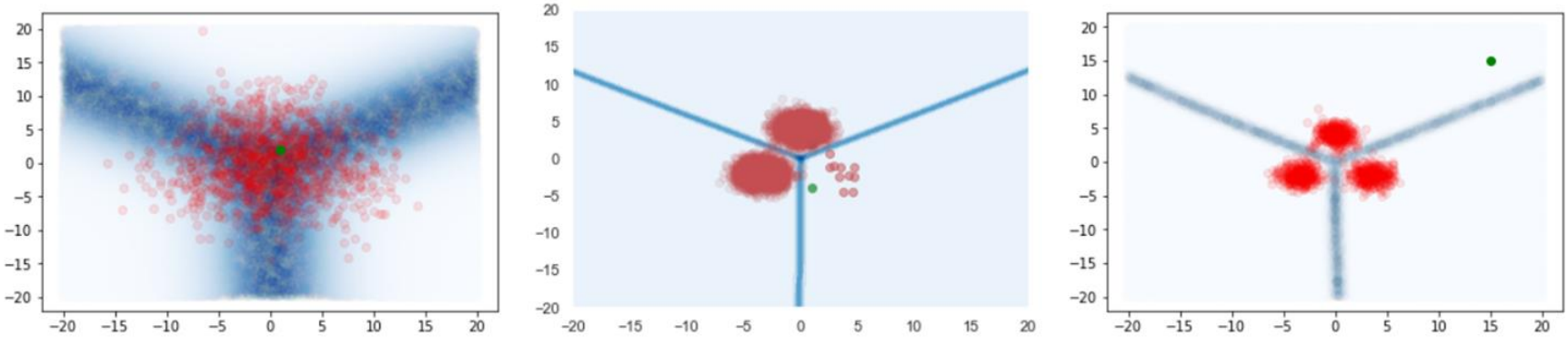
Part 1: General Introduction into Uncertainty & Domain Shift

Vatsal Raina

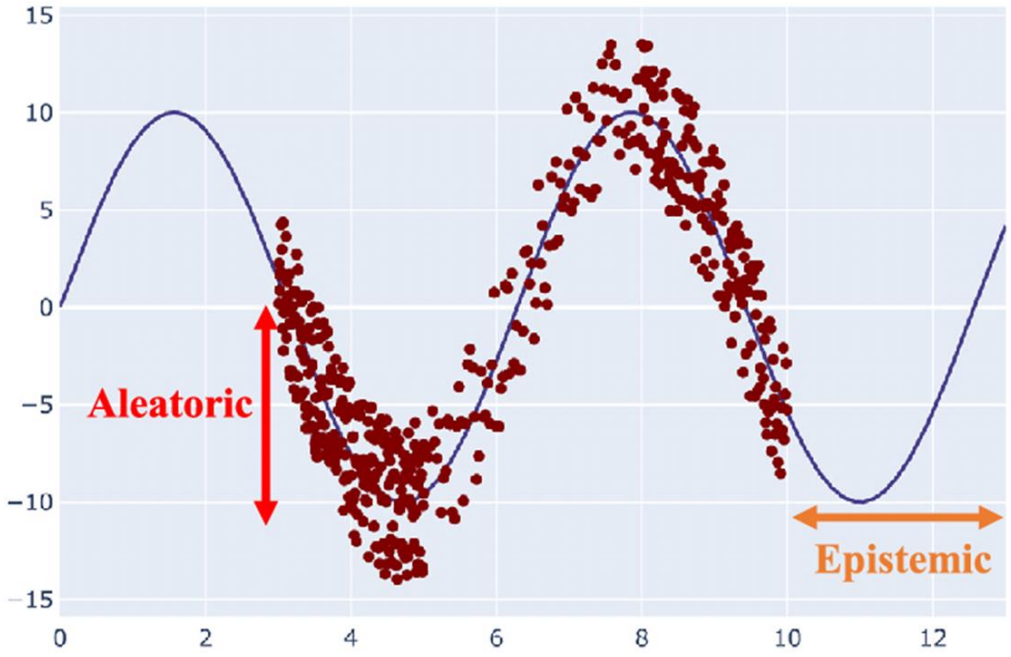
Sources of Uncertainty - *Classification*



