# Uncertain<*T*>

## A First-Order Type for Uncertain Data


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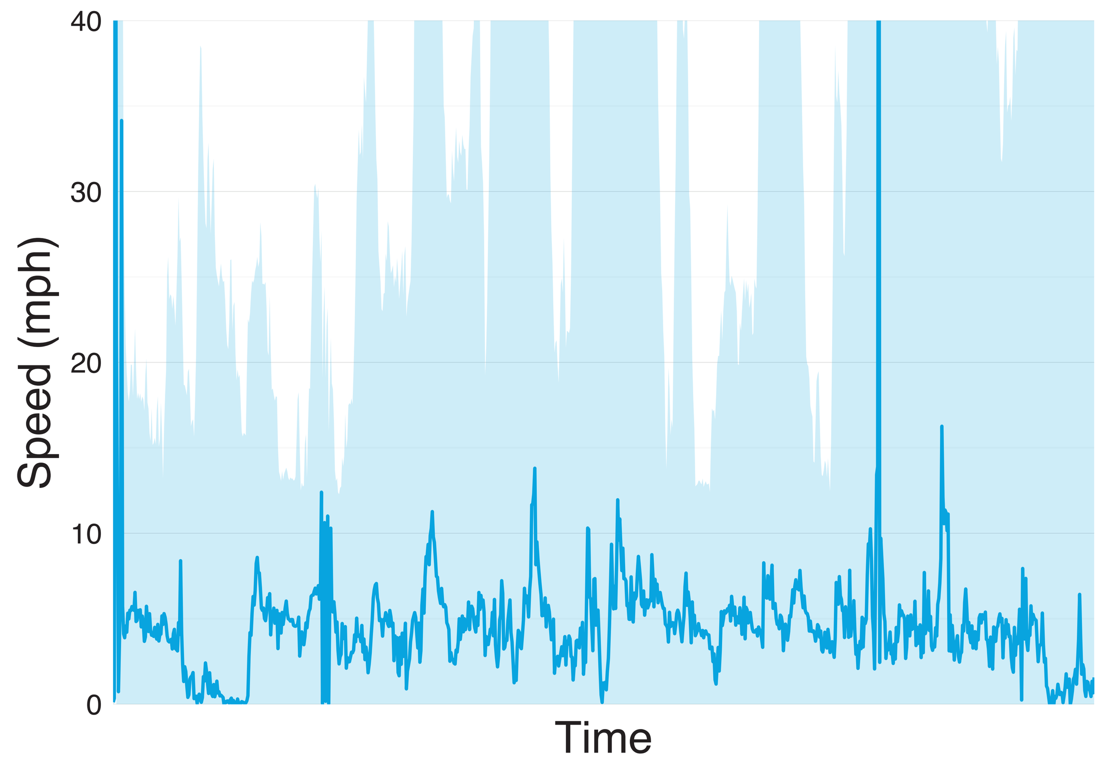
## Uncertainty bugs: Applications use estimated data, but languages use discrete types

**Using estimates as facts** — Discrete types ignore random error. 95% of WinPhone apps ignore GPS error.

**Computation compounds error** — Calculations induce more uncertainty, making results even more inaccurate.

**Inference asks wrong questions** — Code asks boolean questions, but estimated data is probabilistic.

```
Location LastLoc = GetGPSLoc();
while (true) {
  Sleep(dt);
  Location Loc = GetGPSLoc();
  PlotOnMap(Loc);
  double Speed
    = Dist(LastLoc, Loc) / dt;
  if (Speed > 65)
    SpeedLimitWarning();
  LastLoc = Loc;
}
```

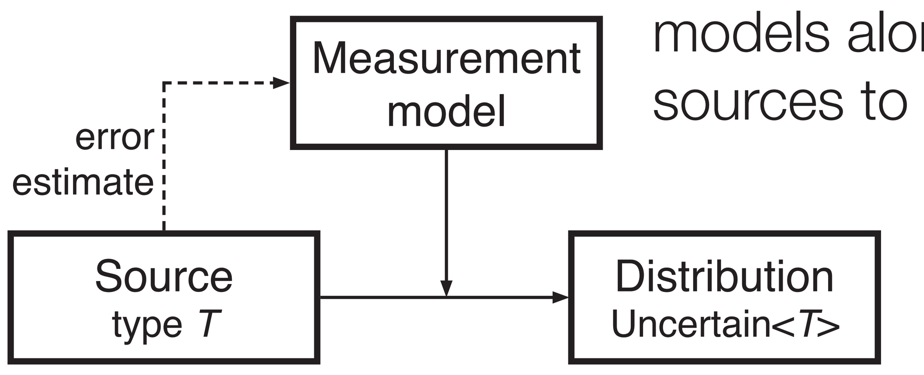



This app measures speeds with GPS, and reports absurd data like walking at 59 mph. Compounding error causes a wide 95% confidence interval.

