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REGULATING AUTONOMOUS VEHICLES: LEVERAGING SCENARIOS AND SIMULATIONS

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16TH NOVEMBER 2017

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WHAT DO THE REGULATORS WANT?

- Regulators need to be able to assure their respective Governments that autonomous vehicles (AVs) are **safe to be brought to market**
- Regulators need to be able to reassure the public that AVs will not behave recklessly
- The level of safety needed is not yet clear; but AVs will certainly need to be safer than human-driven vehicles
- Regulators do not want to stifle innovation

Department for Transport

NHTSA

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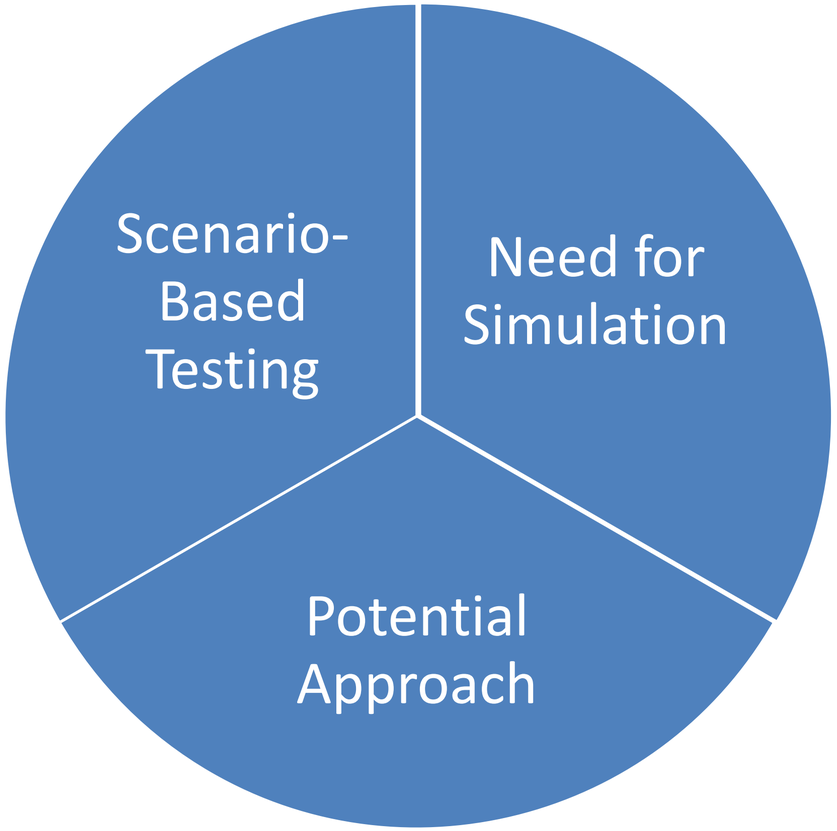
CONTENT OF THIS PRESENTATION



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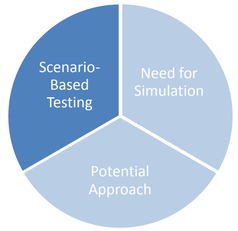

WHY THIS ISN'T LIKE TRADITIONAL AUTOMOTIVE SOFTWARE

- An Automated Driving System (ADS) is not like traditional automotive software
- It's impossible to write a specification document

Example

- Level crossing with barriers down

Does the specification include:

- If there's already a queue of vehicles at the barrier
- If there's a lorry at the front of the queue, obscuring part of the barriers
- If the flashing lights aren't working
- If it's nearly (but not quite) dark
- If it's nearly dark and there's a grey car at the back of the queue
- …

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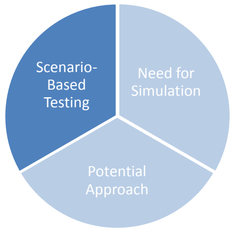

HOW DOES THIS COMPLEXITY IMPACT TESTING?

- The ADS must respond to a large number of factors (the type & location of every actor in the scene, road type & layout, traffic signals,…)
  - Different decisions may be required for each possible combination
  - Not feasible to write an infinite number of test scripts

- Hard to separate problem into independent modules – need take everything in the environment into account when driving