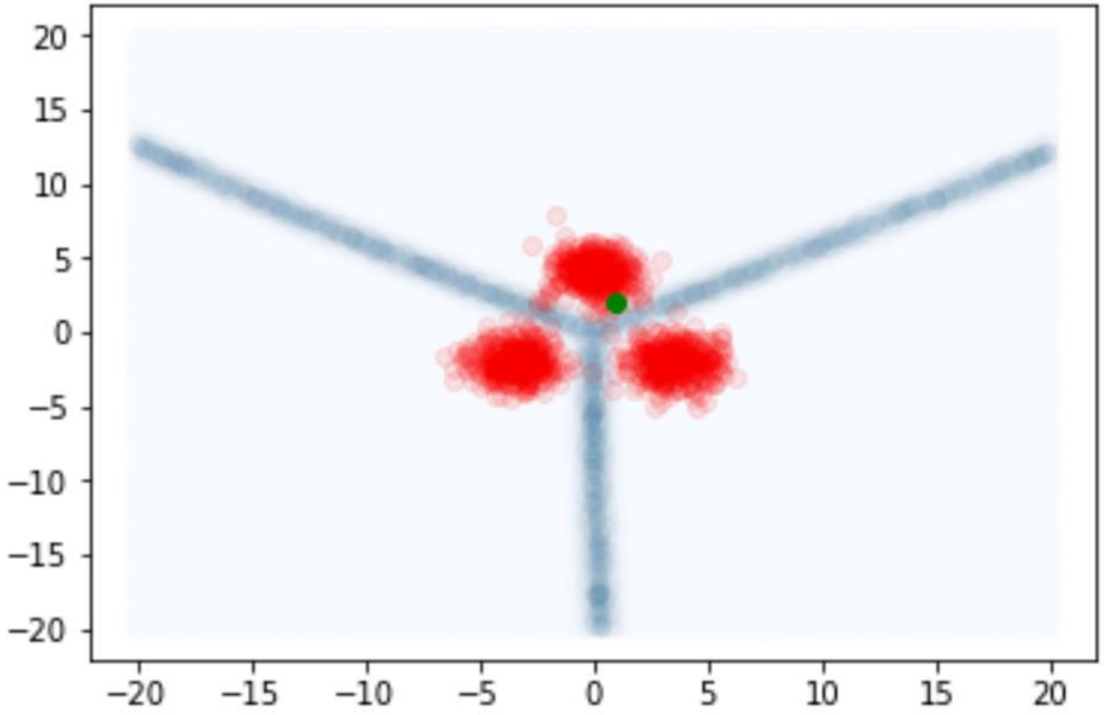
(a) Data Uncertainty (b) Knowledge Uncertainty (c) Knowledge Uncertainty

- Data Uncertainty $\rightarrow$ Aleatoric Uncertainty
- Knowledge Uncertainty $\rightarrow$ Epistemic Uncertainty

