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A QUANTITATIVE METHOD TO DETERMINE WHAT COLLISIONS ARE REASONABLE FORSEEABLE AND PREVENTABLE

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RISK QUANTIFICATION FOR AUTOMATED DRIVING SYSTEMS

This presentation is based on the following publication:

De Gelder, E., Elrofai, H., Khabbaz Saberi, A., Paardekooper, J.-P., Op den Camp, O., and De Schutter, B., “Risk quantification for automated driving systems in real-world driving scenarios”, IEEE Access **9**, 168953 (2021), https://doi.org/10.1109/ACCESS.2021.3136585

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INTRODUCTION
NEW REGULATIONS FOR AUTOMATED DRIVING SYSTEMS

- Automated driving systems (ADSs) with a higher level of automation (SAE level 3 or higher) will be ready to be introduced!
- Vienna convention on road traffic from 1968 (!) is still applicable:
  - Human driver must be in charge of driving.
  - Clearly, this convention does not consider higher levels of ADS!
- New regulations are drafted by the World Forum for Harmonization of Vehicle Regulations:
  - “Proposal for a new UN Regulation on uniform provisions concerning the approval of vehicles with regards to automated lane keeping systems”
  - From this proposal:

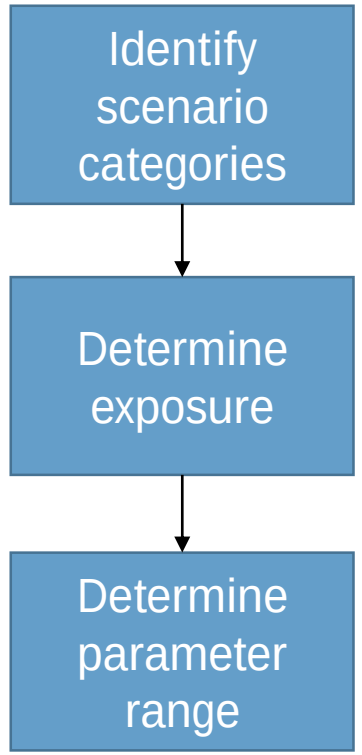
> “The activated system shall not cause any collisions that are reasonably foreseeable and preventable.”

INTRODUCTION
NEW REGULATIONS FOR AUTOMATED DRIVING SYSTEMS

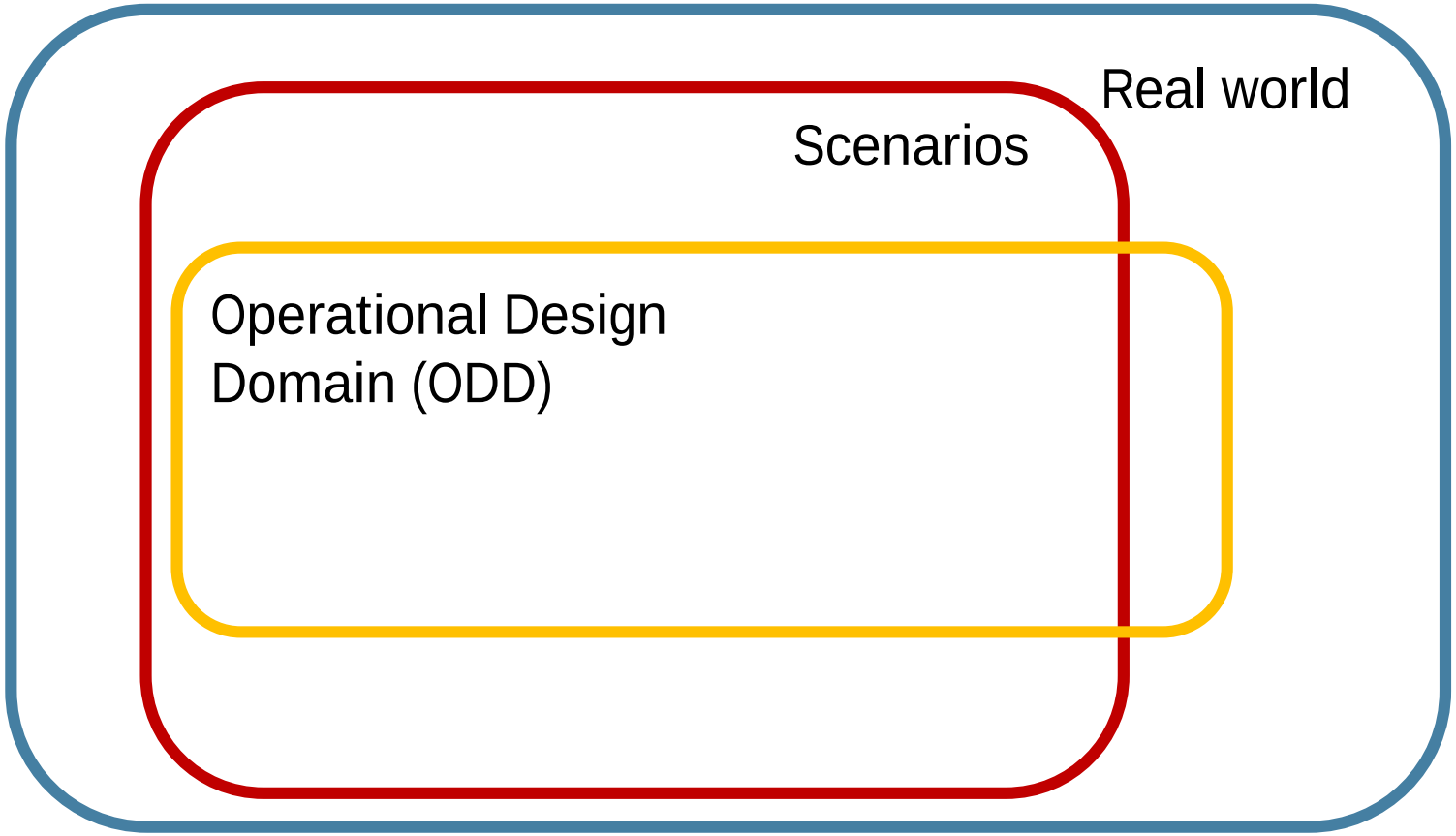
- This proposed requirement leaves room for interpretation.
- Hence, this presentation addresses the following research questions:
- **Research question 1: How to determine what are reasonable foreseeable scenarios?**
- **Research question 2: How to determine to which extent collisions are preventable?**