Examples

Las Vegas Navya collision

Google/Waymo bus collision

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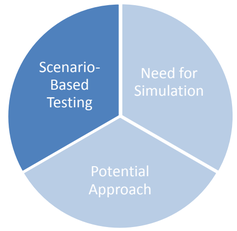
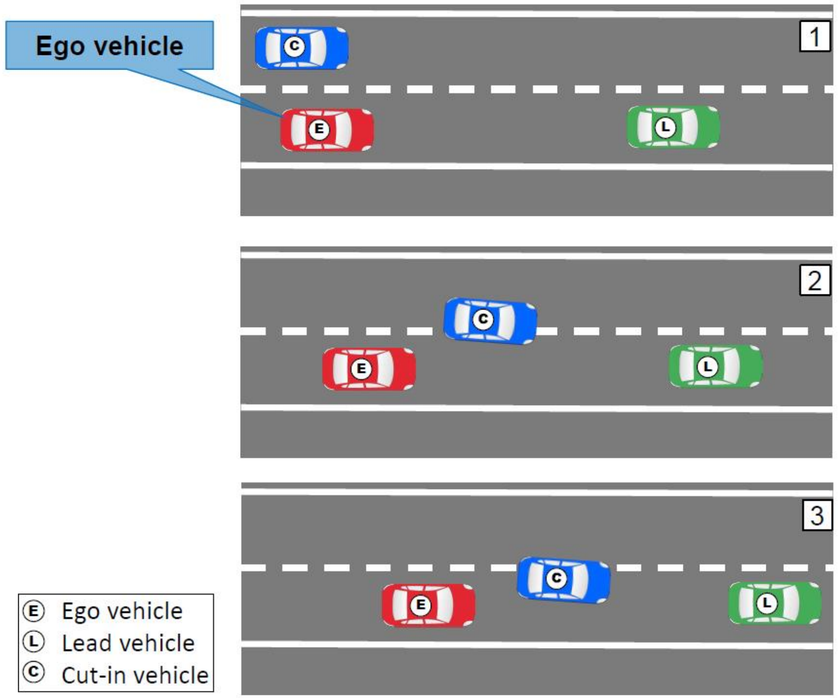


SAFETY ASSURANCE: SCENARIO-BASED TESTING

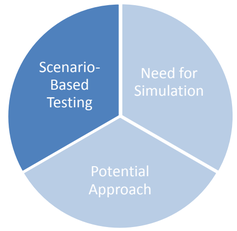


- Scenarios capture key test cases for autonomous driving
- Allow focused, efficient testing of AVs
- NHTSA: “entities are encouraged to consider all known behavioural competencies in the design, test and validation of their ADS”[1]

Hungar 2017, “Test Specifications for Highly Automated Driving Functions: Highway Pilot”, DLR / PEGASUS project

Autonomous Vehicle Test & Development Symposium

1. *https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf*



HOW OUR PROPOSAL FITS IN

- Our focus is on scenarios and simulation, to help validate the **behaviour** of SAE Level 4/5 vehicles
- We propose physical testing of sensor processing, and simulation of scenarios
- Our approach is consistent with OICA's 3 pillars

Type Approval

- Existing TA + use case tests
- Verification of sensor processing

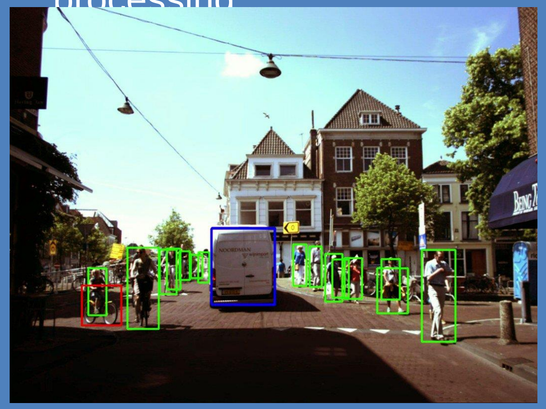
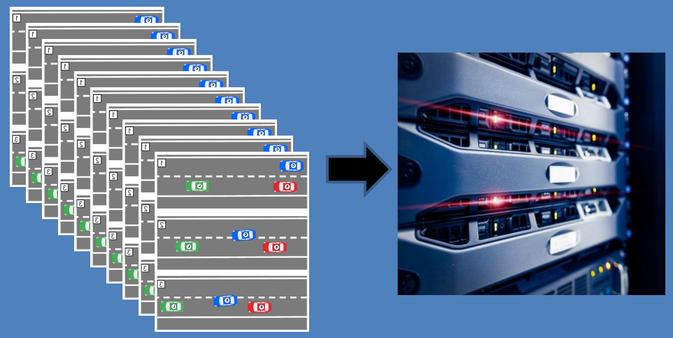


Image from TU Delft

ADS Audit

- Supplementary to OICA ideas: simulate many scenarios



Real World Test Drive

- Key part of process
- Is 60 minutes enough?

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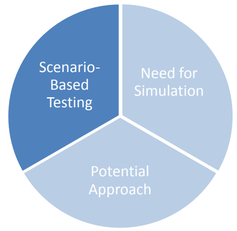

HOW DO WE USE SCENARIOS?

