🌀The Core Idea of Uncertainty

When a model makes a prediction, it's not just about the **number** it outputs (e.g., stock price = 105). What really matters in the real world is:

- **How sure is the model?**
- **What's the range of plausible outcomes?**
- **What's the probability of being wrong?**

That's **uncertainty quantification (UQ)**: attaching **confidence, distributions, or intervals** to predictions.

Types of Uncertainty

There are two main categories:

1. **Aleatoric Uncertainty** ("noise in data")
    - It comes from randomness in the world.
    - Example: Even if you know everything about a dice, rolling it is inherently random.
2. **Epistemic Uncertainty** ("lack of knowledge")
    - Comes from limited data or model limitations.
    - Example: A medical model trained on European patients may be uncertain when predicting for African patients (out-of-distribution).

How Models Typically Fail

Most ML/finance/AI models give a **point estimate**:

- "House price = $200,000"
- "Stock tomorrow = 105"
- "Patient has 80% chance of disease"

But in reality, the truth is:

- House price might be anywhere between $180,000 and $230,000.
- Stock might move ±10% depending on volatility.
- Disease probability might vary depending on unseen risk factors.

Without **uncertainty**, decisions made on predictions can be dangerous.

How We Attach Uncertainty

Different methods estimate how much trust we can put into a prediction:

- **Confidence Intervals** → range around prediction.
- **Predictive Distributions** → full probability curve.
- **Coverage Guarantees** → intervals that are guaranteed to contain the truth X% of the time.

Example:

Instead of saying:
`Stock price = 105`

We say:
`Stock price = 105 ± 7 (95% confidence)`
or
`P(Stock between 100 and 110) = 0.85`

Why It Matters

- **Finance** → Risk-adjusted trading, portfolio hedging.
- **Healthcare** → Doctors need confidence, not just guesses.
- **AI Safety** → Autonomous cars should know when they're unsure.
- **Science** → Reliable statistical inference.

👉 The **core idea of this library** is to make this *plug-and-play* for any model, so uncertainty isn't an afterthought but a standard output.