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Presentation

A Study on Mitigating Hard Boundaries of Decision-Tree-based Uncertainty Estimates for AI Models

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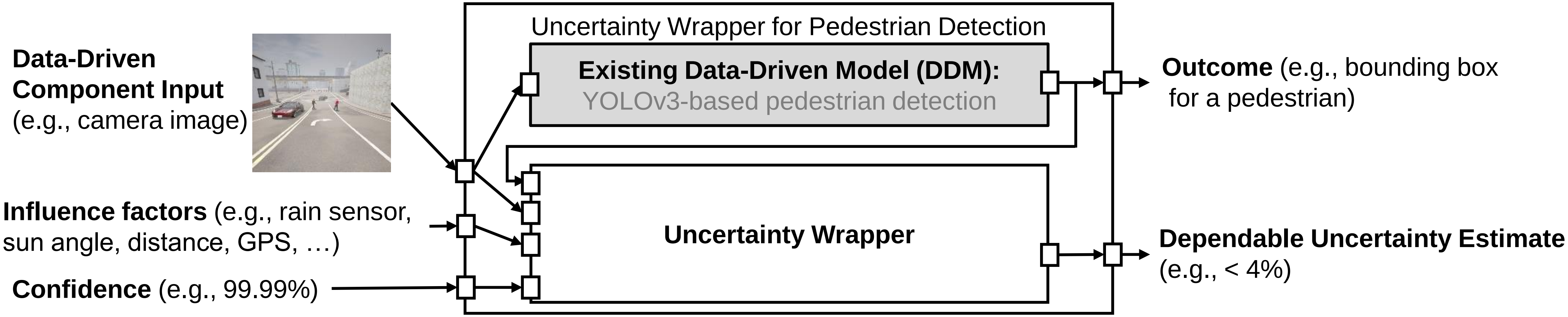
Model-agnostic Uncertainty Wrappers provide dependable uncertainty estimates

Motivation

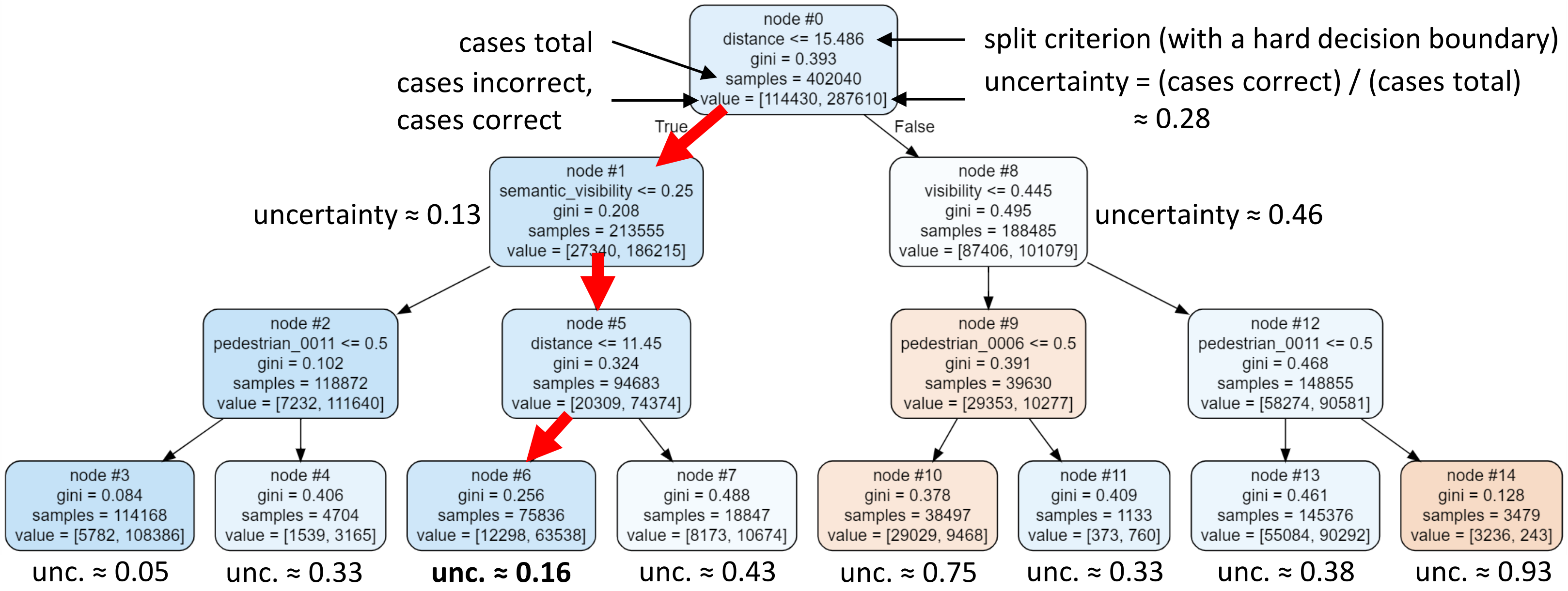
- The outcomes of Data-Driven Models (DDMs) cannot be assumed to be always correct
  - The **outcomes of DDMs are subject to uncertainty**
- Different approaches exist to provide 'inside-model' or 'outside-model' uncertainty estimates
- An example of the latter is the concept of **model-agnostic *Uncertainty Wrappers***
  - Uncertainty Wrappers enrich DDMs with a dependable uncertainty estimate