- Widely-recognised need for a scenario library, maintained by an independent body
  - Available to all ADS developers
  - Ensures that new, **safety-critical scenarios are shared** with everyone
  - Use common electronic formats for sharing

- A subset of scenarios would be part of the audit assessment
  - Non-audited scenarios are still useful to help ADS development
- Updates to the scenario library must have their integrity and relevance verified
- Start small, with perhaps just 100 scenarios
  - Some may require manual updates to include key information

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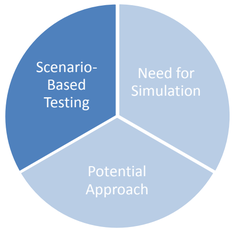

SCENARIO APPLICABILITY

- Scenarios should cover:
  - Edge cases
  - Normal driving (international)
  - Normal driving (country-specific conventions and laws)

- Scenarios should be tagged with the list of countries they are applicable for
  - Allow easy extraction of a test suite to show compliance to laws and regulations for a specific territory

- Scenarios should be tagged with recommended or audited, normal or edge-case, …

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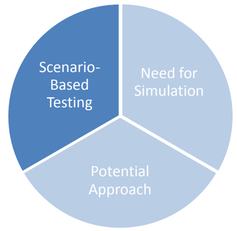
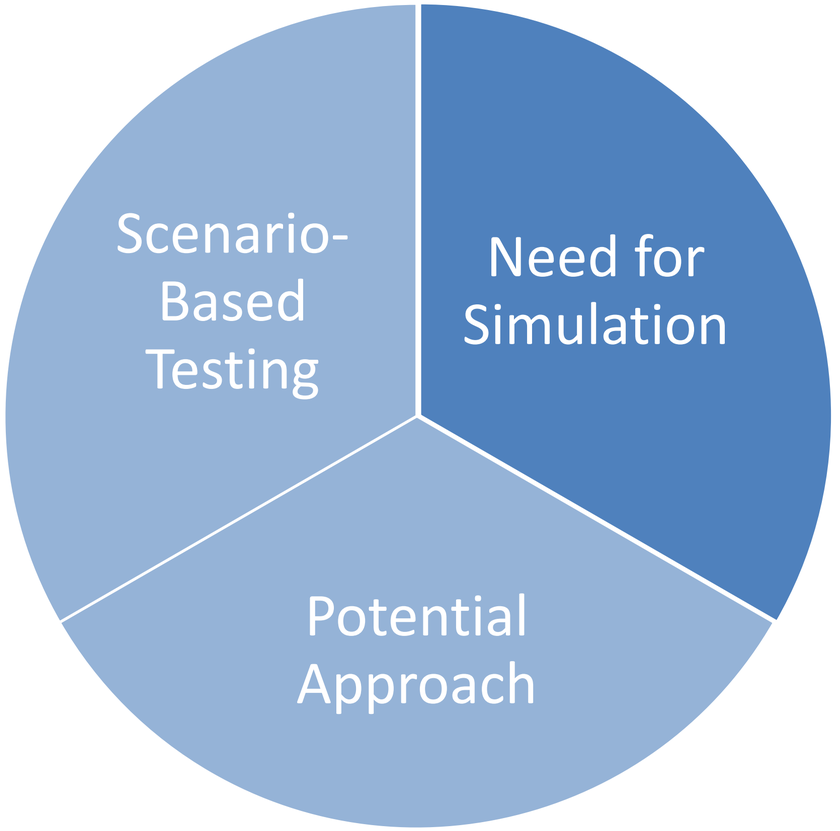


SOURCES OF SCENARIOS

- Expert knowledge
  - TSC report “Taxonomy of Scenarios for Automated Driving”[1]
  - NHTSA “Federal Automated Vehicles Policy”, September 2016[2]
- Pre-existing scenario repositories (CR&D, industry)
- Data recorded from sensor-equipped vehicle fleets
  - Automatic processing to extract collisions, near-misses, and other undesirable incidents
    - Use heuristics such as brake pressure applied
    - Will probably need human review
  - Existing MOVE_UK project[3] is collecting a highly relevant dataset
- Real-world collisions
  - New AV collisions and near-misses (requires data recording on production vehicles)
  - Existing collision databases

1. https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25114137/ATS34-Taxonomy-of-Scenarios-for-Automated-Driving.pdf
2. https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016
3. http://www.move-uk.com/

PART 2



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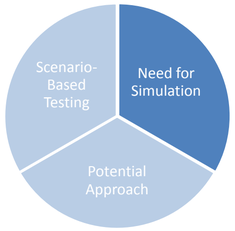

NEED FOR VERIFICATION IN SIMULATION

"To demonstrate that fully autonomous vehicles have a fatality rate of 1.09 fatalities per 100 million miles [...] with a fleet of 100 autonomous vehicles being test-driven 24 h a day, 365 days a year at an average speed of 25 miles per hour, this would take about 12.5 years."[1]

- Using *scenarios* means we can focus testing on the critical and challenging cases
- Can we run enough scenarios in the real world to have reasonable confidence in the safety of AVs?

