Young Researchers Seminar 2025

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Towards **Runtime Monitoring** of spatial system properties of **Automated Driving Functions** using **Abstract Scene Graphs**

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Outline

- Motivation
- Background – Software Testing
- Software Testing of Automated Vehicles
- Research Questions
- Example System Property
- Proposed Concept
- Recap

Motivation - Does this automated vehicle drive properly?

Credit: https://www.futureelectronics.com/blog/article/understanding-autonomous-vehicle-safety/

Q: What is "proper" driving?

- Correct / Proper
  - relative to needs and expectations

- Here, Proper = Safe Driving
  - Follow traffic regulations
  - Respect social norms
  - Not cause accidents

- How to check whether an automated vehicle is driving safely?

Detour – Software Testing

Source: https://www.blogs.unicamp.br/zero/4336/

Adding device

Test-Case Expected Result

(1,3 : 4)

(0,6 : 6)

(2,5 : 7)

Detour – Software Testing

Source: https://www.blogs.unicamp.br/zero/4336/

System

Test-Case | Expected Result

(1,3 : 4)

(0,6 : 6)

(2,5 : 7)

Specification

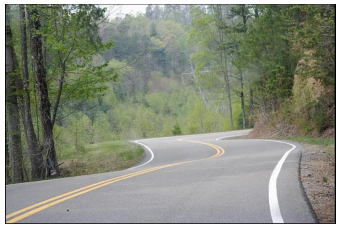
Is an Automated Vehicle driving safely?

Credit: © DLR

System

Credit: Photo from Tony Hsu on Unsplash

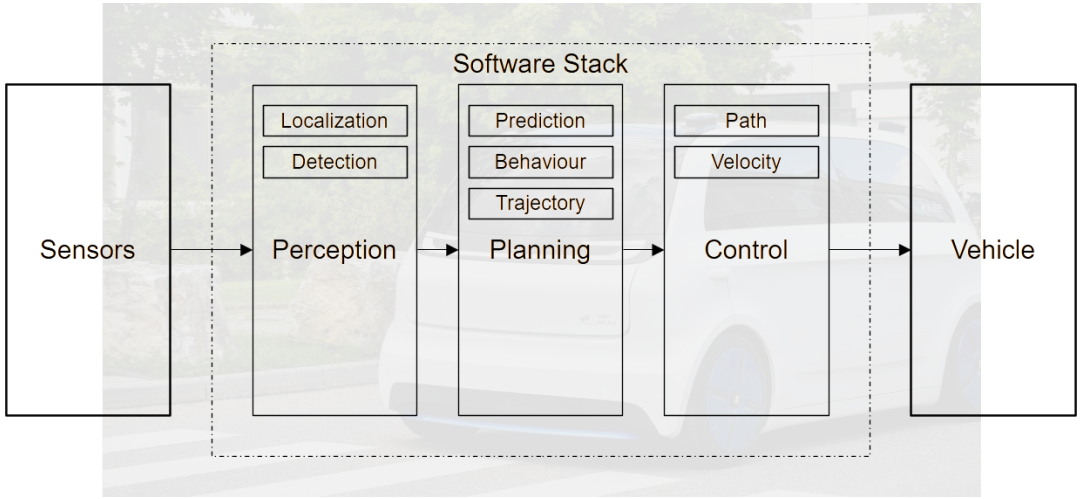
Credit: Photo from Robert Calvert on Unsplash