Decision Trees can be used to obtain interpretable uncertainty estimates

Motivation

- Uncertainty Wrappers **cluster inputs with similar uncertainties** based on influence factors using Decision Trees
- Benefit of Decision Trees: uncertainty estimates are **easy to interpret**



- Example: $x_1: \text{semantic\_visibility} = 0.3, \ldots, distance = 11.450$ => **uncertainty estimate = 16%**

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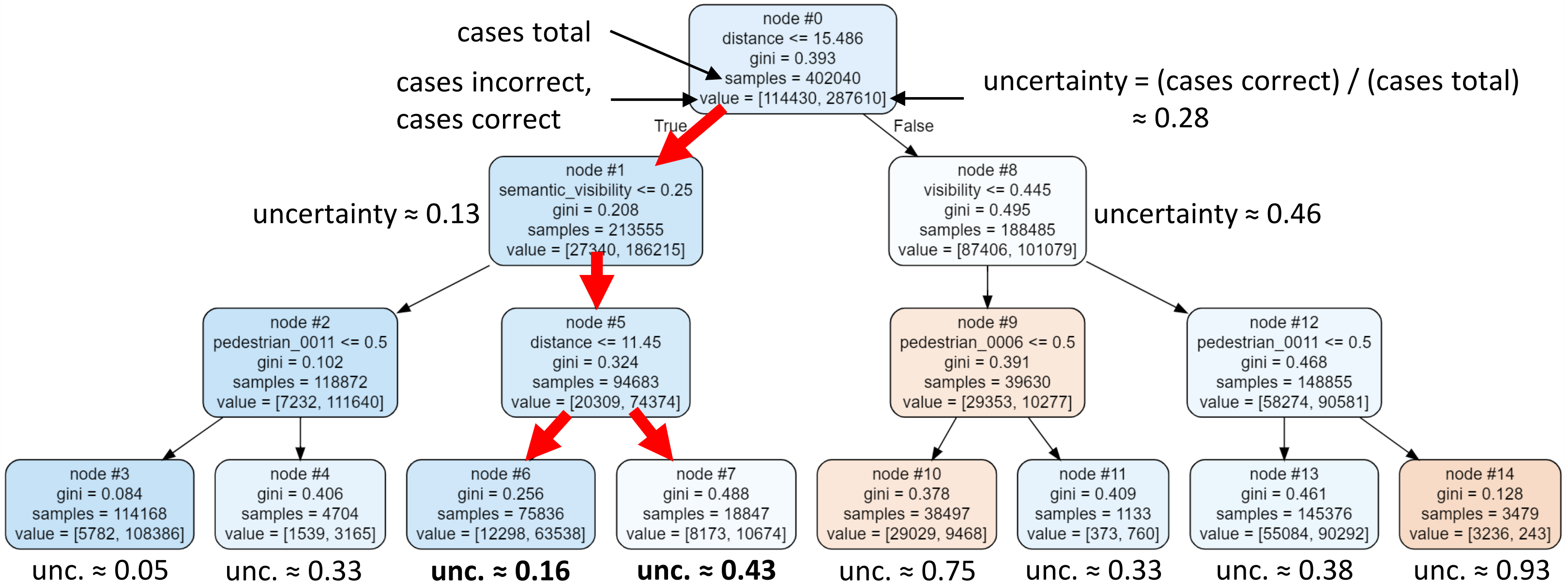
Decision Trees may lead to undesired hard decision boundaries