Waymo's "Castle" test centre

1. "Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?" Nidhi Kalra & Susan M. Paddock, RAND Corporation 2016. https://www.rand.org/pubs/research_reports/RR1478.html

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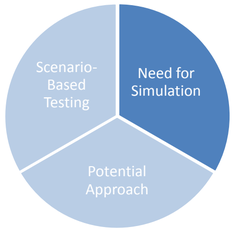

NUMBER OF SCENARIOS

Everyday scenarios (examples on right): but also

- Light aircraft landing on the road
- Smoke from a forest fire blowing across the road
- …

Timescales for physical testing

- Assume, given one test vehicle, you can test 15 scenarios per day
- 1,000 scenarios takes over 3 months
- Waymo use a library of >20,000 scenarios

In summary, physical testing:

- Takes too long
- Costs too much
- Endangers participants

Merging onto a motorway

Roadworks with human-controlled contraflow

Narrow bridge tunnel, with other oncoming traffic

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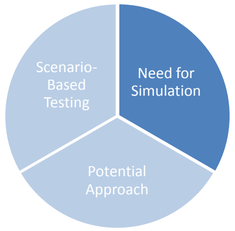
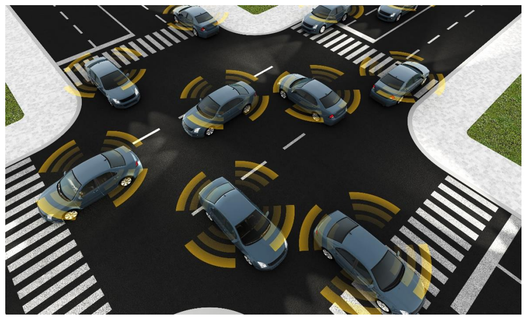


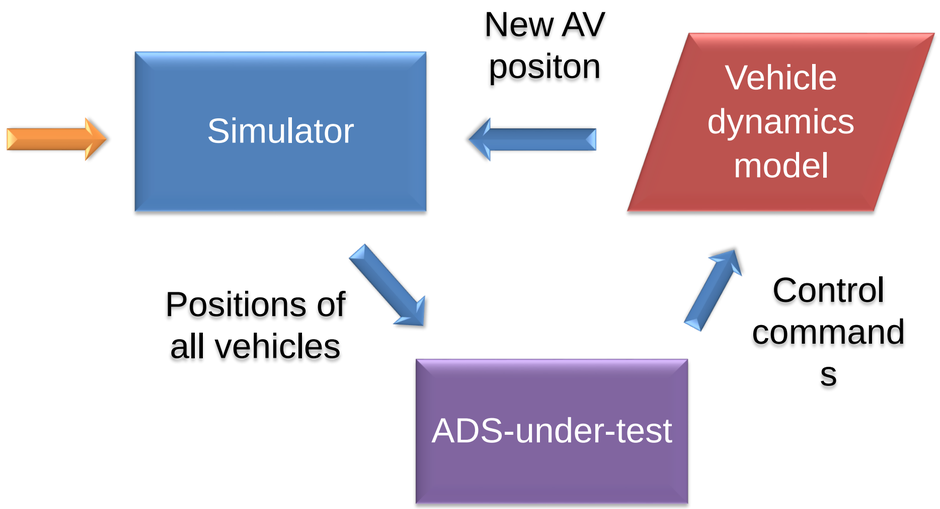
VERIFICATION IN SIMULATION: OVERVIEW

- To realise the ambition of this approach will require co-operation between ADS developers, OEMS and regulators
- Access to executable copies of their automated driving system (ADS), with associated vehicle dynamics models, expected to be key

Allows many scenarios to be to be tested quickly



Scenario: initial conditions



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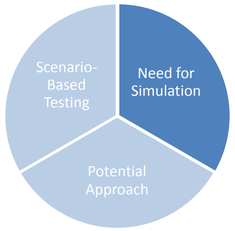

SIMULATION: OTHER ACTORS

- Most scenarios will need several actors – other vehicles, pedestrians, bicycles, …
- Often these will have to react to the decisions made by the ADS. E.g.:
  - If the ADS gives way unexpectedly, a simulated human-driven vehicle might run into the back of it
  - When an ADS is attempting to merge into fast-moving traffic, actor vehicles should slow down to make space for it