Credit: https://theblackurbanist.com/cruising-down-a-curved-road/

System Properties

Software Testing of Automated Vehicles - I

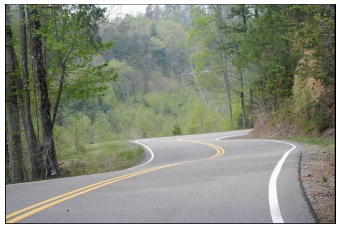


Credit: © DLR

System

Credit: Photo from Tony Hsu on Unsplash

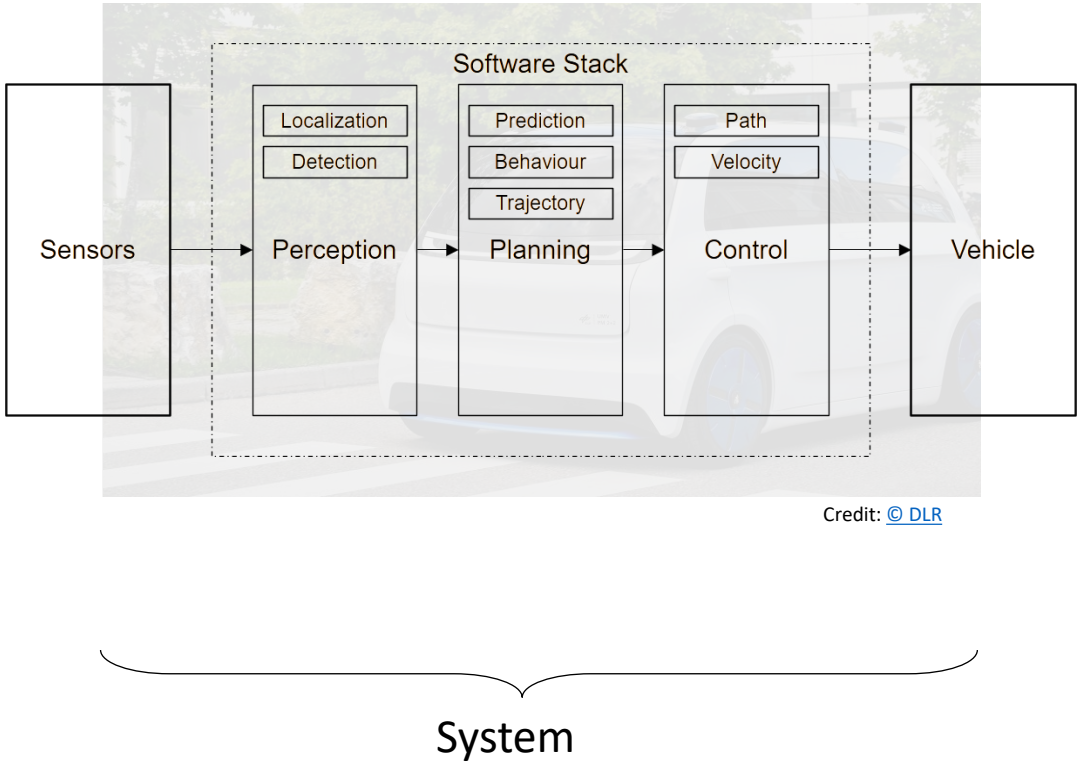
Credit: Photo from Robert Calvert on Unsplash



Credit: https://theblackurbanist.com/cruising-down-a-curved-road/

System Properties

Software Testing of Automated Vehicles - II



Credit: © DLR

Automated Vehicle System:

- AI-based components
  - Black-box behaviour
- Infinite input space
  - Cannot capture all input values for testing

-> Need for a mechanism that can ensure safety of such a system

Software Testing of Automated Vehicles -III

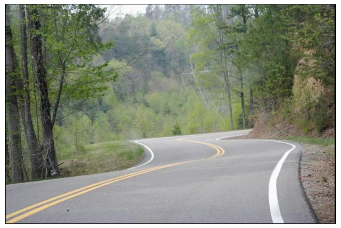
Automated Vehicle Properties:

- Textual
  - Traffic Rules & Regulations
- Complex
  - Legal terminology, multi-stakeholder knowledge
- Vague
  - Rely on Human Intuition

-> Need for precise and objective expression (formalization) of such system properties

