UNCERT

PyTorch Based Implementation of Semi-Model-Based Reinforcement Learning with Uncertainty

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Motivation

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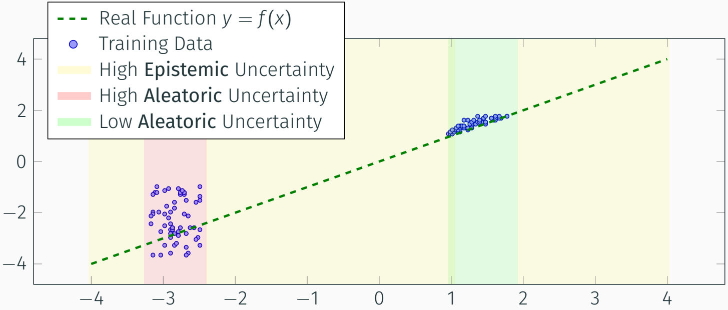
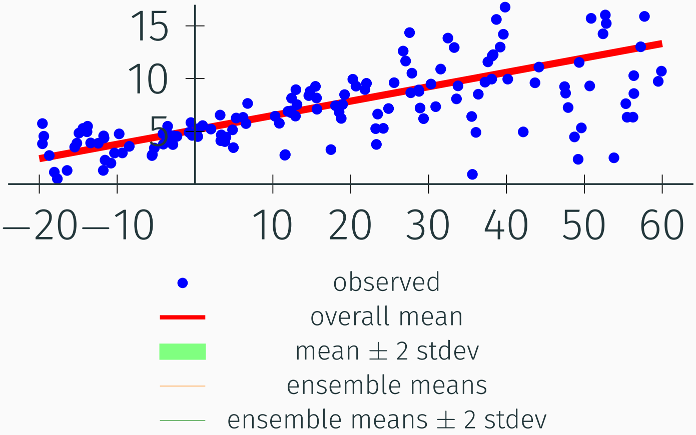


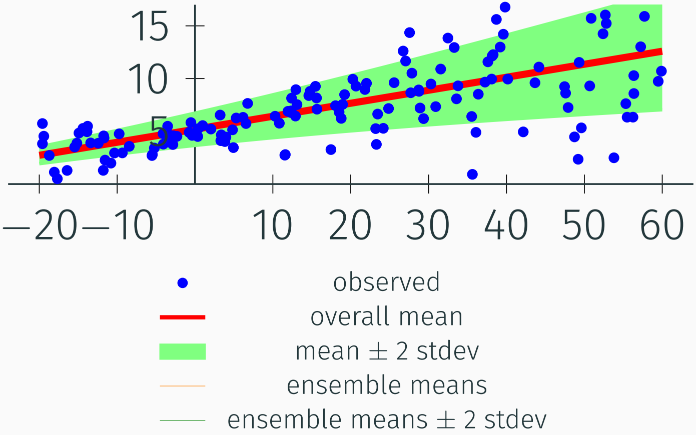
No Uncertainty (linear regression)

Mean captures the overall trend, but misses that y becomes more variable as x becomes larger.



Aleatoric Uncertainty

Standard deviation represents variation inherent to the underlying process. This uncertainty can not be reduced.



Convolutional Neural Network (CNN) vs. Bayesian Neural Network (BNN)

BNN has weights and biases that are probability distributions instead of single fixed values. These are updated during every output calculation.

