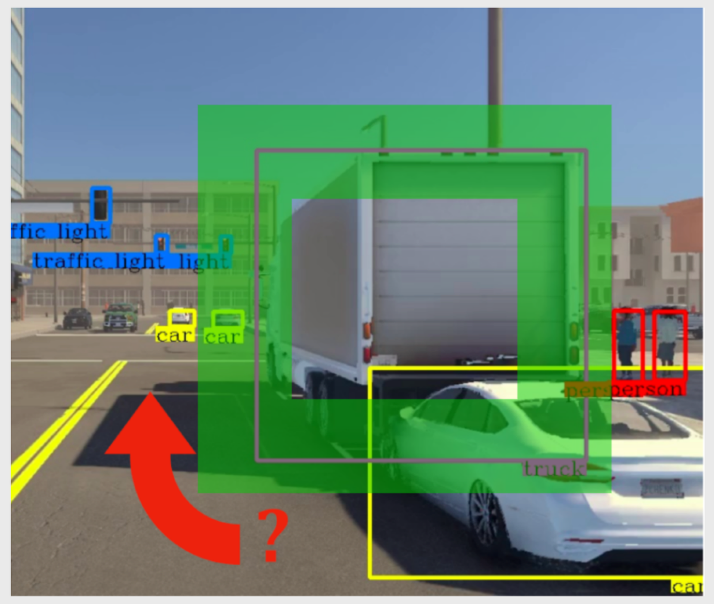
# Adaptive Bounding Box Uncertainties via Two-Step Conformal Prediction

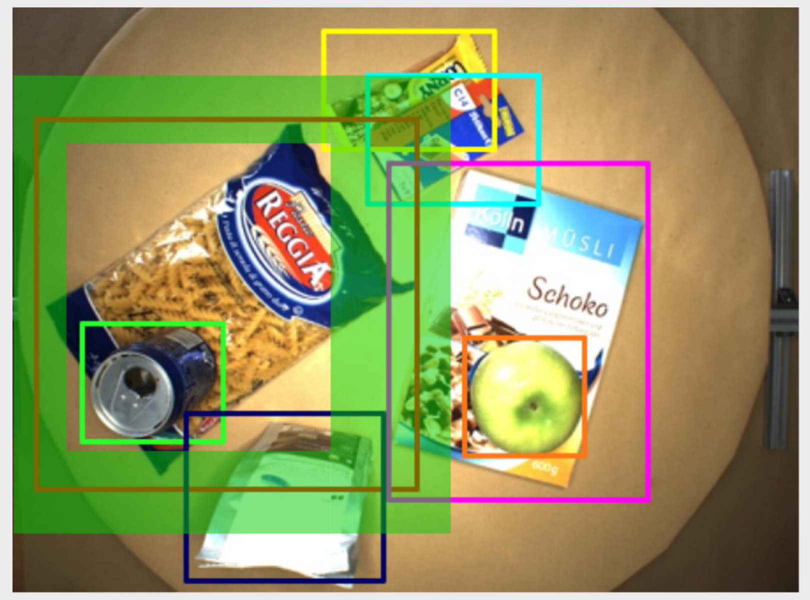
Alexander Timans [1], Christoph-Nikolas Straehle [2], Kaspar Sakmann [2], Eric Nalisnick [3]
— [1] University of Amsterdam, [2] Bosch Center for Artificial Intelligence, [3] Johns Hopkins University —

## Motivation

Autonomous agents should be able to reliably and efficiently quantify their predictive uncertainty to make safer decisions when relying on real-time bounding box predictions.

- ▶ Problem #1: How to obtain reliable bounding box uncertainties, and in what form?
- ▶ Problem #2: Object detectors predict an object's class label and its box coordinates. Both tasks exhibit uncertainty that needs to be accounted for.
- ▶ Solution (TLDR): Employ post-hoc, distribution-free conformal prediction in <u>two steps</u> to provide bounding box prediction intervals with coverage guarantees.