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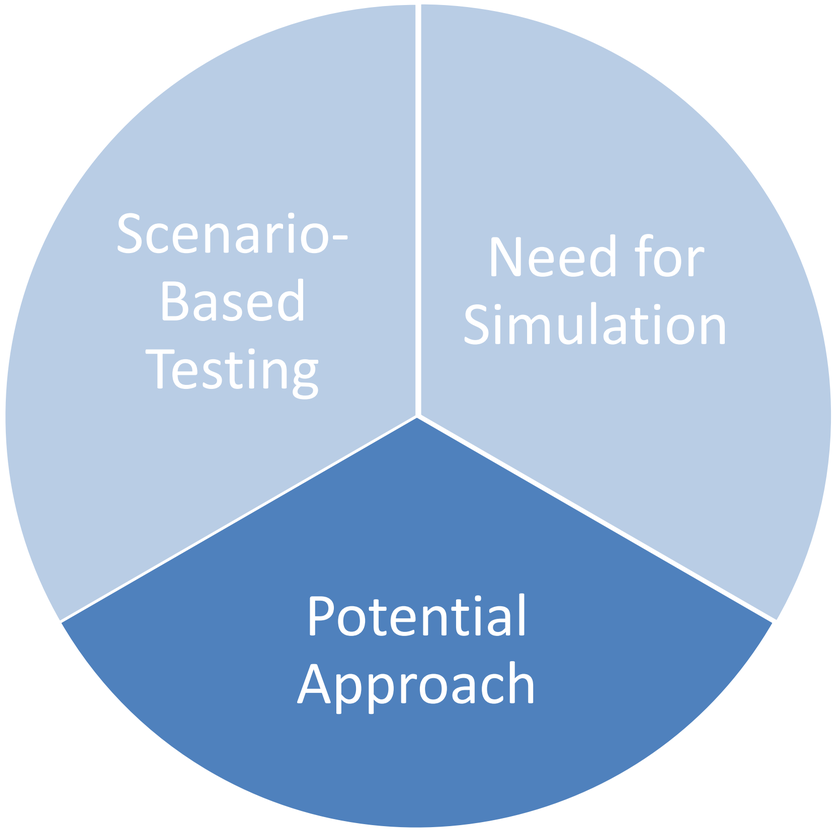
PART 3



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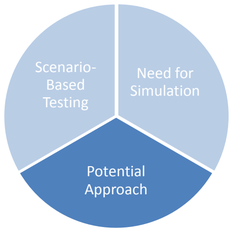
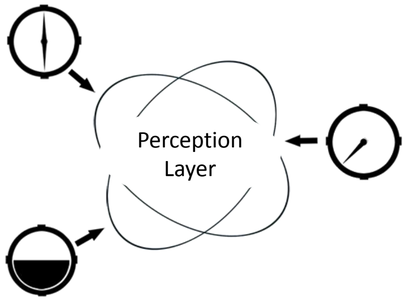
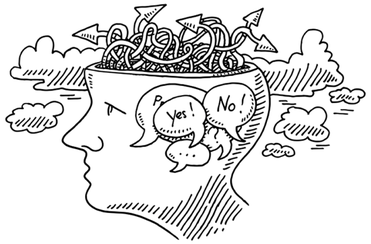


INTEGRATED FRAMEWORK

Controlled test facility with a 'Digital Twin'		Public Road
Type Approval Tests	**Audit (simulation)**	**Real-World Test Drive**



Y/N



Y/N

Do the sensors give the right output?

- Drive a vehicle along a test route with known targets
- Compare with ground truth

Does the ADS make the right decision based on data received?

- Simulation of scenarios, with randomisation

Does the vehicle at a system level perform appropriately?