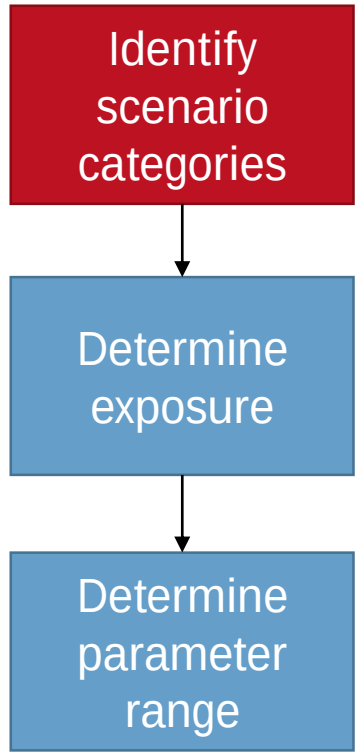
> “The activated system shall not cause any collisions that are reasonably foreseeable and preventable.”

REASONABLY FORESEEABLE



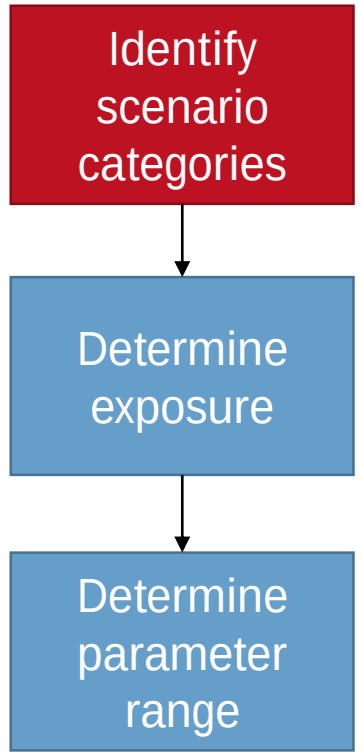
REASONABLY FORESEEABLE
IDENTIFY SCENARIO CATEGORIES





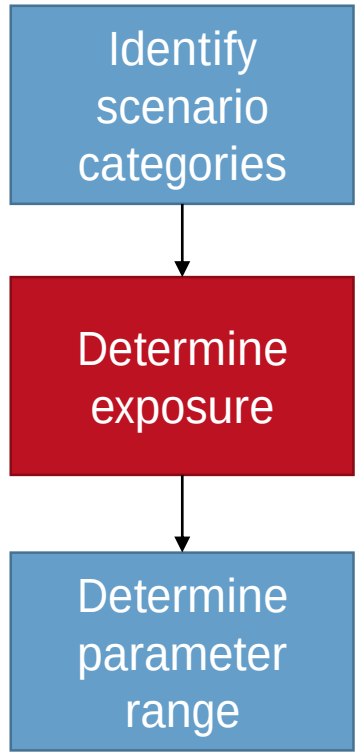
REASONABLY FORESEEABLE
IDENTIFY SCENARIO CATEGORIES

