nonconform: Conformal Anomaly Detection (Python)

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Summary

The Python package `nonconform` provides statistically principled uncertainty quantification for unsupervised anomaly detection. It implements methods from conformal anomaly detection (Bates et al., 2023; Jin & Candès, 2023; Laxhammar & Falkman, 2010) based on the principles of one-class classification (Petsche & Gluck, 1994). The ability to quantify uncertainty is a fundamental requirement for AI systems in safety-critical domains, where reliable decision-making is essential.

Based on the underlying principles of conformal inference (Lei & Wasserman, 2013; Papadopoulos et al., 2002; Vovk et al., 2005), `nonconform` converts raw anomaly scores from an underlying detection model into statistically valid p-values. This is achieved by calibrating the model on a hold-out set of normal data; the p-value for a new test instance is then calculated as the relative rank of its anomaly score compared to the scores from the calibration set. By framing anomaly detection as a series of statistical hypothesis tests, these p-values allow for the systematic control of the False Discovery Rate (FDR) (Bates et al., 2023; Benjamini & Hochberg, 1995) at a pre-defined significance level (e.g., $\alpha \leq 0.1$). The library integrates with the popular `pyod` library (Chen et al., 2024; Zhao et al., 2019), making it easy to apply these conformal techniques to a wide range of anomaly detection models.

Statement of Need

A primary challenge in anomaly detection is setting an appropriate anomaly threshold, which directly impacts the false positive rate. In high-stakes domains such as fraud detection, medical diagnostics, and industrial quality control, controlling the proportion of false positives is crucial, as frequent false alarms can lead to *alert fatigue* and render a system impractical. The `nonconform` package addresses this by replacing raw anomaly scores with p-values, which enables formal FDR control. This makes the conformal methods *threshold-free*, as decision thresholds are a direct result of respective statistical procedures.

Moreover, conformal methods are *non-parametric* and *model-agnostic*, making them compatible with any model that produces consistent anomaly scores. The `nonconform` package provides a range of strategies for creating the calibration set from training data. With this calibration set, the package can compute standard conformal p-values or modified *weighted* conformal p-values (Jin & Candès, 2023), which are more robust in low-data regimes (Hennhofer & Preisach, 2024). Weighted p-values are particularly useful when the statistical assumption of exchangeability is weakened by covariate shift between calibration and test data. By providing these tools, `nonconform` enables researchers and practitioners to build anomaly detectors whose outputs are statistically controlled to cap the FDR at a desired nominal level:

$$FDR = \frac{\text{Efforts Wasted on False Alarms}}{\text{Total Efforts}}$$

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(Benjamini et al., 2009; Benjamini & Hochberg, 1995).

The core assumption for the methods in `nonconform` is that the data is exchangeable, meaning the joint probability distribution is invariant to the order of observations. This makes the methods suitable for many cross-sectional data analysis tasks but not for time-series data where temporal ordering is informative.

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