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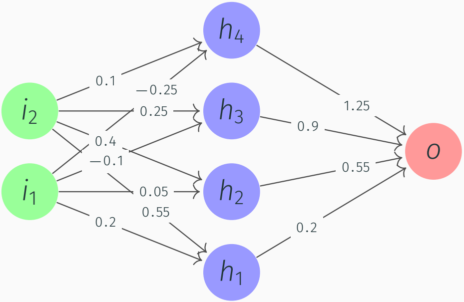
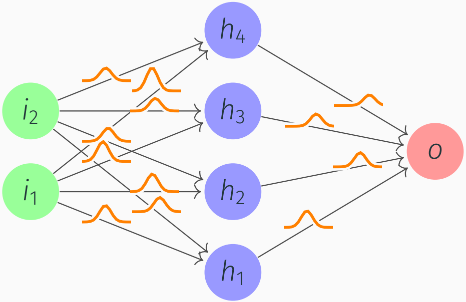
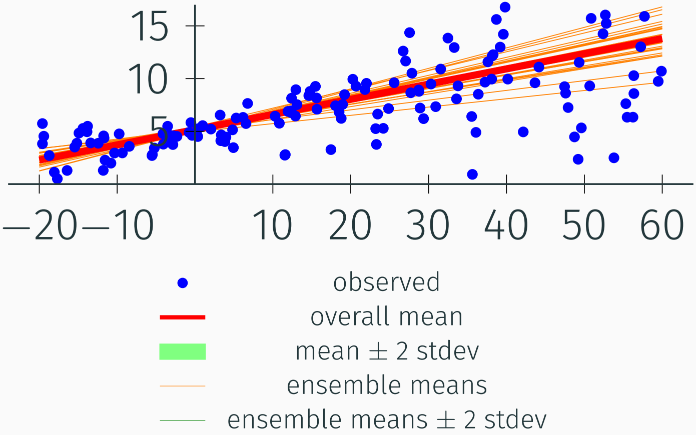
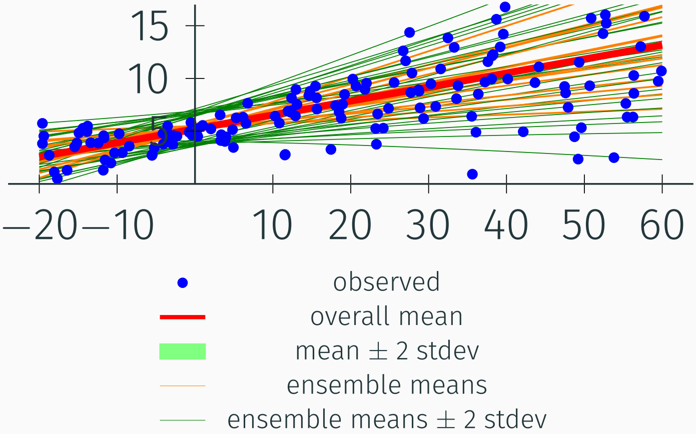




Each line represents a different random draw of the model parameters from the posterior distribution. Model is uncertain about the linear relationship.



This model correctly predicts more variability as towards the extremes of x.



Concept

Workflow

1. Sample data from noisy Cartpole Environment

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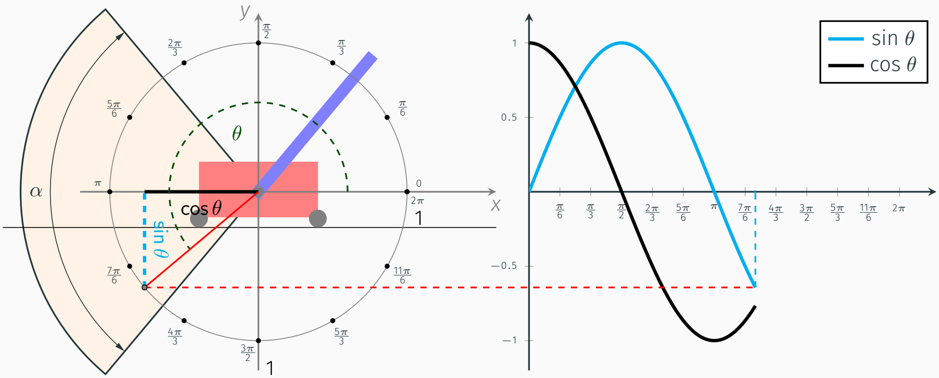
1. Sample data from noisy Cartpole Environment
2. Learn neural network for one-step dynamics
3. Train RL policy against dynamics model

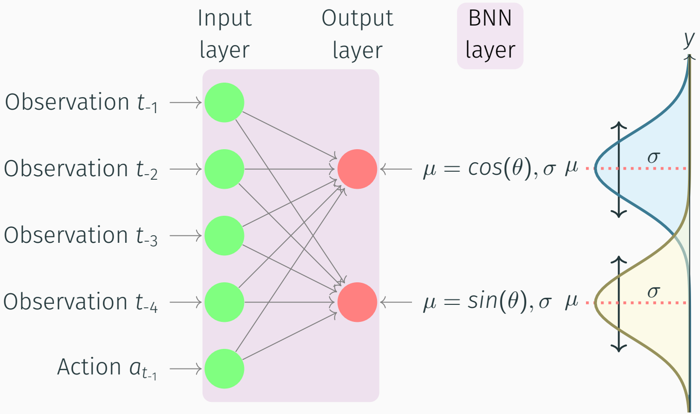
Data Sampling

CartPole superimposed with the unit circle.[1] α is the noisy section. The angle of the pole θ can be decomposed into sine and cosine. Action space is quantized.



