What Uncertainties Do We Need in Bayesian Deep Learning for Computer Vision? Kendall & Gal

Bayesian Non Parametric & Bayesian ML Project

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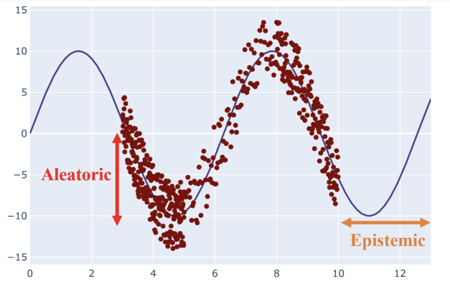
Main Concepts

Kendall & Gal (2017)
Aleatoric & epistemic uncertainties



Two types of uncertainty:

Aleatoric uncertainty: Captures noise inherent in the observations.

Epistemic uncertainty: Accounts for uncertainty in the model, which can be explained away with enough data.

Traditional methods

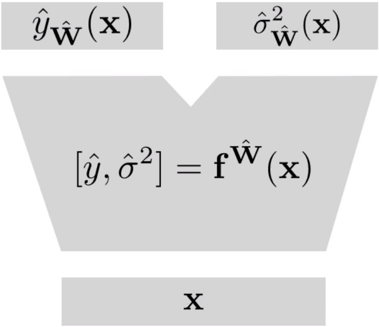
Capturing **Epistemic Uncertainty** using Bayesian Neural Networks with MC dropout:

$$\mathcal{L}_{\text{BNN}}(\theta, p) = -\frac{1}{N}\sum_{i=1}^{N} \log \mathbb{P}(y_i | f_{\hat{W}_i}(x_i)) + \frac{1-p}{2N}||\theta||^2$$

Capturing **Heteroscedastic Aleatoric Uncertainty** for regression:

$$\mathcal{L}_{\text{NN}}(\theta) = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{2\sigma(x_i)^2}\|y_i - f(x_i)\|^2 + \frac{1}{2}\log\sigma(x_i)^2\right)$$

Key Results



$$\hat{\mathbf{W}} \sim q(\mathbf{W})$$

$$\mathcal{L} = -\frac{1}{N}\sum_{i=1}^{N} \log \mathcal{N}(y_i; \hat{y}_{\hat{\mathbf{W}}}(\mathbf{x}), \hat{\sigma}^2_{\hat{\mathbf{W}}}(\mathbf{x}))$$

Aleatoric Uncertainty with Probabilistic Deep Learning

Modeling Aleatoric Uncertainty with Probabilistic Deep Learning

	Deep Learning	Probabilistic Deep Learning
Model	$[\hat{y}\,] = f(x)$	$[\hat{y}, \hat{\sigma}^2] = f(x)$
Regression	$Loss = \|y - \hat{y}\|^2$	$Loss = \frac{\|y - \hat{y}\|^2}{2\hat{\sigma}^2} + \log \hat{\sigma}^2$
Classification	$Loss = SoftmaxCrossEntropy(\hat{y}_t)$	$\hat{y}_t = \hat{y} + \epsilon_t \quad \epsilon_t \sim N(0, \hat{\sigma}^2)$ $Loss = \frac{1}{T}\sum_t SoftmaxCrossEntropy(\hat{y}_t)$

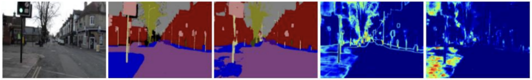
Experiments

Semantic Segmentation Performance on CamVid

CamVid Results	IoU Accuracy
DenseNet (State of the art baseline)	67.1
+ Aleatoric Uncertainty	67.4
+ Epistemic Uncertainty	67.2
+ Aleatoric & Epistemic	67.5

Monocular Depth Regression Performance

NYU Depth Results	Rel. Error
DenseNet (State of the art baseline)	0.167
+ Aleatoric Uncertainty	0.149
+ Epistemic Uncertainty	0.162
+ Aleatoric & Epistemic	0.145



(a) Input Image (b) Ground Truth (c) Semantic Segmentation (d) Aleatoric Uncertainty (e) Epistemic Uncertainty