Problem Statement

- Problem: The discrete approach of Decision Trees realizes **hard decision boundaries**
- For *continuous features*, these boundaries may be rather unintuitive



- Example evaluation:
  - x_1: semantic_visibility $= 0.3, \ldots, distance = 11.45\mathbf{0}$ => uncertainty estimate = **16%**
  - x_2: semantic_visibility $= 0.3, \ldots, distance = 11.45\mathbf{1}$ => uncertainty estimate = **43%**

Goals to be met by the softening approaches

Solution search

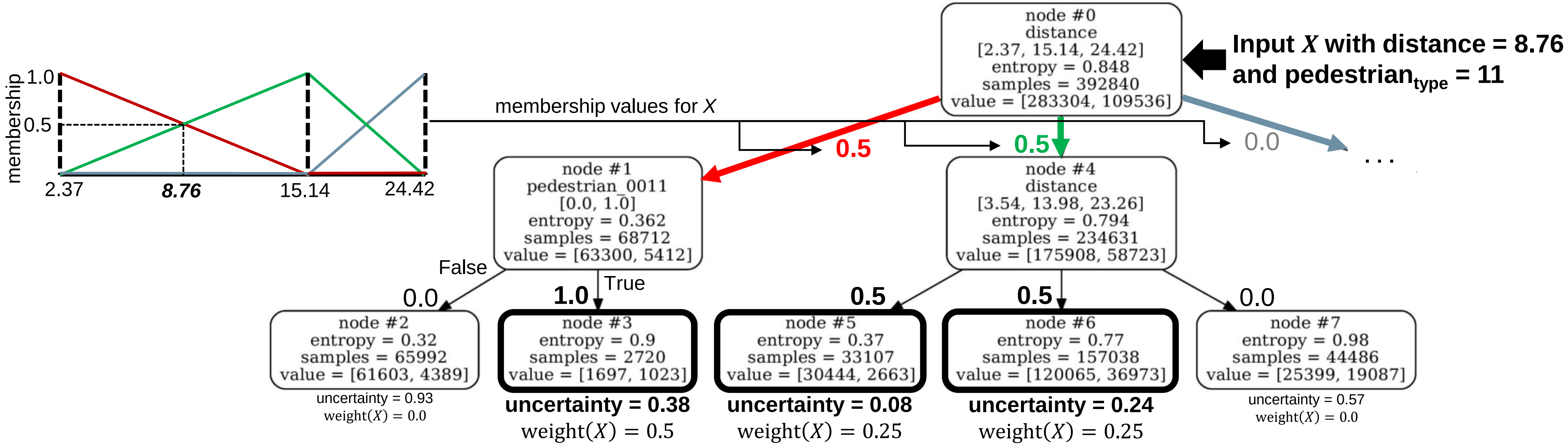
- Approaches need to satisfy the following goals:
  - G1: Implement **soft decision boundaries**
  - G2: **Interpretable** uncertainty estimates
  - G3: Reasonable **runtime complexity**
  - G4: Reasonable **uncertainty estimation performance**

- Identified approaches:
  - **Random Forests:**
    Breiman, L. 2001. Random forests. Machine learning, 45(1).
  - **Fuzzy Decision Trees / Random Forests:**
    Marcelloni, F.; Matteis, A. D.; and Segatori, A. 2015. A new approach to fuzzy random forest generation. In Proceedings of Int. Conf. on Fuzzy Systems, 1-8. IEEE.
  - **Soft Decision Trees / Bagged Soft Decision Trees:**
    Alpaydin, E.; Irsoy, O.; and Yildiz, O. T. 2016. Bagging soft decision trees. In Machine Learning for Health Informatics, 25-36. Springer, Cham.