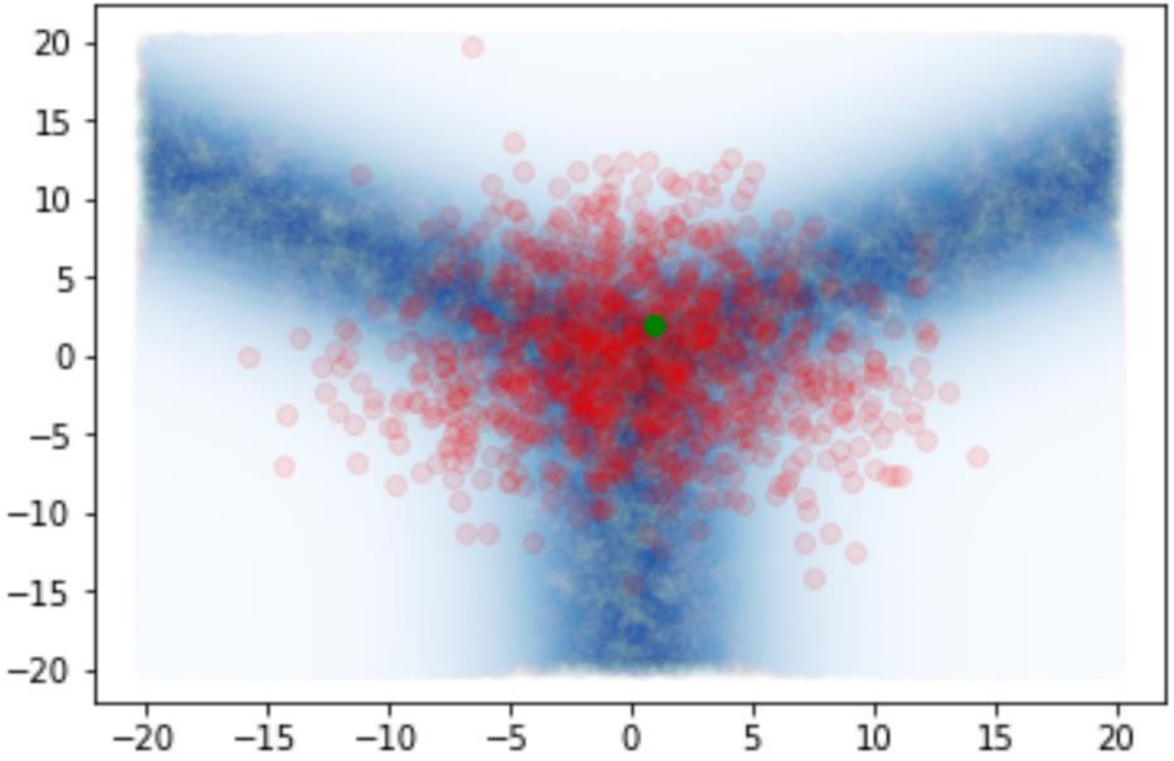
Sources of Uncertainty - *Regression*



Data (Aleatoric) Uncertainty - Classification

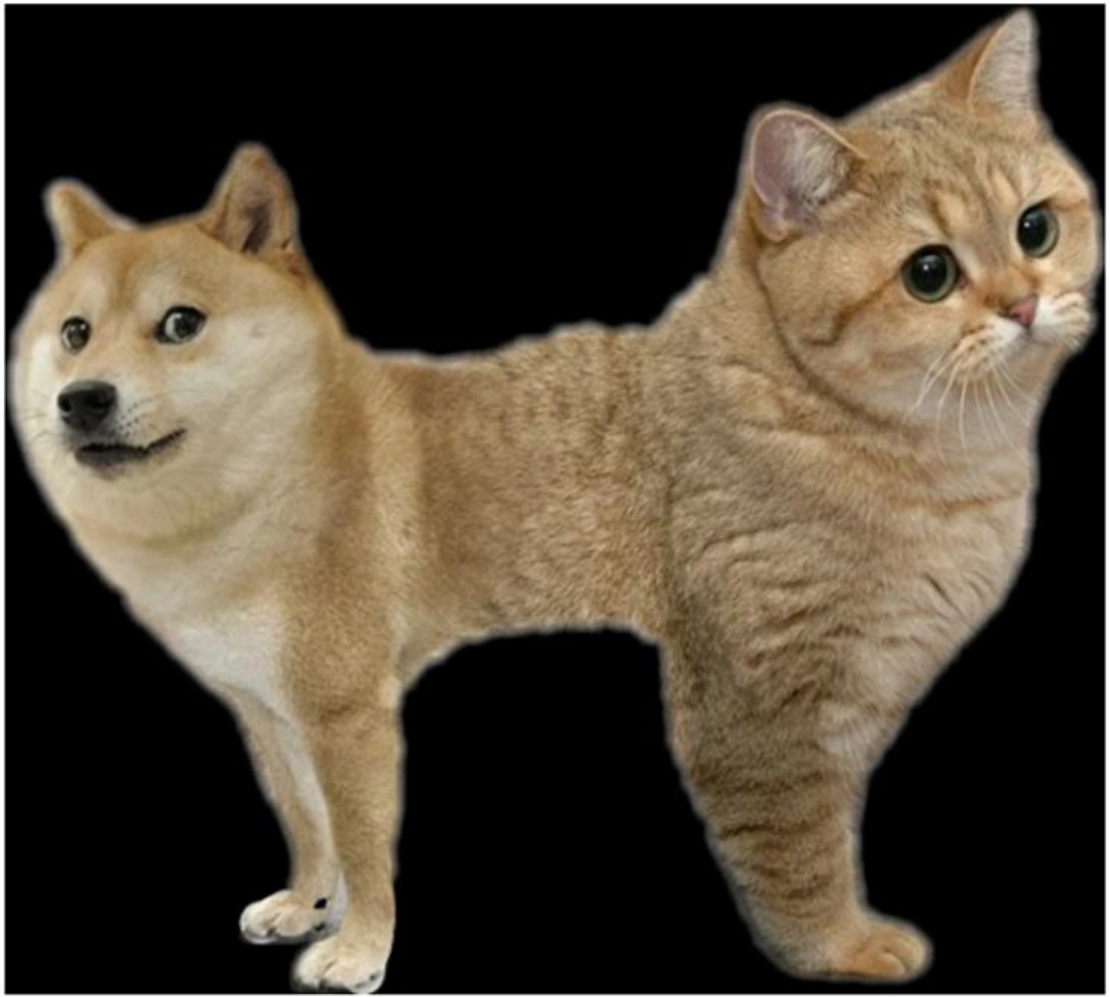


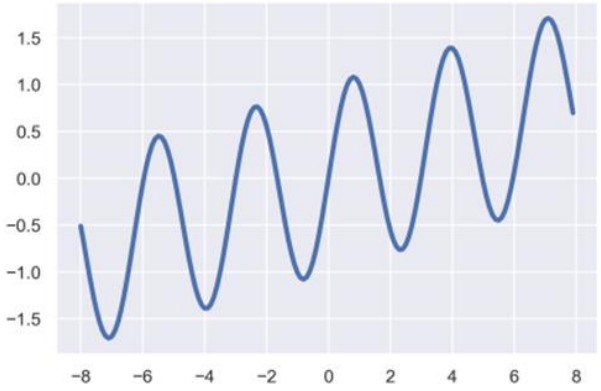
Data (Aleatoric) Uncertainty - Classification



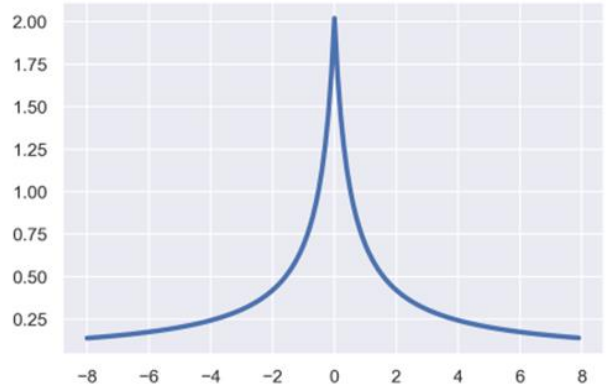
- Distinct Classes

- Overlapping Classes

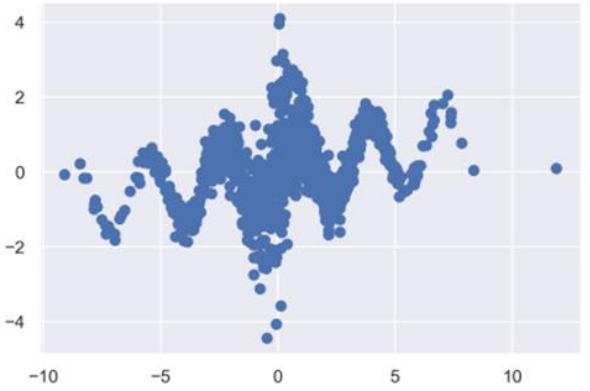




(a) Function $\mu(x) = \sin(2x) + \frac{x}{10}$



(b) Noise std $\sigma(x) = 0.02 + \frac{2}{|x^2|+1}$

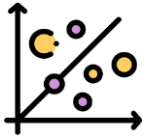


(c) Sampled Data $y \sim \mathrm{p}(\mu(x), \sigma(x)))$

- Data Uncertainty for Regression $\rightarrow$ additive noise $\sigma(\boldsymbol{x})$
  - Homoscedastic - input **independent** $\sigma(\boldsymbol{x}) = C$
  - Heteroscedastic - input dependant $\sigma(\boldsymbol{x}) = g(\boldsymbol{x})$