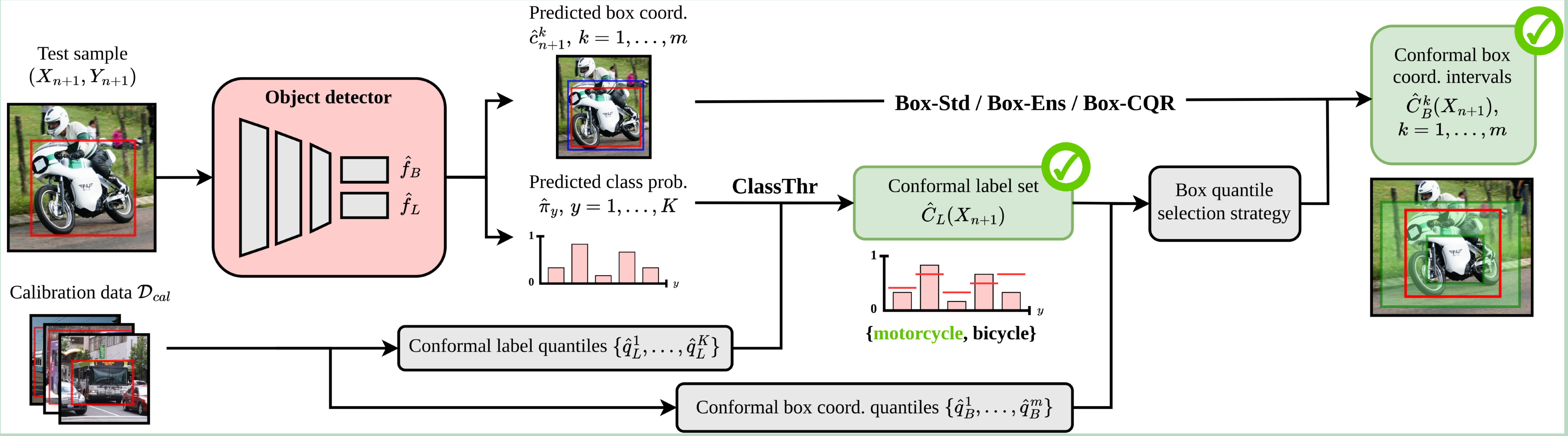


## Two-Step Conformal Prediction

STEP 0
- ▶ Precompute conformal quantiles on $\mathcal{D}_{cal}$ .
- ▶ Pass test sample through object detector.

STEP 1
- ▶ Apply conformal classification (ClassThr) to class probabilities to get a label set.

STEP 2
- ▶ Apply conformal regression and use label set from Step 1 to build final prediction intervals for bounding box coordinates.