- Physical testing

This is a short-term goal to achieve a basic level of validation for AVs

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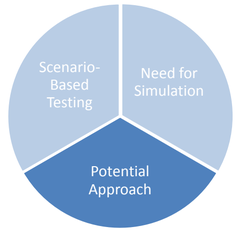
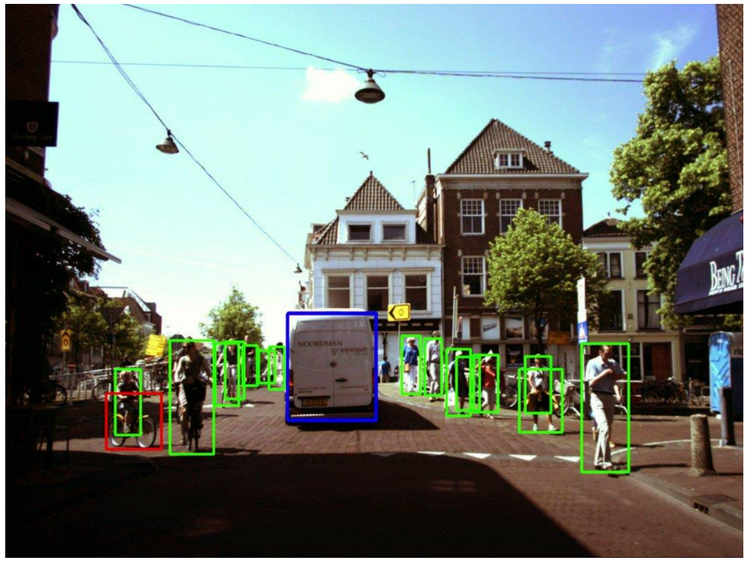
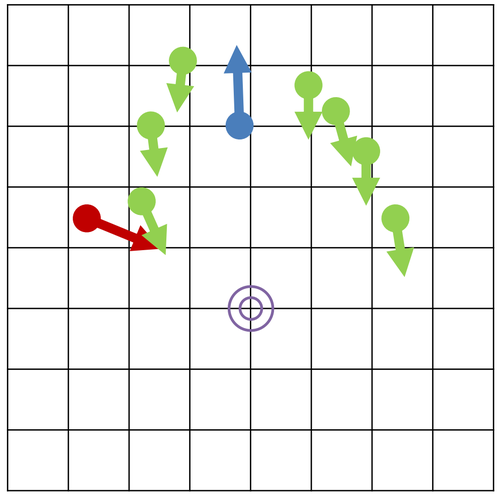


ADS ARCHITECTURE REQUIRED FOR THIS APPROACH

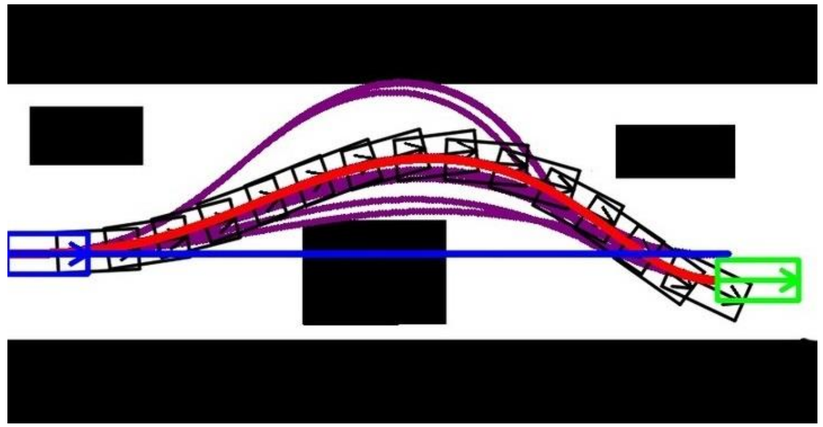
- The solution presented relies on the ADS having two key modules, with a defined interface between them



Sensor processing



Object model



Decision making /
Path planning

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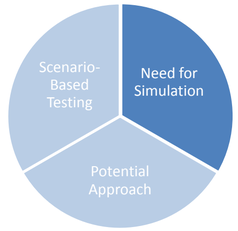
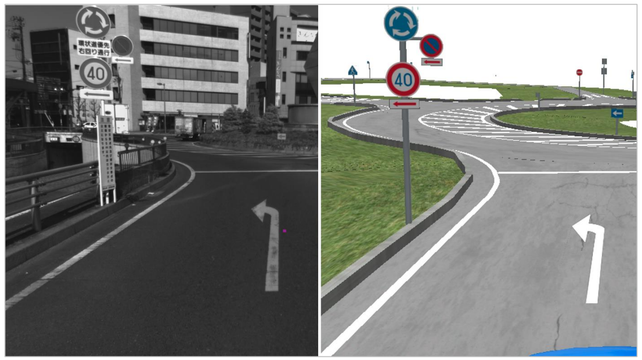


TECHNICAL CHALLENGE: SENSOR FIDELITY

- Sensor technology is rapidly evolving and maturing
- Many types of sensor exist, all are complex
- AVs use a variety of sensors that need to operate in many conditions
- Sensor simulation is computationally demanding