Example reasons for data uncertainty

Measurement Error



Data Noise

Temporal Uncertainty

Sampling Uncertainty

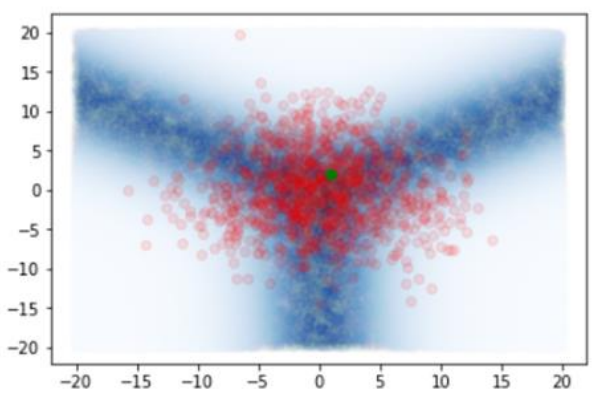
Bias in Data Collection

Inconsistent Data Formats

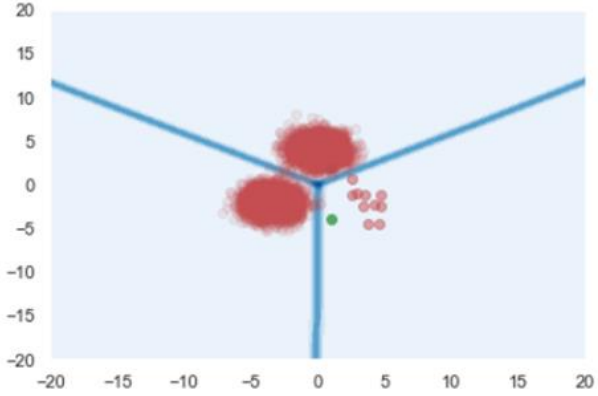
Missing Data

Ambiguity in Data Sources