Credit: Photo from Tony Hsu on Unsplash

Credit: Photo from Robert Calvert on Unsplash



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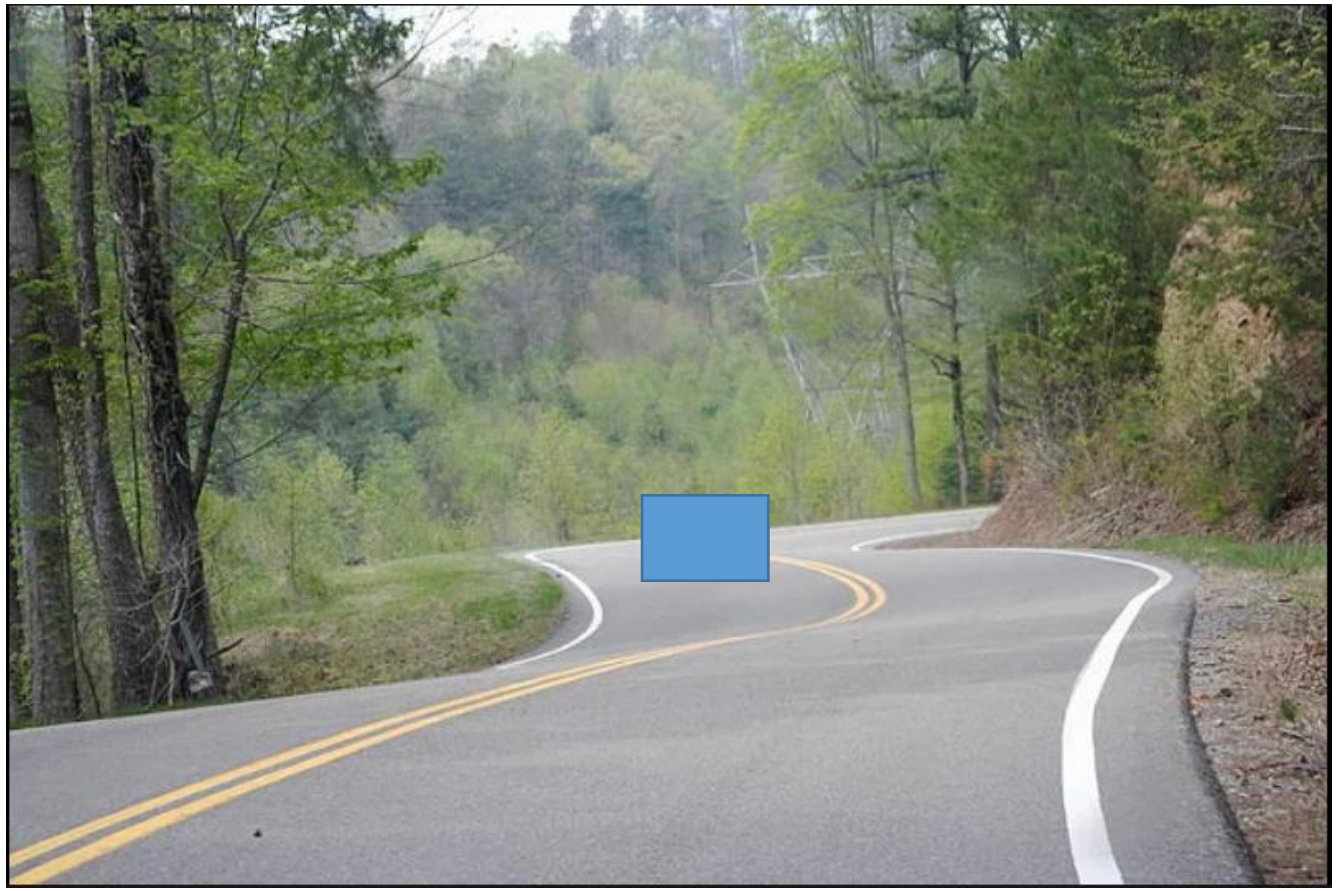
System Properties

Challenges with formalization of spatial properties

Automated Vehicle observes an obstacle in front of it



Credit: https://theblackurbanist.com/cruising-down-a-curved-road/

Research Questions

R1: Can **Abstract Scene Graphs** can be used to formalize spatial system properties occuring in automotive domain?

R2: How can **Runtime Monitoring** be performed using **Abstract Scene Graphs**?