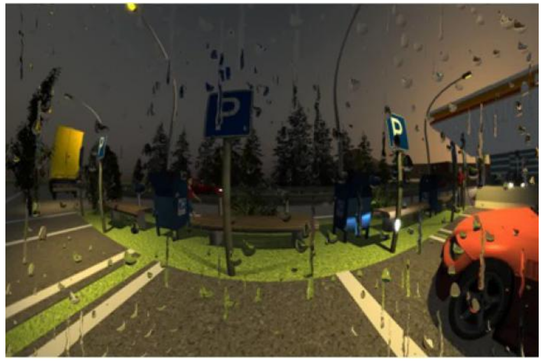
rfPro

Simulated Scenario



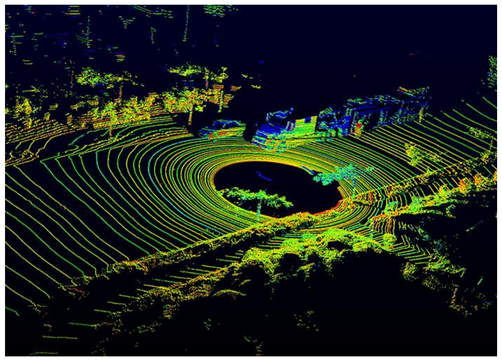
Atlatec, using CarSim

Real and Simulated Scenario

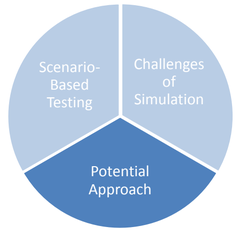


TASS PreScan

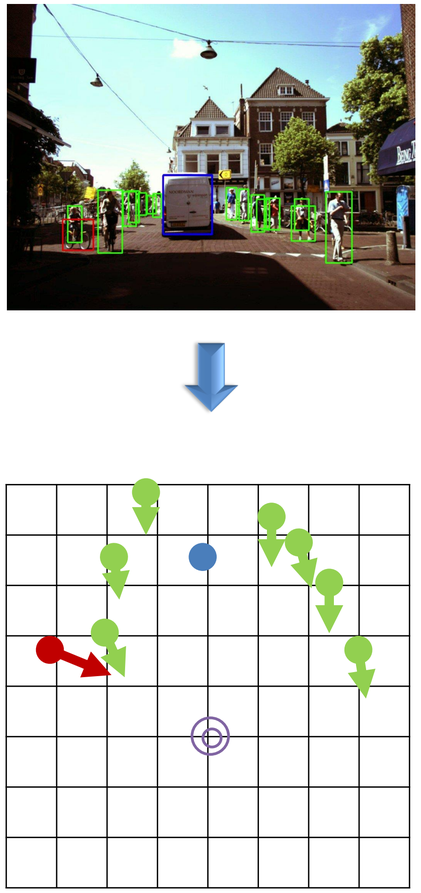
Simulation of rain on a fish eye lens



LiDAR Plot



SENSOR PROCESSING VERIFICATION (PHYSICAL)



- Perform all sensor testing in the real world
- Use dedicated test centres, where ground truth for the movement of all actors can be measured
- Compare the ADS's "object model" with the ground truth
  - False negatives should carry a higher weight than classification and position errors

Benefits

- No need for highly accurate sensor or environment modelling
- Clear and objective scoring of performance

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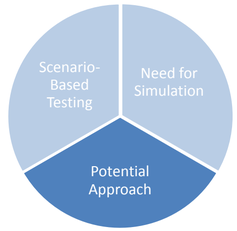
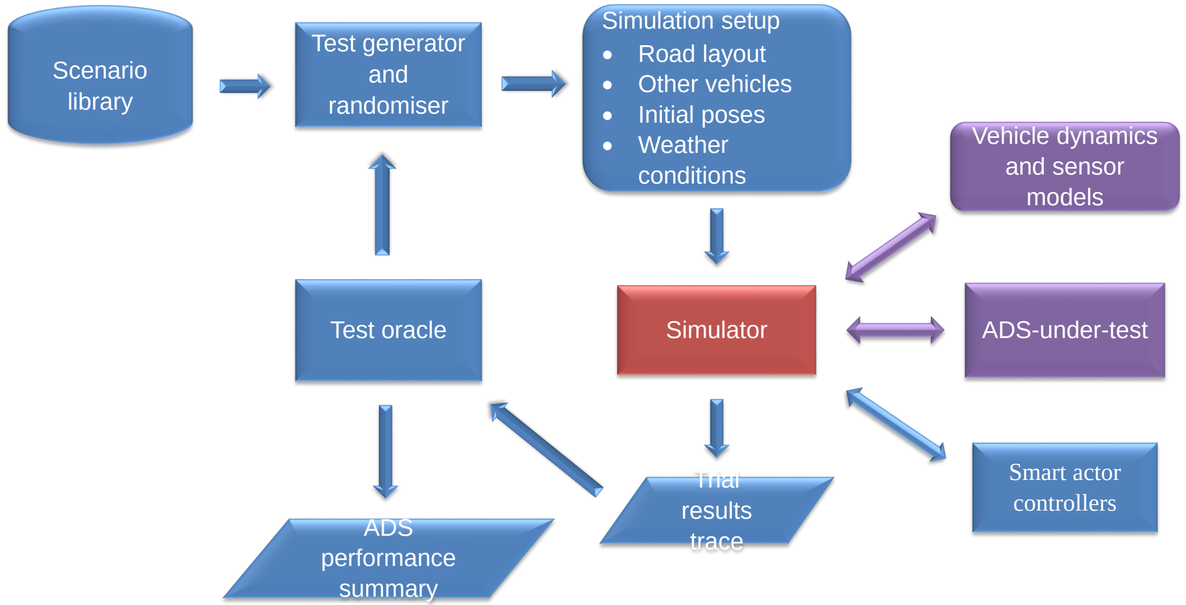
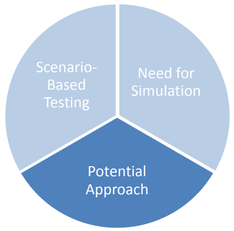