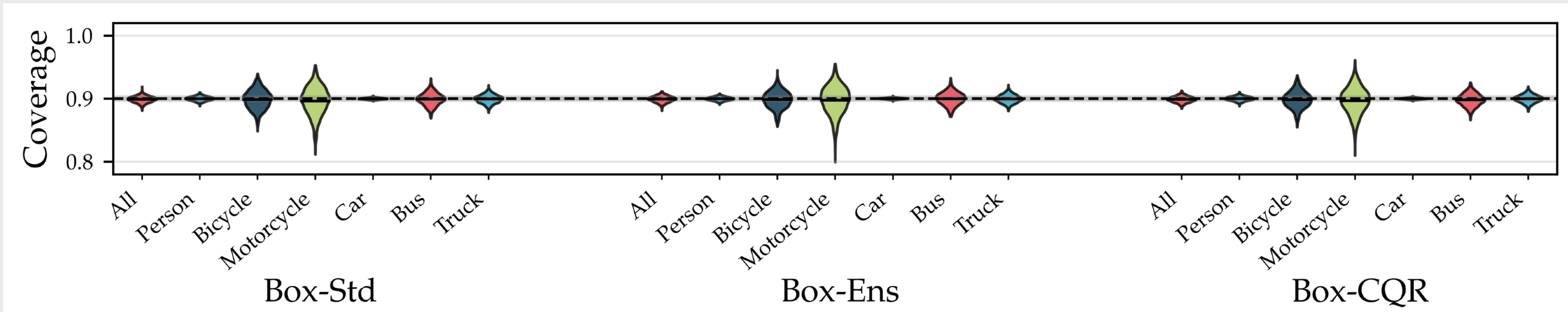


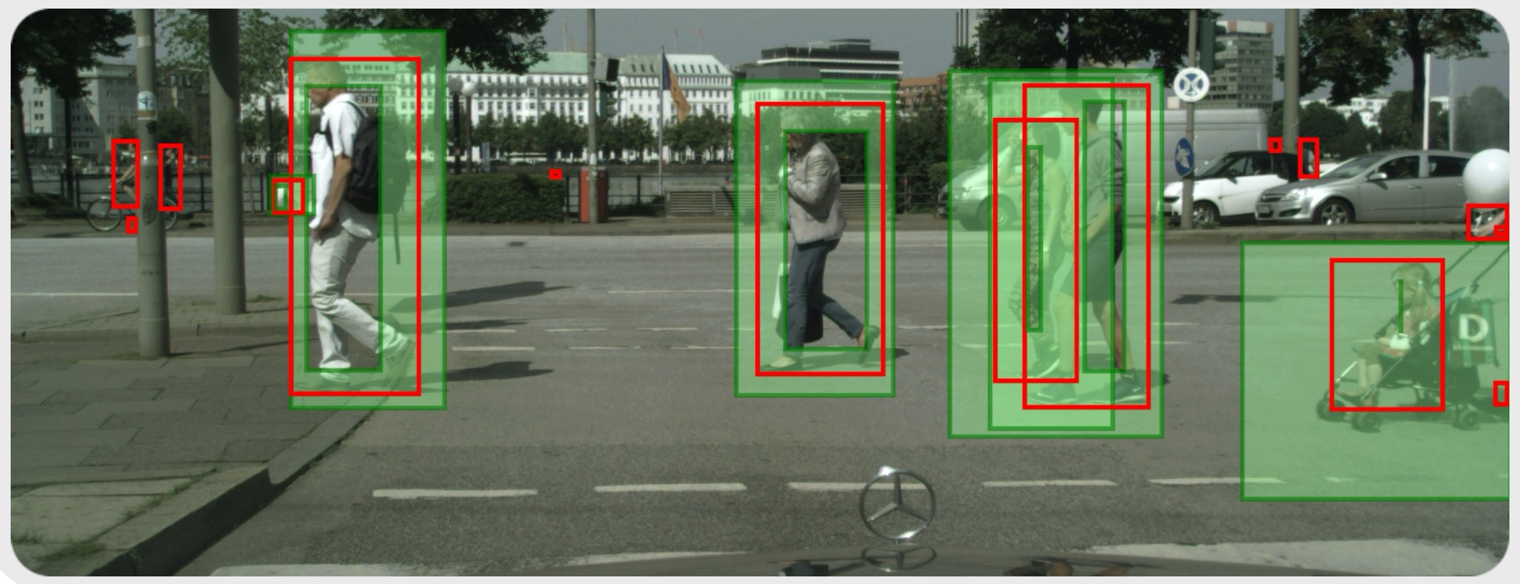

<u>Our coverage guarantee:</u> For exchangeable (iid) calibration data $\mathcal{D}_{cal}$ and test sample $(X_{n+1}, Y_{n+1})$ where $Y = (c^1, c^2, c^3, c^4, l)$, it holds that:

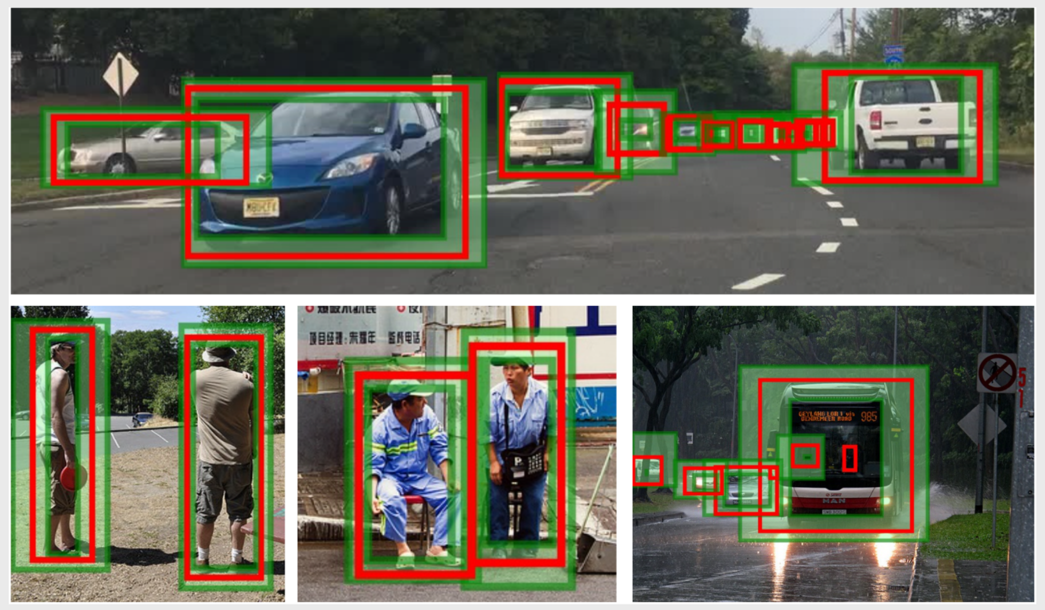
$$\mathbb{P}\left(l_{n+1} \in \hat{C}_L(X_{n+1}) \wedge \bigcap_{k=1}^{m} \left(c^k_{n+1} \in \hat{C}^k_B(X_{n+1})\right) \mid l_{n+1} = y\right) \geq (1-\alpha_L)(1-\alpha_B) \approx (1-\alpha_B) \quad \forall y \in \mathcal{Y}$$

## Results

- ▶ Bounding box intervals are tight and scale adaptively with class instances.
- ▶ Guarantees hold across object classes, datasets, and 'black-box' models.





## References

▶ Shafer & Vovk (2008). A Tutorial on Conformal Prediction (JMLR)
▶ Lei et al. (2018). Distribution-free Predictive Inference (JASA)
▶ Andéol et al. (2023) Confident object detection via conformal prediction ... (COPA)
▶ Angelopoulos & Bates (2023). Conformal prediction: A gentle introduction (F&T in ML)
▶ Romano et al. (2019). Conformalized Quantile Regression (NeurIPS)
▶ Sadinle et al. (2019). Least Ambiguous Set-Valued Classifiers with Bounded Error Levels (JASA)