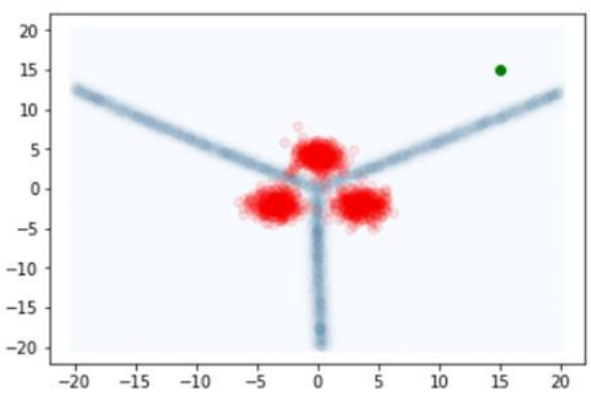
Sources of Uncertainty



(a) Data Uncertainty



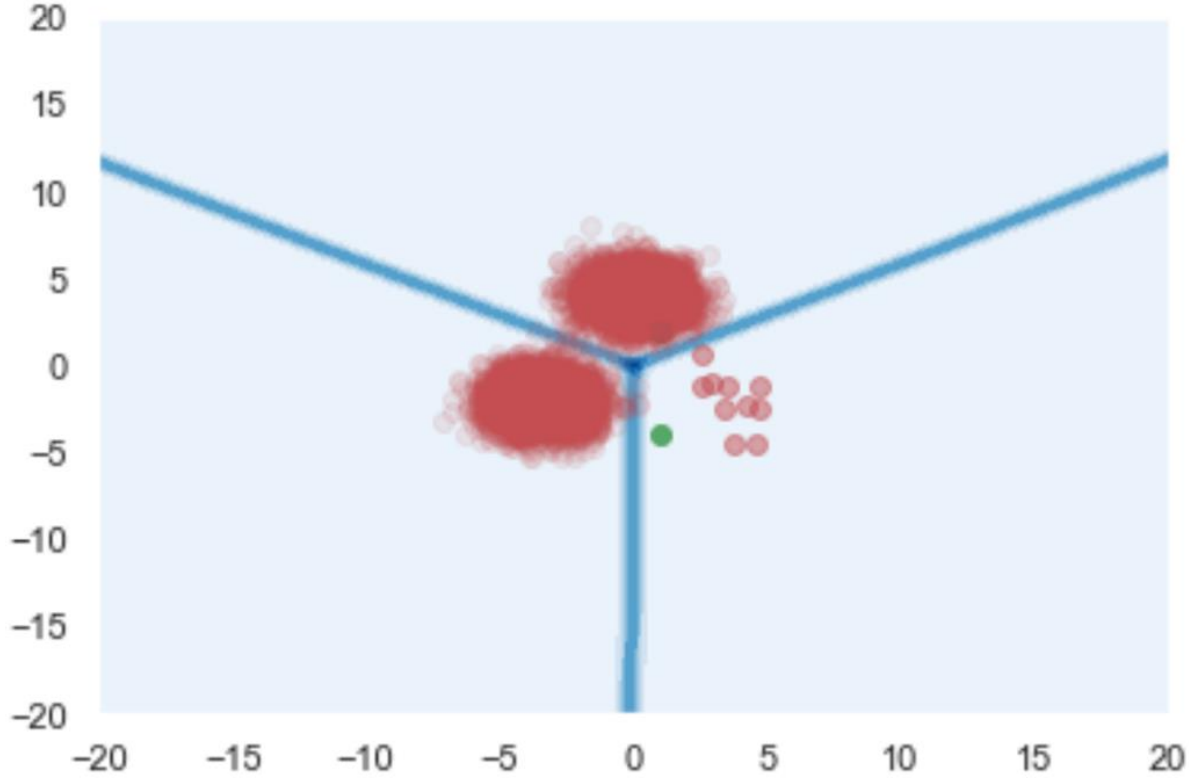
(b) Data Sparsity



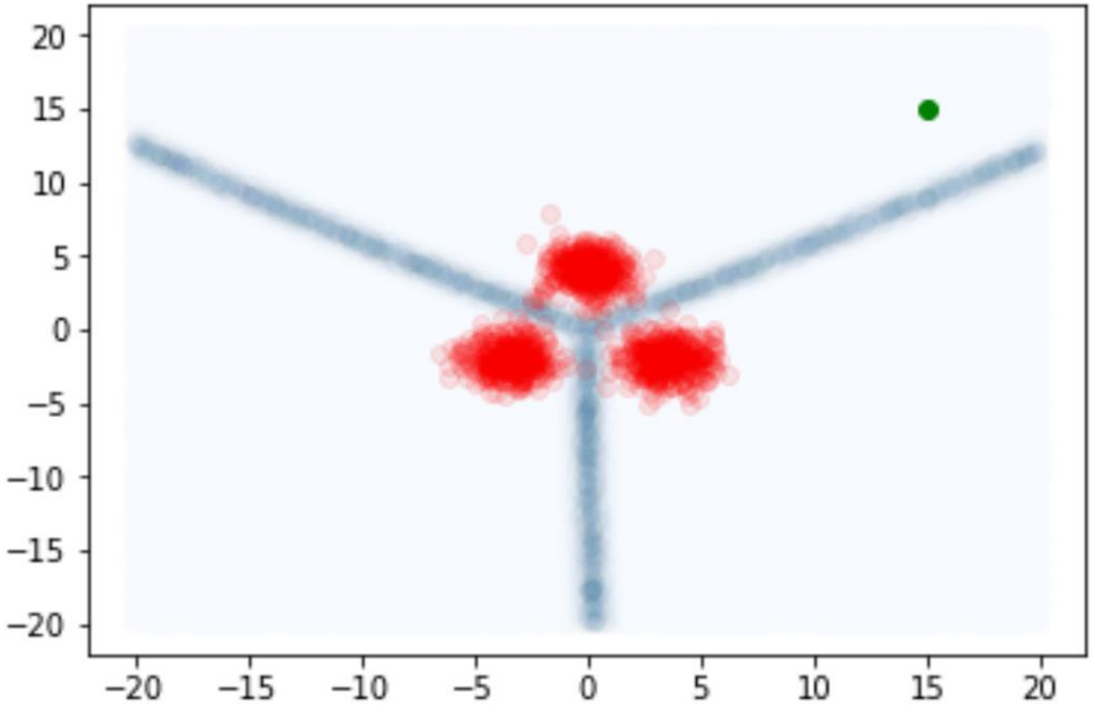
(c) Out-of-Distribution inputs

- Knowledge (epistemic) uncertainty refers to both:
  - Data Sparsity and Out-of-distribution inputs