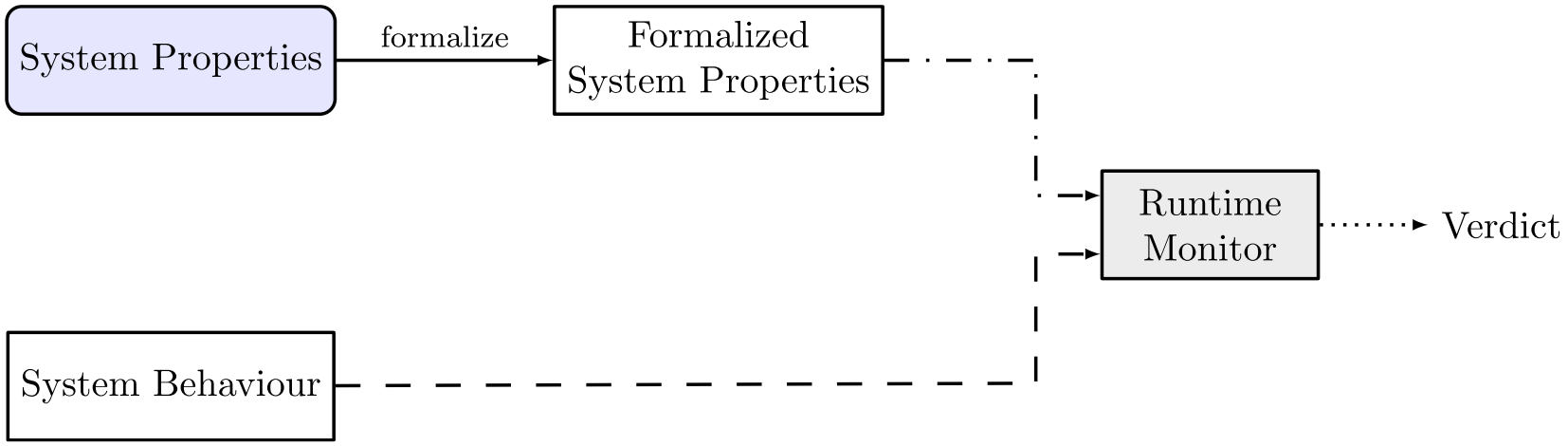
Example System Property

Requirement: *"A vehicle, when approaching a stationary obstacle present in its lane must come to a complete halt at a safe distance from the obstacle"*

Source: CARLA Simulator

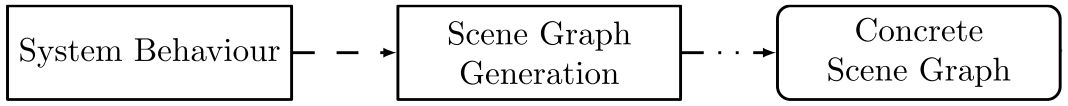
Runtime Monitoring (RM)

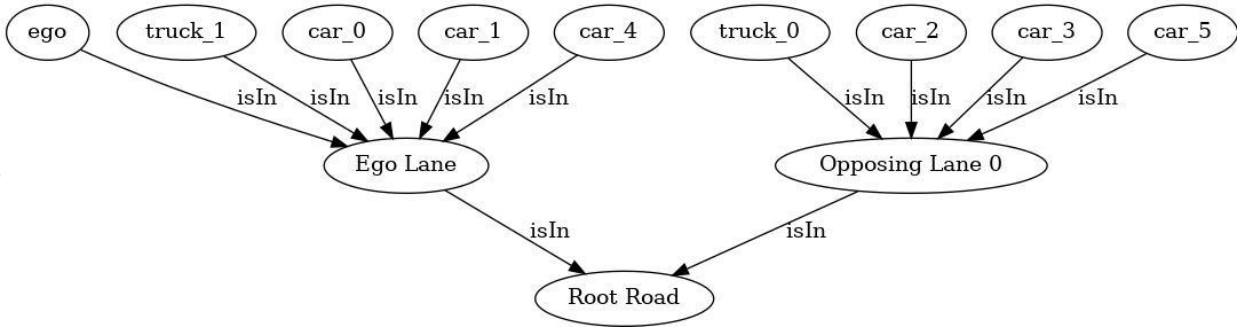
- Provides continuous verdicts at system runtime whether system properties are satisfied
- Verdict used to trigger preventive action
- In the automotive domain, requires formalized (machine-interpretable) system properties