[1] Actual environment has the circle turned 90° anti-clockwise.

Bayesian Neural Network Architecture



Observation includes x position of the cart, its velocity, the angle of the pendulum θ and its angular velocity. 21 input nodes (5 oberservation parameters $*$ 4 time steps $+$ 1 action $=$ 21) and two outputs. Action $a_{t_{-1}}$ will take the agent from observation t_{-1} to observation t_0.

Experiments & Results

Experiment Configuration

Table 1: Hyperparameter used to run the experiments.

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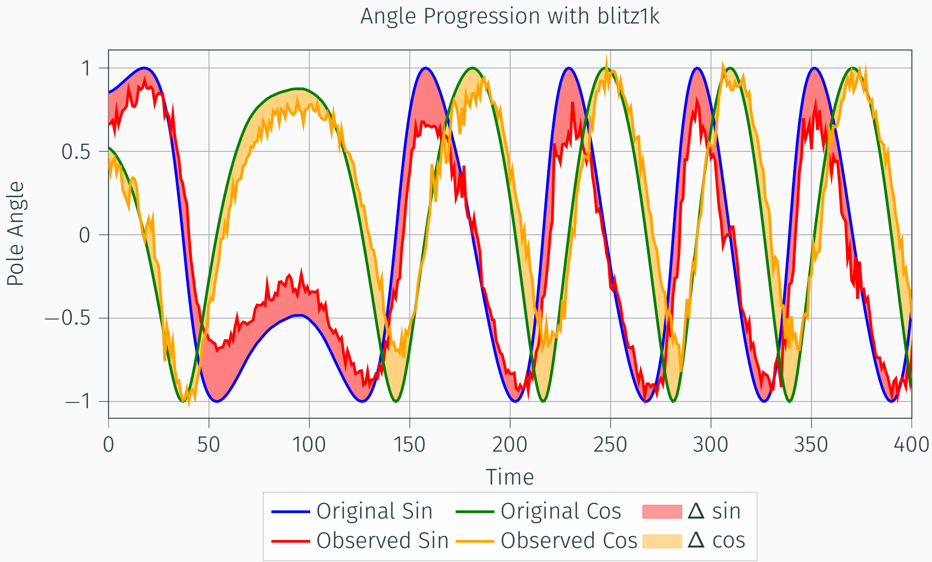
`RL algorithms`	PPO

Experiments & Results

Bayesian Neural Network.
Random actions.

BNN predictions: 1k time series, random actions



BNN predictions: 50k time series, random actions

Experiments & Results

Well-trained PPO agent.
50k time series training data.
75k time steps learning.

Video Demo Links

Without Uncertainty
https://youtu.be/Xuhp5B6EwWY

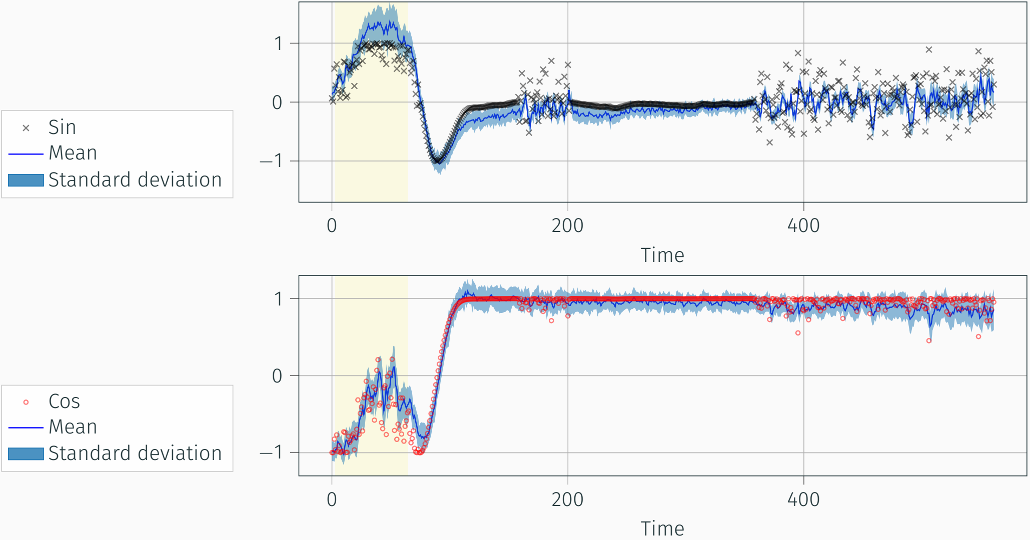
With Uncertainty
https://youtu.be/vAIEon3I5lw