Knowledge (Epistemic) Uncertainty - Classification

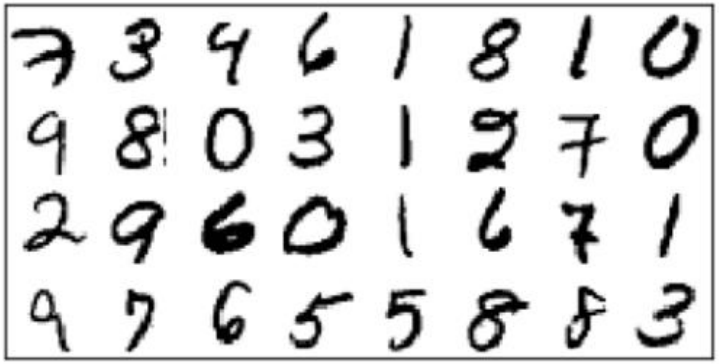


Knowledge (Epistemic) Uncertainty - Classification

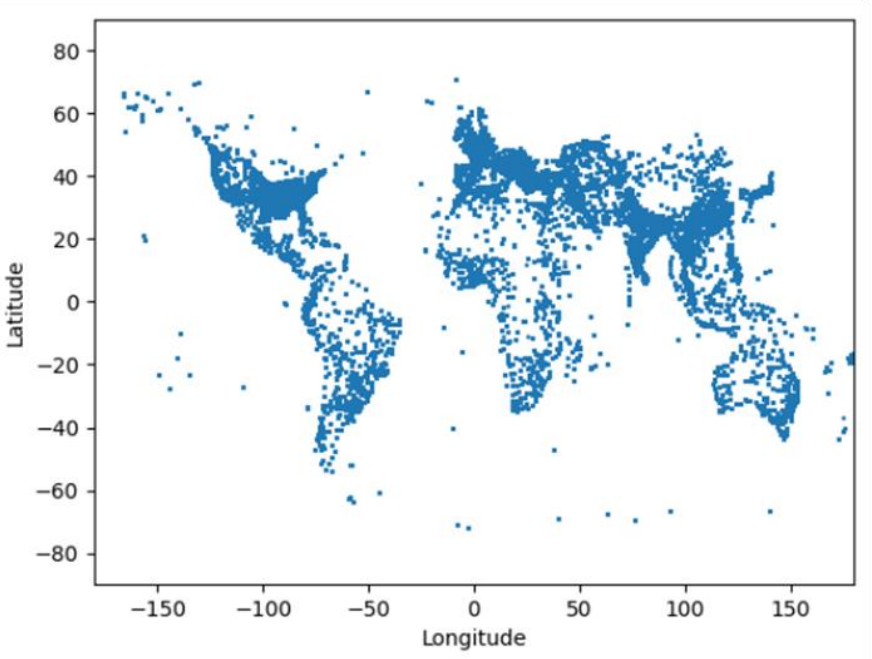


Data Sparsity + OOD is all
DOMAIN SHIFT

- Unseen classes



- Unseen variations of seen classes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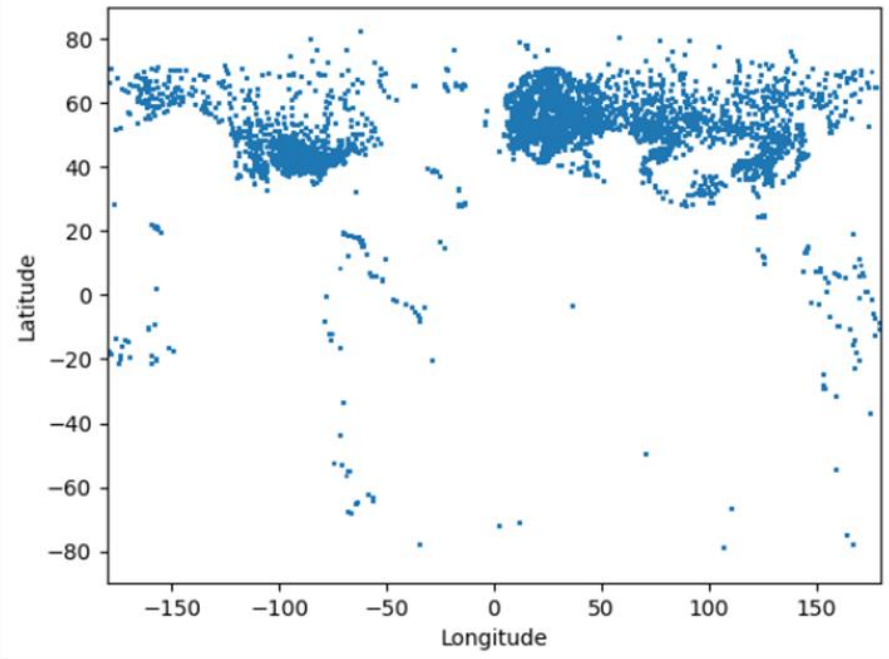
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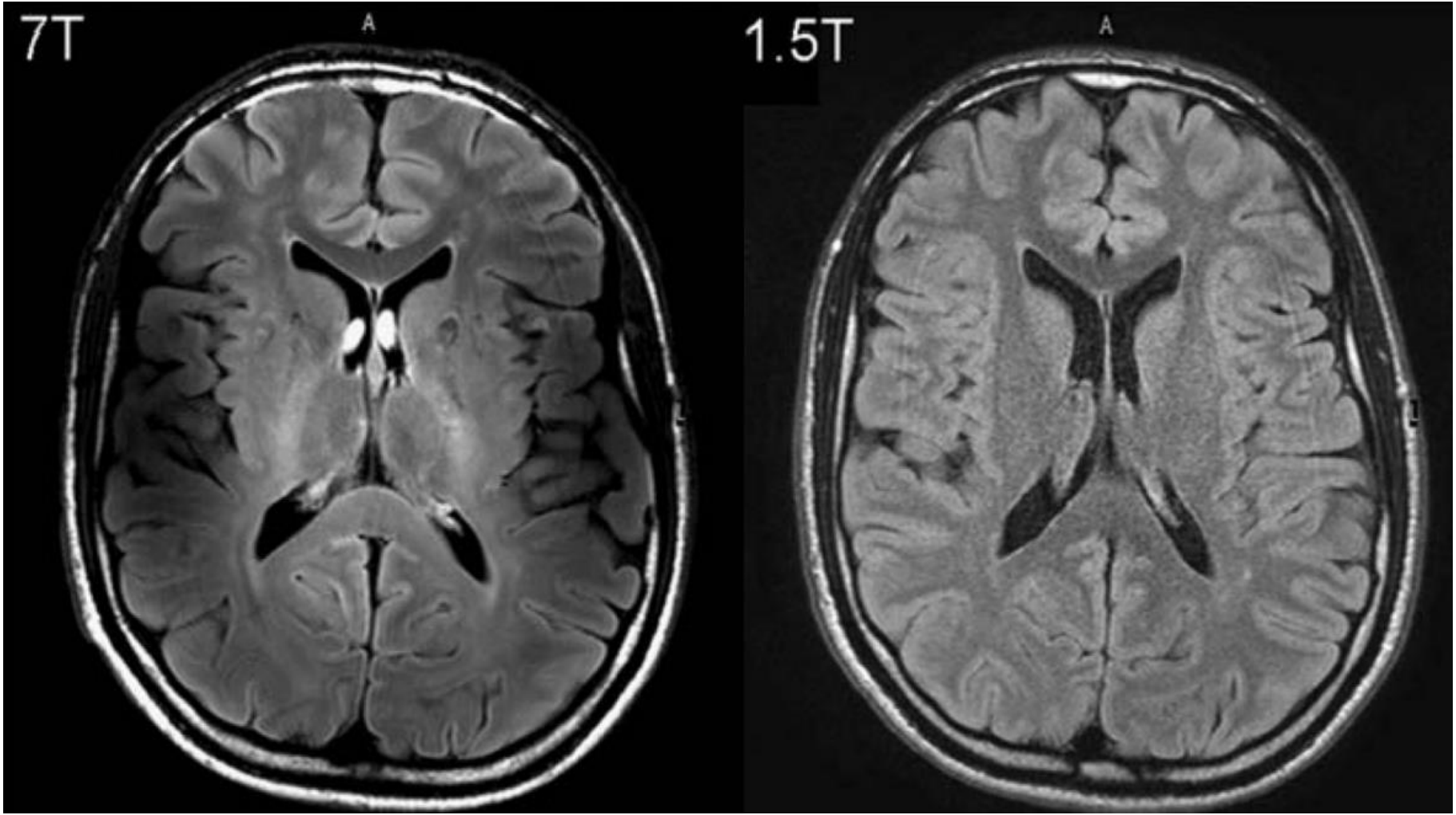
7T
A
1.5T
A

Formal definitions - *Bayesian framework*

$$\mathbf{X} = \{\mathbf{x}_1, \dots, \mathbf{x}_N\}$$

$$\mathbf{Y} = \{\mathbf{y}_1, \dots, \mathbf{y}_N\}$$

$$\underbrace{p(\mathbf{y}^*|\mathbf{x}^*, \mathbf{X}, \mathbf{Y})}_{\text{Interested in uncertainty of this distribution}} = \int \underbrace{p(\mathbf{y}^*|\mathbf{x}^*, \boldsymbol{\omega})}_{\text{Uncertainty of this distribution is DATA uncertainty}} \underbrace{p(\boldsymbol{\omega}|\mathbf{X}, \mathbf{Y})}_{\text{Uncertainty of this distribution is KNOWLEDGE uncertainty}} \mathrm{d}\boldsymbol{\omega}$$

Y. Gal, PhD thesis, 2016

Next

- The sources of uncertainty in medical imaging?
- Why is measuring uncertainty useful?
- How can we practically measure uncertainty?
- How to assess the quality of uncertainty quantification?

Q&A