Concrete Scene Graphs

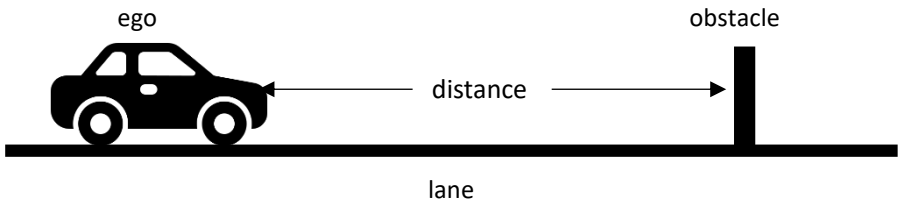
- Represents the current traffic situation around a vehicle as a scene graph
- Generated using sensor data present inside the vehicle
- Currently being used for Scene Understanding, Risk Assessment, Motion Prediction, etc.

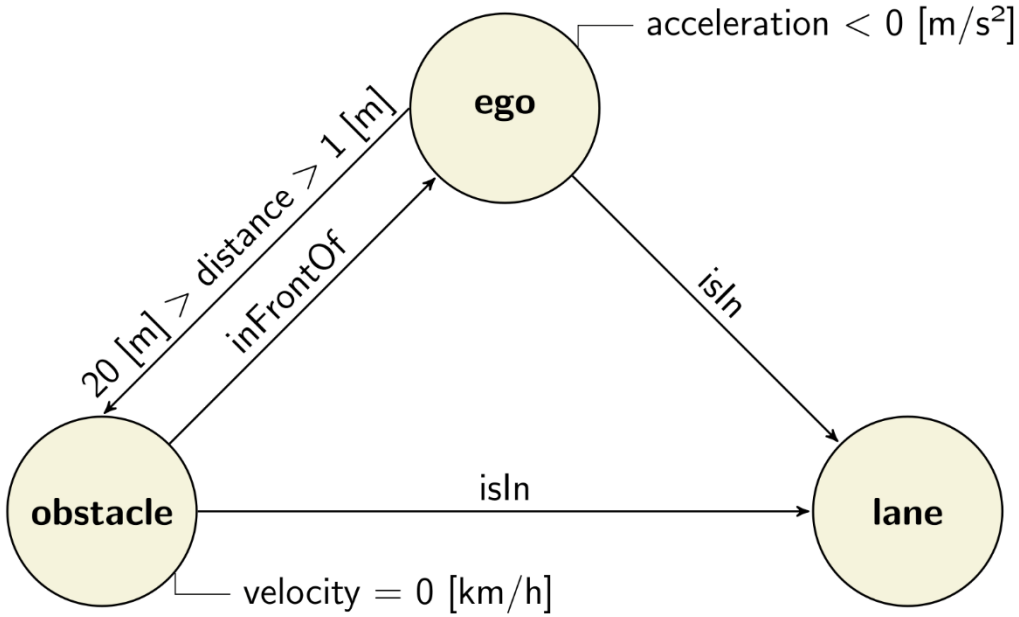




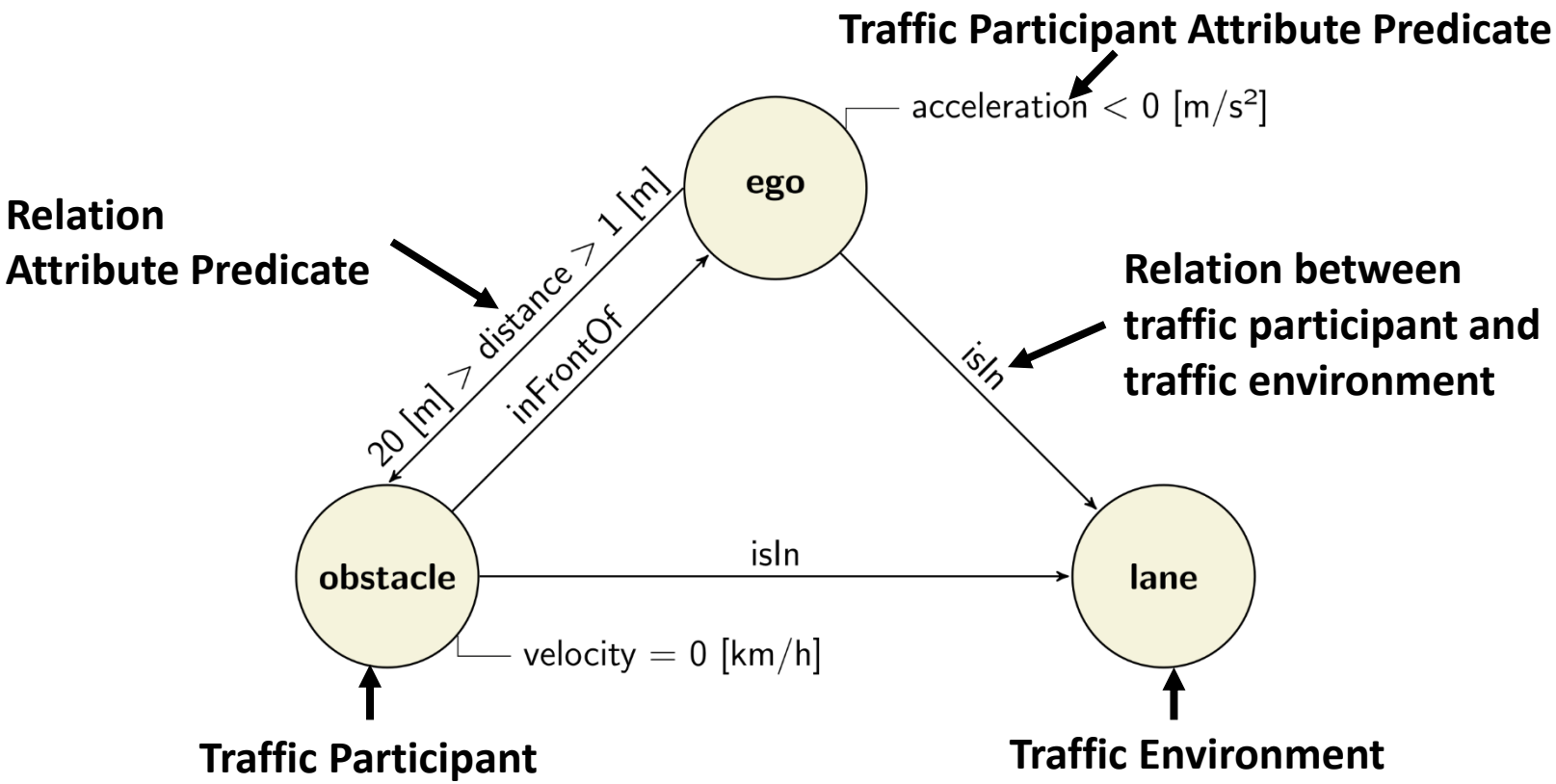
Source: https://github.com/less-lab-uva/carla_scene_graphs

Abstract Scene Graphs (proposed formalism)





Abstract Scene Graphs (a closer look)



Example System Property (again)

Requirement: *" A vehicle, when approaching a stationary obstacle present in its lane must come to a complete halt at a safe distance from the obstacle "*