Reward function

$$reward = \cos(\alpha) - \left(\sqrt{{\sigma_{sin}}^2 + {\sigma_{cos}}^2} * \epsilon\right)$$

```
reward = cosine - (math.sqrt(std_sin ** 2 + std_cos ** 2)*factor)
```

BNN Uncertainty: PPO 75k training steps



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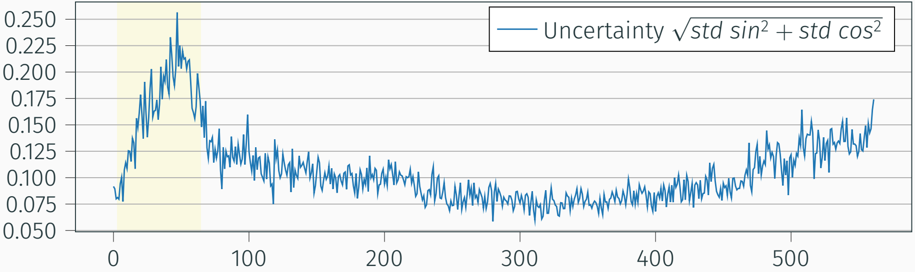

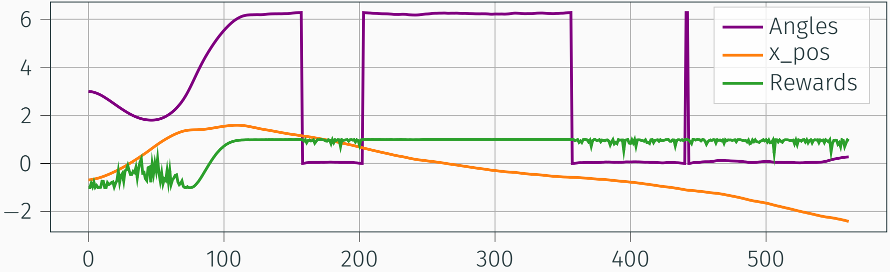

Implementation

> “Talk is cheap. Show me the code.”
>
> *Linus Torvalds*

Conclusion

Take Aways

1. RL agent detects noisy sector and avoids it

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2. RL agent is able to ”solve” the environment even with uncertainty

Take Aways

1. RL agent detects noisy sector and avoids it
2. RL agent is able to "solve" the environment even with uncertainty
3. Use PyTorch ;-)

Questions?[2]

[2] Source code, presentation and an exhaustive report are at github.com/github-throwaway/ARL-Model-RL-Unsicherheit

References

P. Sountsov, C. Suter, J. Burnim and J. V. Dillon. *Regression with Probabilistic Layers in TensorFlow Probability — The TensorFlow Blog*. 12th Mar. 2019. URL: `https://blog.tensorflow.org/2019/03/regression-with-probabilistic-layers-in.html` (visited on 2nd Sept. 2021).

A. Raffin, A. Hill, M. Ernestus, A. Gleave, A. Kanervisto and N. Dormann. *Stable Baselines3*. `https://github.com/DLR-RM/stable-baselines3`. 2019.

Â. Lovatto. *angelolovatto/gym-cartpole-swingup: A simple, continuous-control environment for OpenAI Gym*. 7th July 2019. URL: https://github.com/angelolovatto/gym-cartpole-swingup (visited on 2nd Sept. 2021).

G. Brockman, V. Cheung, L. Pettersson, J. Schneider, J. Schulman, J. Tang and W. Zaremba. 'OpenAI Gym'. In: (2016). eprint: arXiv:1606.01540. URL: https://gym.openai.com/.

C. Blundell, J. Cornebise, K. Kavukcuoglu and D. Wierstra. *Weight Uncertainty in Neural Networks*. 2015. arXiv: 1505.05424 [stat.ML].

