FOSD 2025 - Köthen

Conformal Prediction for Uncertainty Quantification in Performance Modelling

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PERFORMANCE MODELLING

Performance modeling is the process of analyzing and predicting how a system performs under different configurations and workloads.[1]

- Purpose:
  - Helps in **performance optimization, capacity planning, debugging,** and **system design**
- Challenges:
  - Systems are highly configurable, leading to **huge configuration spaces**
  - Performance is influenced by **individual configuration options and their interactions**
  - **Sampling and learning** the performance behavior efficiently is complex

UNCERTAINTY QUANTIFICATION

Uncertainty quantification is the process of identifying, characterizing, and reducing uncertainty in models and predictions.[2]

Types of uncertainty:

- **Aleatoric Uncertainty**:
  - Inherent randomness in the system (e.g., measurement noise)
- **Epistemic Uncertainty**:
  - Lack of knowledge due to limited data
  - Model limitations

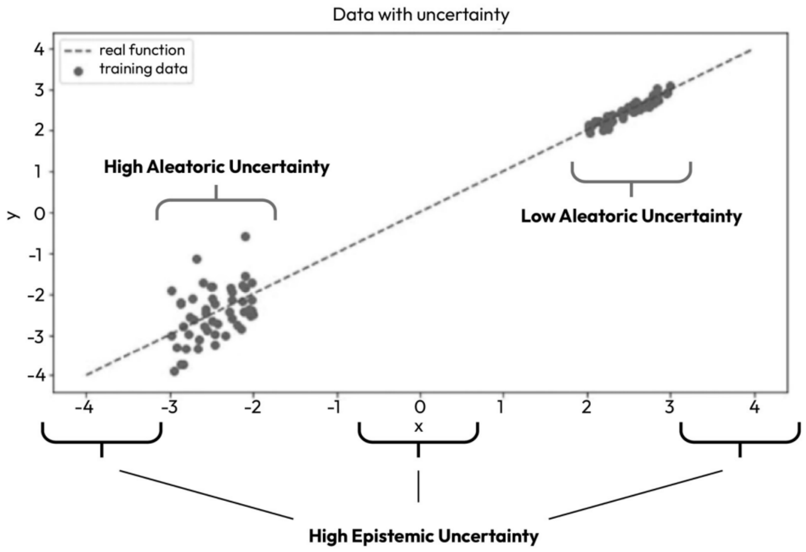


Image source: Practical Guide to Applied Conformal Prediction- Manokhin

UNCERTAINTY QUANTIFICATION

- Purpose:
  - Ensures models are **interpretable and trustworthy**
  - Helps in making more **reliable predictions** and **informed decisions**

- Challenges in Performance Modelling:
  - Traditional models use **point estimates**, ignoring uncertainty
  - Sources of uncertainty include:
    - **Measurement bias** (inaccurate data collection)
    - **Model choice** (different models give different results)
    - **Incomplete data** (not all configurations can be tested)

UNCERTAINTY QUANTIFICATION

Accurate performance models are essential, but without uncertainty quantification, we risk making overconfident and unreliable decisions.[3]

Solutions:

- Bayesian Regression
- Conformal Prediction

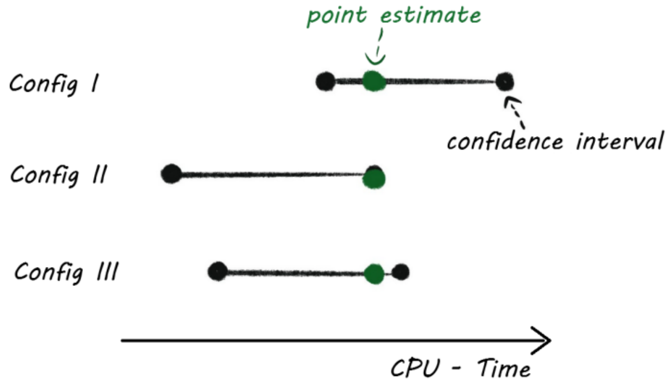
CONFORMAL PREDICTION

- Why choose conformal prediction over Bayesian regression?
  - Requires only the assumption of **exchangeable data**
  - Compatible with **any machine learning model** without modification
  - **Guarantees** of valid uncertainty quantification

CONFORMAL PREDICTION

A statistical framework that provides valid confidence intervals for predictions.[4]

- **Confidence Interval**:
  - The real value falls within this interval with probability $1 - \alpha$
  - $\alpha :=$ *user chosen error level*



- Core principles:
  - **Law of Large Numbers**
  - **Non-Conformity Measure**

CONFORMAL PREDICTION

- Non-Conformity Measure:
  - Represents how **surprising** a value is (e.g., difference between predicted and actual values) → gives **conformity scores**