LONGER-TERM VISION

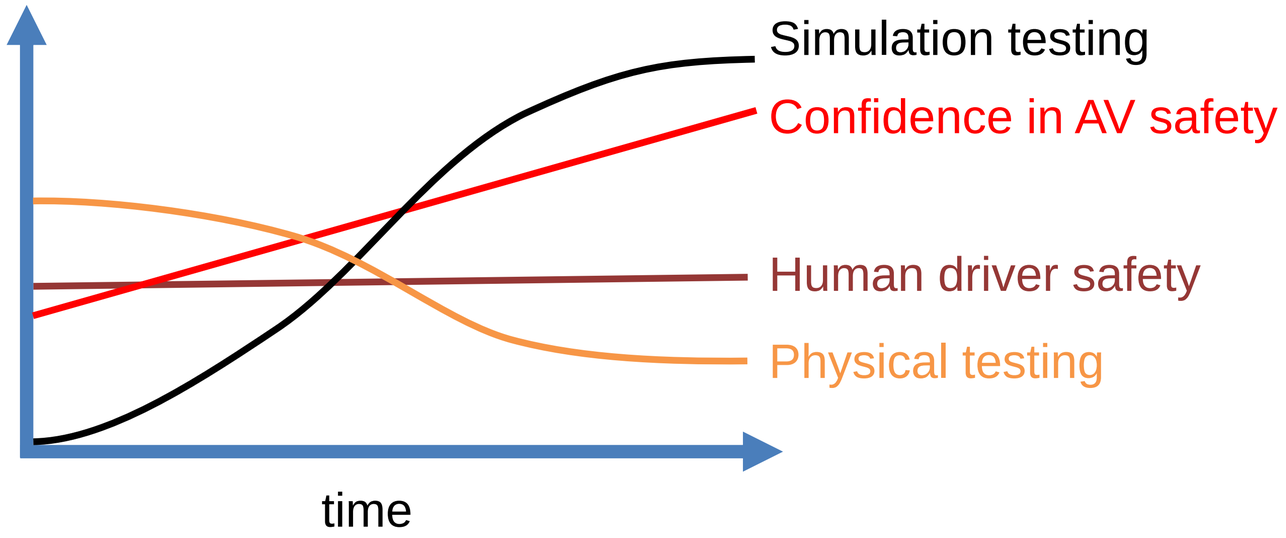
- Longer term: Test the ADS end-to-end in simulation
  - Cheaper and faster
  - Many more vehicle types, pedestrian types, weather, object colours, etc, can be tested
- There will be a learning process as technology evolves





EVOLUTION OF REGULATORY FRAMEWORK

- Simulation allows much higher confidence to be obtained
- As the technology matures, more testing can be done in simulation
- Simulation can never completely replace physical testing



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SUMMARY

- Verification of an ADS is a complex problem
- A pragmatic and effective solution is needed quickly, to support the introduction of highly automated and autonomous vehicles to the market
- Such a solution should be achieved through regulators and industry collaborating to define and meet common but evolving objectives

Type Approval

- Existing TA + use case tests
- Verification of sensor

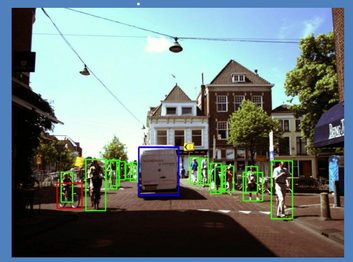

Image from TU Delft

ADS Audit

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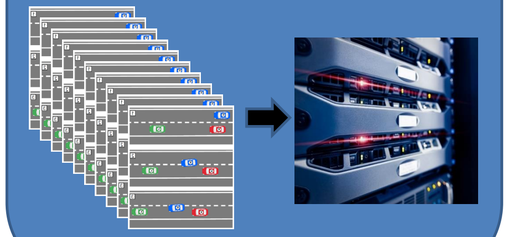

Real World Test Drive

- Key part of process
- Is 60 minutes enough?

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Thank you

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