Softening is achieved by using membership functions

Solution approaches

- *Main concept:* A data point has a membership degree to the leaves
- **Uncertainty estimate = Weighted sum of leaf uncertainties and membership values**
- Key difference between the approaches is the type of membership function used
- Simplified example of a Fuzzy Decision Tree to determine an uncertainty estimate for an input $\boldsymbol{X}$:



$$\rightarrow \mathbf{uncertainty}(\boldsymbol{X}) = \mathbf{0.0 \cdot 0.93 + 0.5 \cdot 0.38 + 0.25 \cdot 0.08 + 0.25 \cdot 0.24 + 0.0 \cdot 0.57 = 0.27}$$

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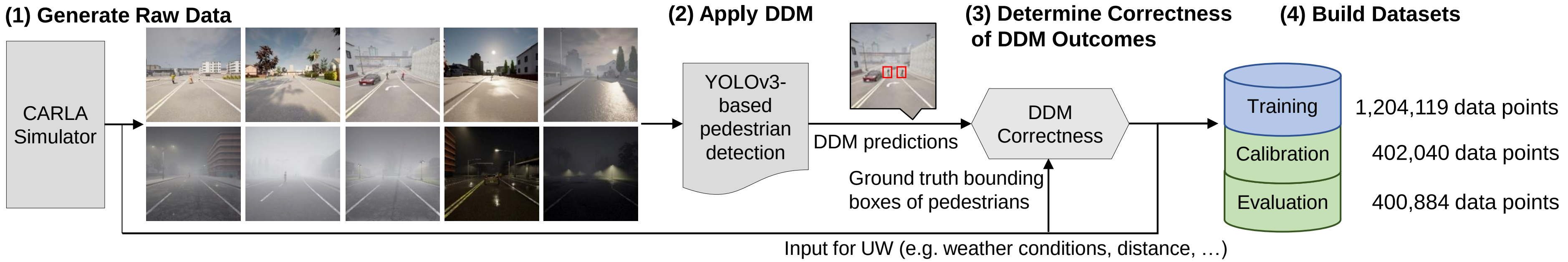
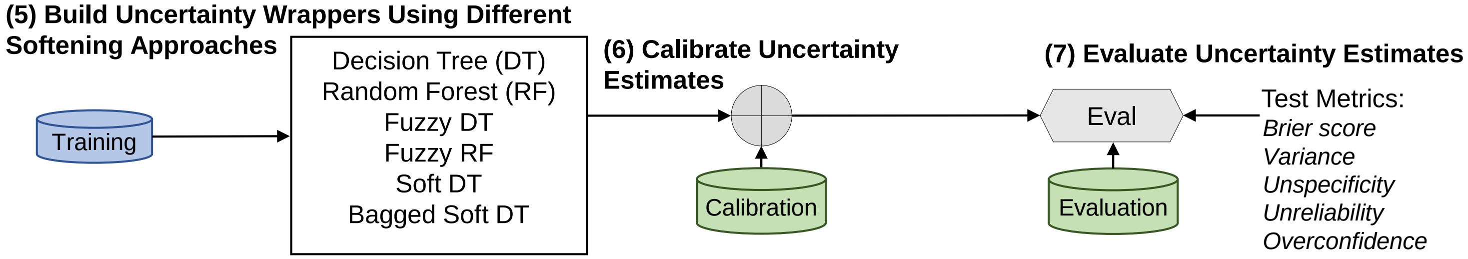
Softening approaches evaluated on pedestrian detection use case and metrics

Evaluation

- Use case: **Pedestrian detection** on roads
- Study execution – **build datasets**:



- Study execution – **evaluate softening approaches**:



Results: Softening achieved, but decreased estimation performance

Evaluation

- Summary of the extent to which the approaches achieve our goals:

Approach	G1: Softening	G2: Interpretability	G3: Runtime Complexity	G4: Estimation Performance
Decision Trees (baseline)	--	++	++	++
Random Forests	o	+	**+**	**+**
Fuzzy Decision Trees	**++**	+	o	o
Fuzzy Random Forests	**++**	o	-	o
Soft Decision Trees	**++**	+	o	**-**
Bagged Soft Decision Trees	**++**	o	-	**-**

Softening is a trade-off decision dependent on the use case

Conclusion and future work

- A general recommendation for the use of a particular approach cannot be provided
- Rather, the **selection of an approach has proved to be a trade-off decision**
- Based on the study results, we see **two main directions** for further work:
  - Develop specific recommendations for choosing an approach for a concrete setting
  - Modify approaches to address the observed uncertainty estimation performance limitations