	D_{Train}	$D_{Calibration}$										D_{val}
Config	$c_i \ldots c_j$	c_{17}	c_{55}	c_{23}	c_{115}	c_{92}	c_6	c_{22}	c_{15}	c_{102}	c_{30}	c_{235}
Real value												
Estimation												
Score												

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Real value	…	10	9	9	14	13	12	8	7	9	10	?
Estimation	x	11	7	8	14	16	9	10	6	9	12	9
Score												

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Score	x											x

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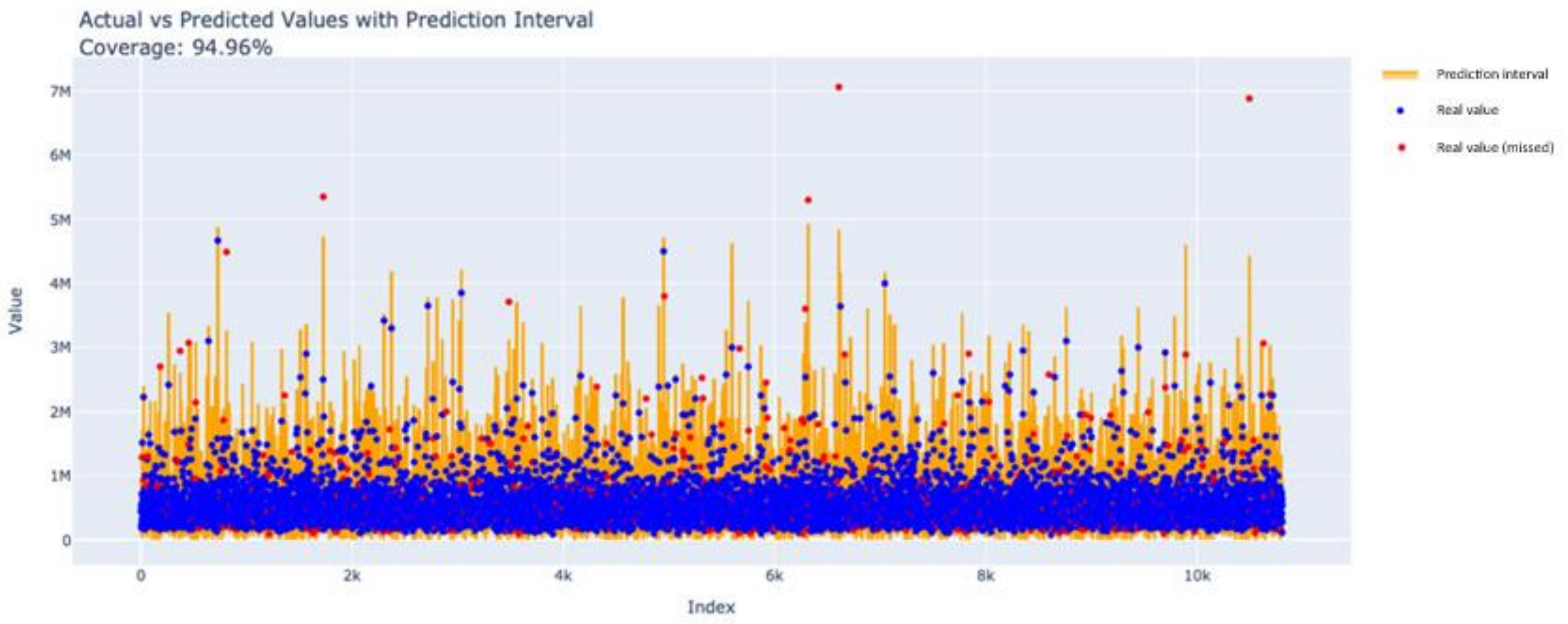
Real value	…	10	9	9	14	13	12	8	7	9	10	?
Estimation	x	11	7	8	14	16	9	10	6	9	12	9
Score	x	1	2	1	0	3	3	2	1	0	2	x

- α: 0.2 → 0.2 x 10 = 2 → choose 2nd largest score (=3)
- Inverse Non-Conformity Measure: 9 ± 3

CONFORMAL PREDICTION



α=0.05

Image source: Practical Guide to Applied Conformal Prediction- Manokhin

Thanks for your attention.

SOURCES

- [1] – https://dl.acm.org/doi/10.1145/2786805.2786845
- [2] – https://doi.org/10.1137/1.9781611973228
- [3] – https://doi.org/10.1007/s10664-022-10250-2
- [4] – ISBN-13: 9781805122760