Source: CARLA Simulator

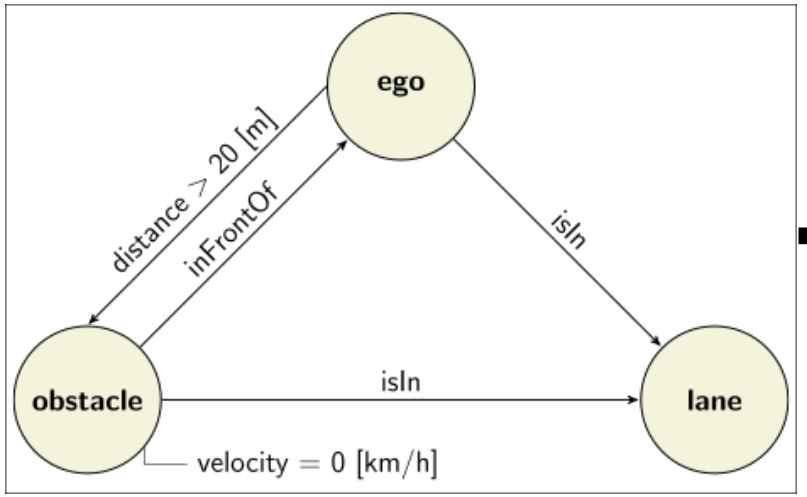
Conversion of textual requirement to abstract form

" A vehicle, when approaching a stationary obstacle present in its lane must come to a complete halt at a safe distance from the obstacle "

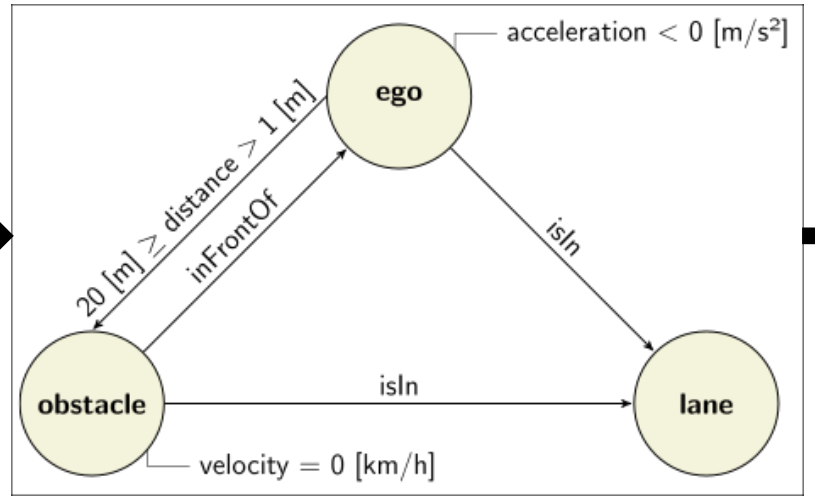
- **Approach:** ego is travelling towards a stationary obstacle present in its own lane
- **Brake:** ego starts braking once it is at most 20 [m] in front of the obstacle
- **Stop:** ego comes to a complete halt at least 1 [m] in front of the obstacle

Abstract Scene Graphs for Example System Property

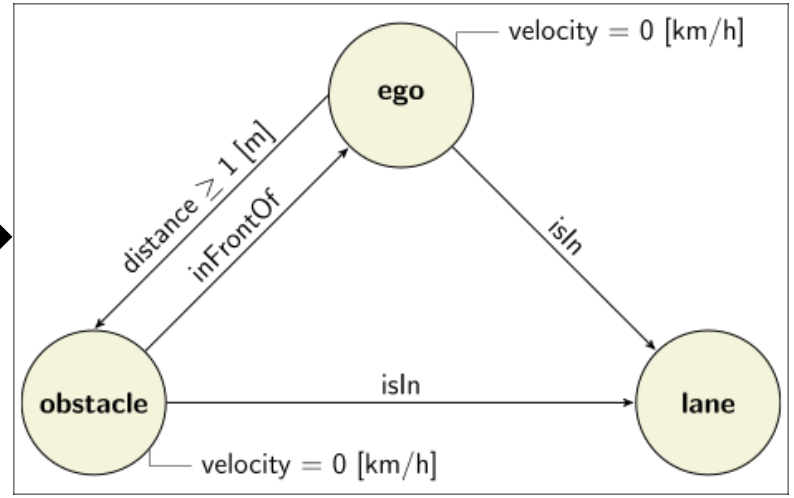
"A vehicle, when approaching a stationary obstacle present in its lane must come to a complete halt at a safe distance from the obstacle"