Can application writers handle estimated data without requiring a PhD in statistics?

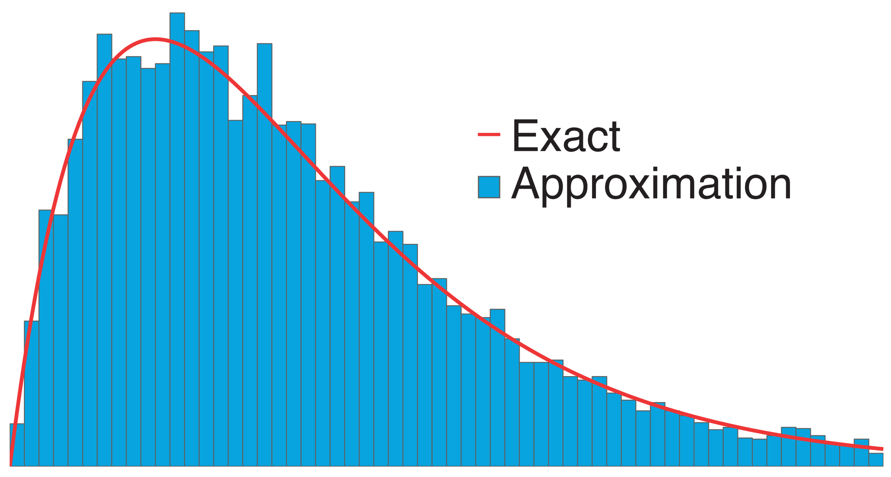
## Four steps to using Uncertain<*T*>, the uncertain type abstraction

### 1 Identifying distributions

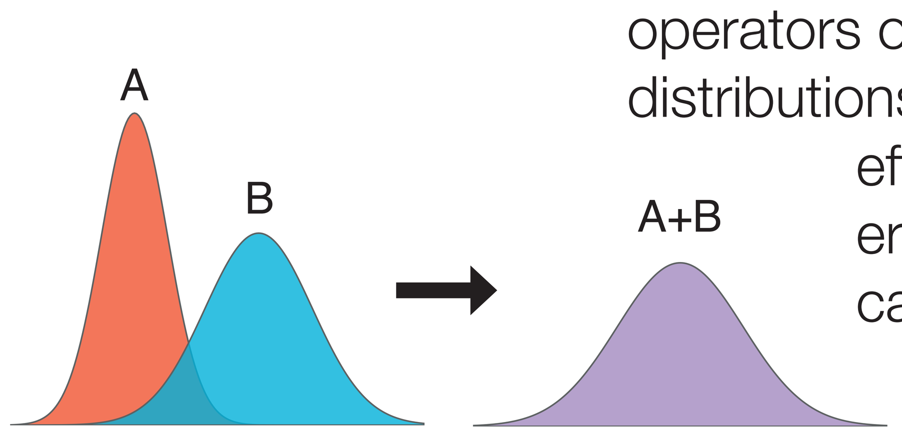



Experts provide measurement models along with uncertain data sources to create distributions.

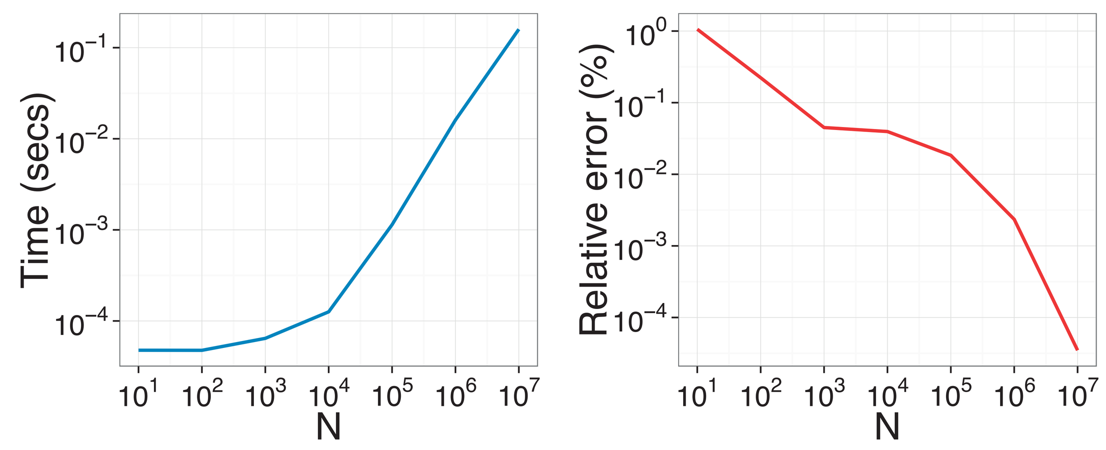
Uncertain<*T*> approximates arbitrary distributions by Monte Carlo random sampling.