A. Paszke, S. Gross, F. Massa, A. Lerer, J. Bradbury, G. Chanan, T. Killeen, Z. Lin, N. Gimelshein, L. Antiga, A. Desmaison, A. Kopf, E. Yang, Z. DeVito, M. Raison, A. Tejani, S. Chilamkurthy, B. Steiner, L. Fang, J. Bai and S. Chintala. 'PyTorch: An Imperative Style, High-Performance Deep Learning Library'. In: *Advances in Neural Information Processing Systems 32*. Ed. by H. Wallach, H. Larochelle, A. Beygelzimer, F. d'Alché-Buc, E. Fox and R. Garnett. Curran Associates, Inc., 2019, pp. 8024–8035. URL: `http://papers.neurips.cc/paper/9015-pytorch-an-imperative-style-high-performance-deep-learning-library.pdf`.

Backup Slides

Backup Slides

BLiTZ Implementation

Creating a variational regressor class

```python
@variational_estimator
class BayesianRegressor(nn.Module):
    def __init__(self, input_dim, output_dim):
        super().__init__()
        self.blinear = BayesianLinear(input_dim, output_dim)

    def forward(self, x):
        return self.blinear(x)
```

Defining a confidence interval evaluating function

```python
def evaluate_regression(regressor, x, y, samples=25, std_multiplier=2):
    preds = [regressor(x) for i in range(samples)]
    preds = torch.stack(preds)
    means = preds.mean(axis=0)
    stds = preds.std(axis=0)
    ci_upper = means + (std_multiplier * stds)
    ci_lower = means - (std_multiplier * stds)
    ic_acc = (ci_lower <= y) * (ci_upper >= y)
    ic_acc = ic_acc.float().mean()
    return ic_acc, (ci_upper >= y).float().mean(), (ci_lower <= y).float().mean()
```

Creating our regressor and loading data

```
optimizer = optim.Adam(regressor.parameters(), lr=0.01)
criterion = torch.nn.MSELoss()
complexity_cost_weight = 1. / x_train.shape[0]
```

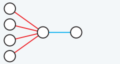
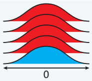
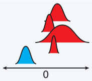
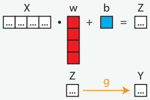
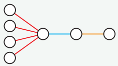
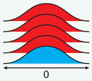
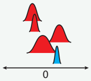
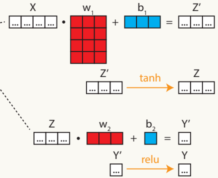
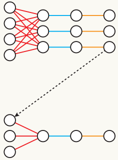
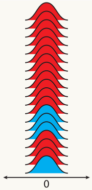
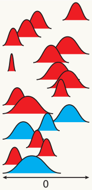
Main training and evaluating loop

```
losses = []
for epoch in tqdm(range(100)):
    new_epoch = True
    for i, (datapoints, labels) in enumerate(dataloader_train):
        optimizer.zero_grad()

        loss = regressor.sample_elbo(
            inputs=datapoints,
            labels=labels,
            criterion=criterion,
            sample_nbr=3,
            complexity_cost_weight=complexity_cost_weight
        )

        loss.backward()
        optimizer.step()
```

Backup Slides

Cheatsheet

Cheatsheet[3]

	function	matrices	computational graph		priors	posteriors
linear regression	$Y = f(X, w_1, b_1)$ $f(x, w, b) = x \cdot w + b$			$w_{1,i} \sim N(0, 100)$ $b_1 \sim N(0, 100)$		
logistic regression (classification)	$Z = f(X, w_1, b_1)$ $Y = g(Z)$ $g(x) = \frac{1}{1 + e^{-x}}$			$w_{1,i} \sim N(0, 100)$ $b_1 \sim N(0, 100)$		
deep net regressor	$Z = \tanh(f(X, w_1, b_1))$ $Y = \mathrm{ReLu}(f(Z, w_2, b_2))$ $\mathrm{ReLu}(x) = \max(x, 0)$ $\tanh x = \frac{e^{2x} - 1}{e^{2x} + 1}$			$w_{1,i} \sim N(0, 1)$ $b_{1,i} \sim N(0, 1)$ $w_{2,i} \sim N(0, 1)$ $b_{2,i} \sim N(0, 1)$		

[3] https://github.com/ericmjl/bayesian-deep-learning-demystified

Backup Slides

Distributions

Probability distributions entangled by Bayes' rule

$$P(\mathbf{w} \mid \mathcal{D}) = \frac{P(\mathcal{D} \mid \mathbf{w})P(\mathbf{w})}{P(\mathcal{D})} \quad \text{where } \mathcal{D} = (x_i, y_i)$$