Approach

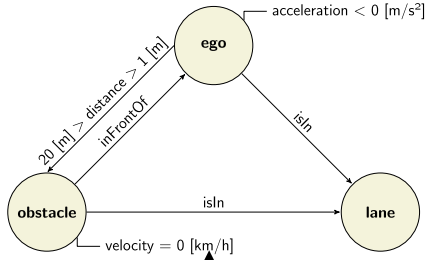


Brake



Stop

Proposed Concept for Runtime Monitoring using Abstract Scene Graphs



Spatial System Properties

formalize

Abstract Scene Graphs

Scene Graph Comparison

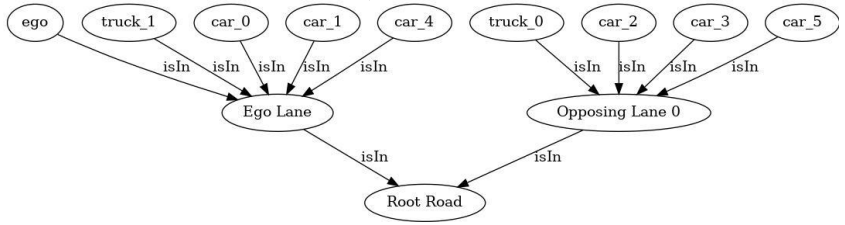
Verdict

System Behaviour

Scene Graph Generation

Concrete Scene Graph

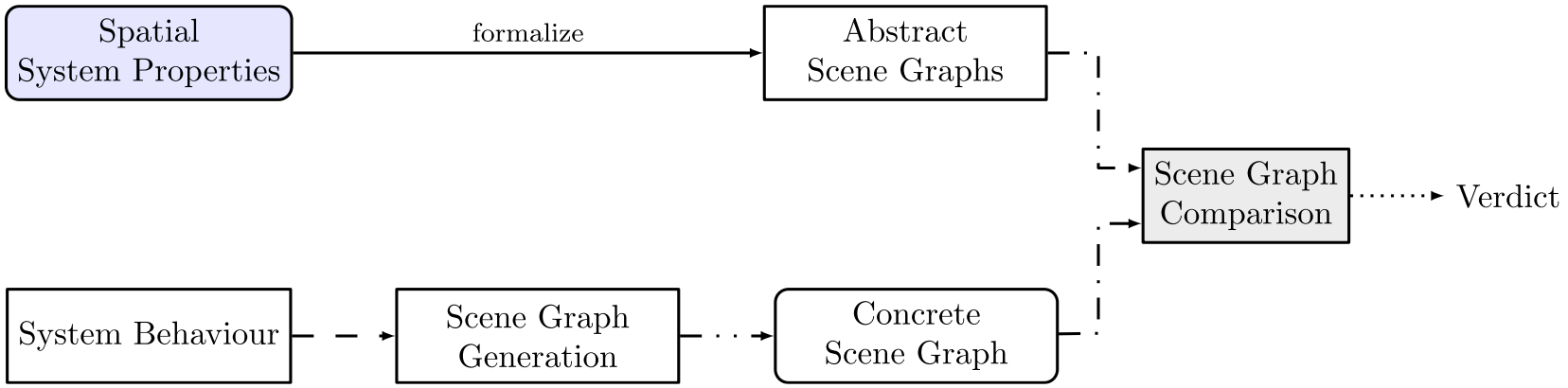
Source: CARLA Simulator



Source: https://github.com/less-lab-uva/carla_scene_graphs

Recap

- Testing of AI-based software is difficult
- Automated Vehicles increasingly use AI-based software components
- In order to make Automated Vehicles safer, there is a need for
  - Formalizing spatial properties – Abstract Scene Graphs
  - Safeguarding of System – Runtime Monitoring using Abstract Scene Graphs



Thank You for your attention!

Questions?

Source: CARLA Simulator