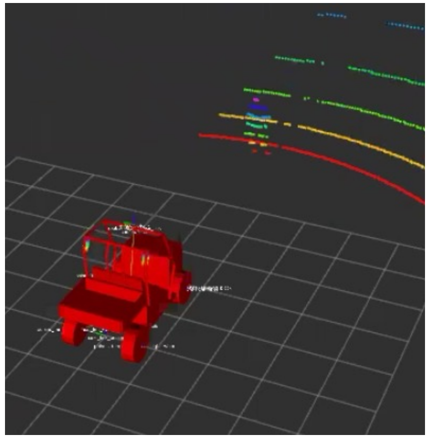


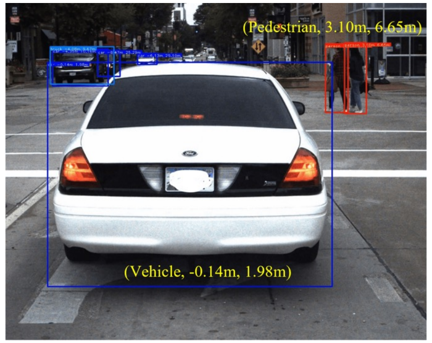
FIGURE 4. A turkey using "evidence"; unaware of Thanksgiving, it is making "rigorous" future projections based on the past. Credit: George Nasr

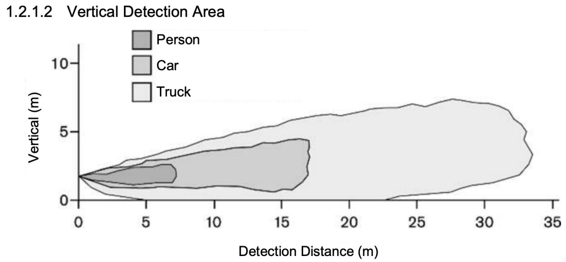


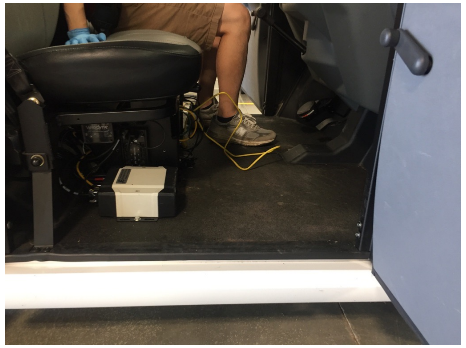
Baked-in Assumptions in our example

- Perception.
  - Sensor detects obstacle **iff** distance $d \leq \ D_{sense}$
  - No false positives, negatives, probabilities
  - Pedestrian is known to be moving with constant velocity from initial position. This will be used in the safety analysis, but not in the vehicle's automatic braking algorithm
- No sensing-computation-actuation delay.
  - The time step in which $d \leq \ D_{sense}$ becomes smaller is exactly when the velocity starts to decrease

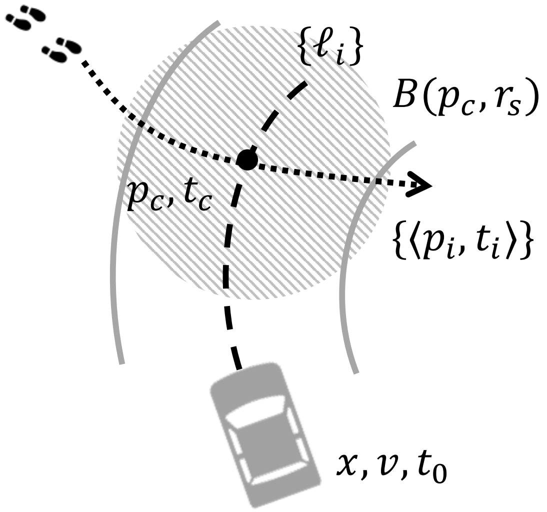








Baked-in Assumptions (continued)



- Mechanical or Dynamical assumptions
  - Vehicle and pedestrian moving in 1-D lane.
  - Does not go backwards.
  - Perfect discrete kinematic model for velocity and acceleration.
- Nature of time
  - Discrete steps. Each execution of the above function models advancement of time by 1 step. If 1 step = 1 second, $x_1(t+1) = x_1(t) + v_1(t).1$
    - We cannot talk about what happens between [t, t+1]
  - Atomic steps. 1 step = complete (atomic) execution of the program.
    - We cannot directly talk about the states visited after partial execution of program

Summary

- Absolute safety checking boils down to showing that none of the executions of the automaton reaches an unsafe set U
- To reason about all executions of we have to work with infinite sets of states
- One way to compute infinite sets is using the Post operator
- But, computing all executions for unbounded time can be hard
- If we can guess an invariant satisfying conditions of Proposition 1.1, that can give a shortcut for proving safety
- The inavariant may contain important information about conserved quantities, and thus, may tell us why the system is safe, and not just that it is so
- Mind the gap between model and reality
- Next. Application of invariants in braking example

Next: How can we use a simple mode to get absolute safety guarantees

- A simple class of models: automata
- What are executions of automata?
- What are safety requirements?
- Reachable states, Invariants for safety guarantees

Modeling the scenario

- What is a model of a system?
- A *mathematical model* describes how a system behaves.
  - What are the key parameters and states?
  - How are the parameters selected by nature?
  - What are the initial conditions of the state?
  - How do the state change over time? …
  - What parts of the model are available for observation/analysis?
- Models include the implicit and explicit assumptions (biases) we are making about the system