- A scenario category is a high-level description of a scenario.
- For example:
  - Leading vehicle decelerating
  - Cut-in
  - Approaching slower vehicle



REASONABLY FORESEEABLE
DETERMINE EXPOSURE

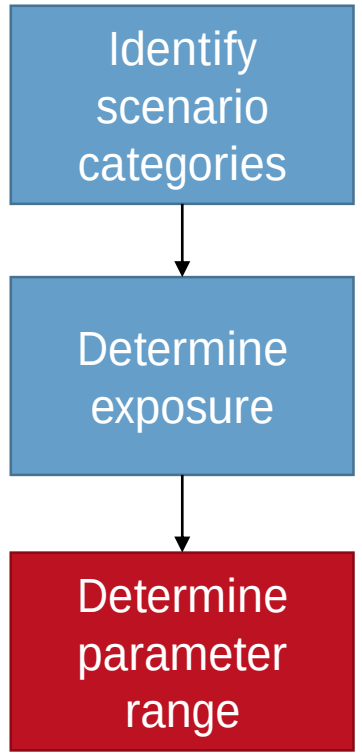
- Given a scenario category, how likely is it that we see a scenario belonging to the scenario category?
- We express this as an expectation of **number of scenarios per hour**.
- Instead of guessing, this number could be based on recorded data.
- For example:
  - We recorded **63** hours of data.
  - 1300 “leading vehicle decelerating scenarios” → $\mathbb{E}[n_C]$ = **20.6 per hour**
  - 297 “cut-in” scenarios → $\mathbb{E}[n_C]$ = **4.71 per hour**
  - 291 “approaching slower vehicle” scenarios → $\mathbb{E}[n_C]$ = **4.62 per hour**



REASONABLY FORESEEABLE
DETERMINE PARAMETER RANGE

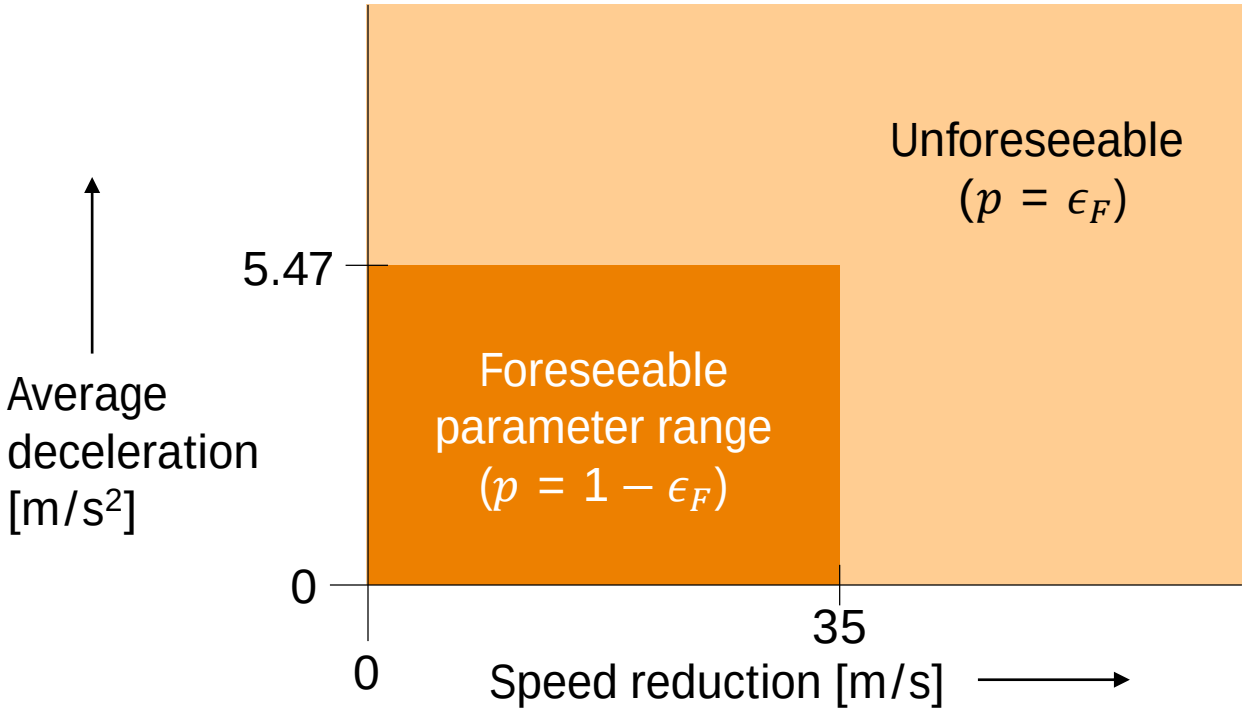
- Threshold for what is reasonably foreseeable: ϵ_{F}
- If the probability of encountering a scenario from a given scenario category is lower than ϵ_{F}:
  - It is not reasonably foreseeable.
- Otherwise, we can look at the parameter range of the reasonably foreseeable scenarios.
  - Determine the parameter vector x that describe the scenarios.
  - Based on the data, estimate the probability density function of x.
  - Determine a lower and upper bound, such that:

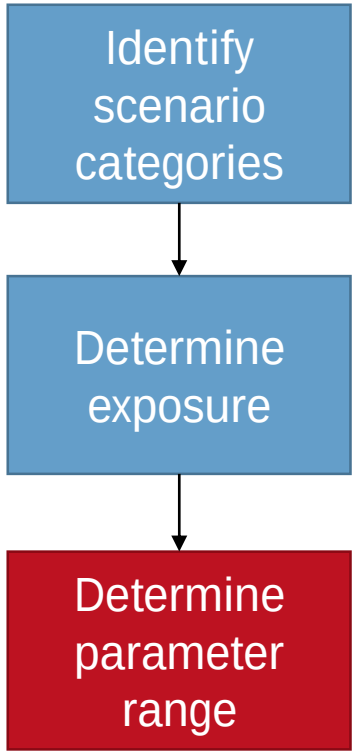
$$\mathbb{P}(L \leq x \leq U) \cdot \mathbb{E}[n_C] = 1 - \epsilon_{\mathrm{F}}$$



REASONABLY FORESEEABLE
DETERMINE PARAMETER RANGE

- For example, for a scenario with a leading vehicle decelerating, the foreseeable parameter range is:





REASONABLY PREVENTABLE

- We consider a collision reasonably preventable if a **skilled and attentive human** can avoid a collision.
- Using a Monte Carlo simulation using the probability density function of the parameters, we can compute the probability of a collision.
- Probability of collision will be low, so the Monte Carlo simulation will take very long.
  - Therefore, we use nonparametric importance sampling to speed up the total simulation time.
  - The main idea is to sample from a different pdf that emphasizes “critical scenarios”.

REASONABLY PREVENTABLE
EXAMPLE

- We conducted simulations of the 3 scenario categories (leading vehicle decelerating, cut-in, approaching slower vehicle).
- The driver is modelled using:
  - Intelligent Driver Model plus (Schakel et al., 2010)
  - With non-zero reaction time (lognormal, mean=0.92 s, std=0.29 s) (Green, 2000)
  - Maximum braking capacity of 6 m/s^2
- We conducted 10.000 simulation run using the Monte Carlo approach and another 10.000 simulation runs using nonparametric importance sample.
- Probability that a human driver can avoid a collision:
  - Leading vehicle decelerating: $2.43 \cdot 10^{-4}$ $(\pm 4.11 \cdot 10^{-5})$
  - Cut-in: $3.19 \cdot 10^{-3}$ $(\pm 1.78 \cdot 10^{-4})$
  - Approaching slower vehicle: $4.77 \cdot 10^{-8}$ $(\pm 4.77 \cdot 10^{-8})$

DISCUSSION

- The presented approach allows for quantifying whether a system does not cause any collisions that are reasonably foreseeable and preventable.
- However, there is room for improvement:
  - We need data… Lots of data…
  - What is the exact threshold for reasonably foreseeable? (i.e., ϵ_F)
  - How to model a skilled and attentive human driver?

CONCLUSIONS

- New regulations are needed to deploy higher levels of automated driving systems (ADS).
- The recently proposed regulation is an important milestone.
- **An ADS shall not cause any collisions that are reasonably foreseeable and preventable.**
- This research provides an approach to determine whether an ADS indeed does not cause reasonably foreseeable and preventable collisions.

THANK YOU FOR
YOUR TIME

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