### 2 Computing with estimates

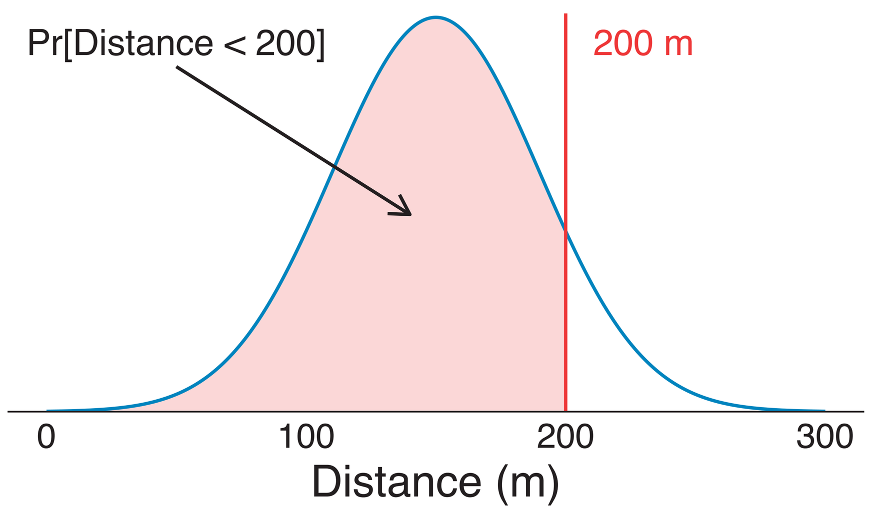



Uncertain<*T*> lifts arithmetic operators over type *T* to act over distributions of *T*, which captures the effect of compounding error when making calculations.




Sample size trades speed for accuracy.

### 3 Asking the right questions




The semantics of conditionals are unclear when distributions are involved. There is a *probability* that A < B; so comparisons have type `Unc<T> -> Unc<T> -> Bernoulli`. But this does not preserve the total order on *T* if it has one.

Alternatively we can use expected values: the expected value of an Uncertain<*T*> is of type *T*, so preserves the order properties of *T*.

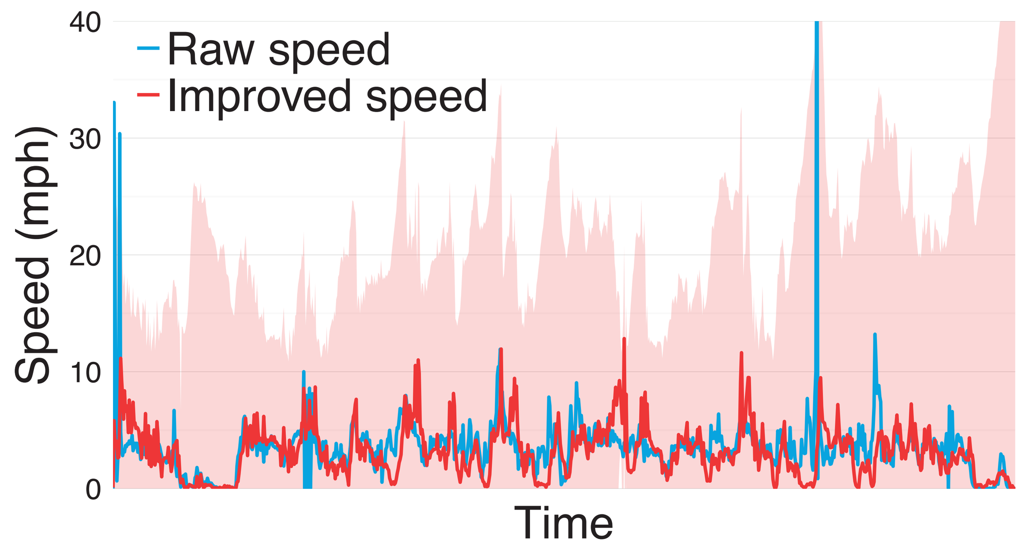
Uncertain<*T*> uses hypothesis tests to control approximation error.

### 4 Improving estimates

$$\Pr[H|E] = \frac{\Pr[E|H]\Pr[H]}{\Pr[E]}$$

Distributions allow experts to apply Bayesian methods: combine evidence (observed data, $E$) with a hypothesis (prior knowledge, $H$) to obtain better estimates (a new hypothesis, $H|E$).

For example, we can apply a physics model to the GPS speed data from above. The model removes the absurd values and tightens the confidence interval.




## Uncertain<*T*> makes programs more expressive and more correct

Australian National University
Microsoft Research

Full tech report
`http://bit.ly/182RWEj`