Advanced Section: Variational Inference

CS109B Data Science 2

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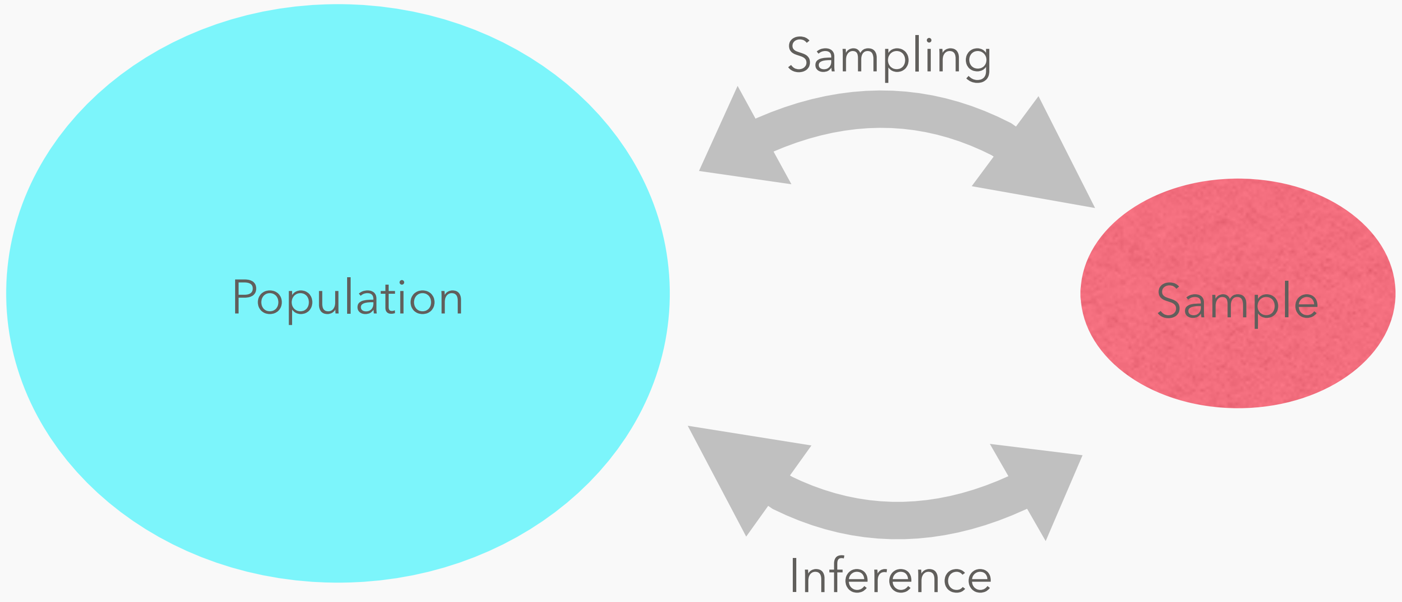
Statistical Inference

Draw conclusions about an underlying distribution of probabilities from a sample



Outline

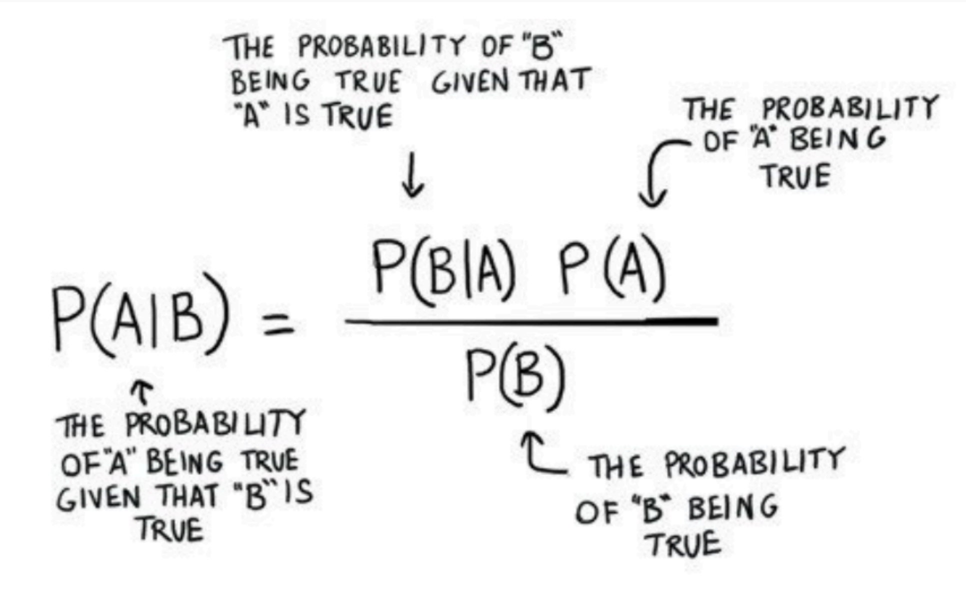
1. Bayesian Inference
2. Markov Chain Monte Carlo
3. Bayesian Neural Networks
4. Variational Inference
5. Drop Out as a Bayesian Approximation
6. Bootstrap for Inference

Bayesian Inference

Probability as a measure of *believability in an event*

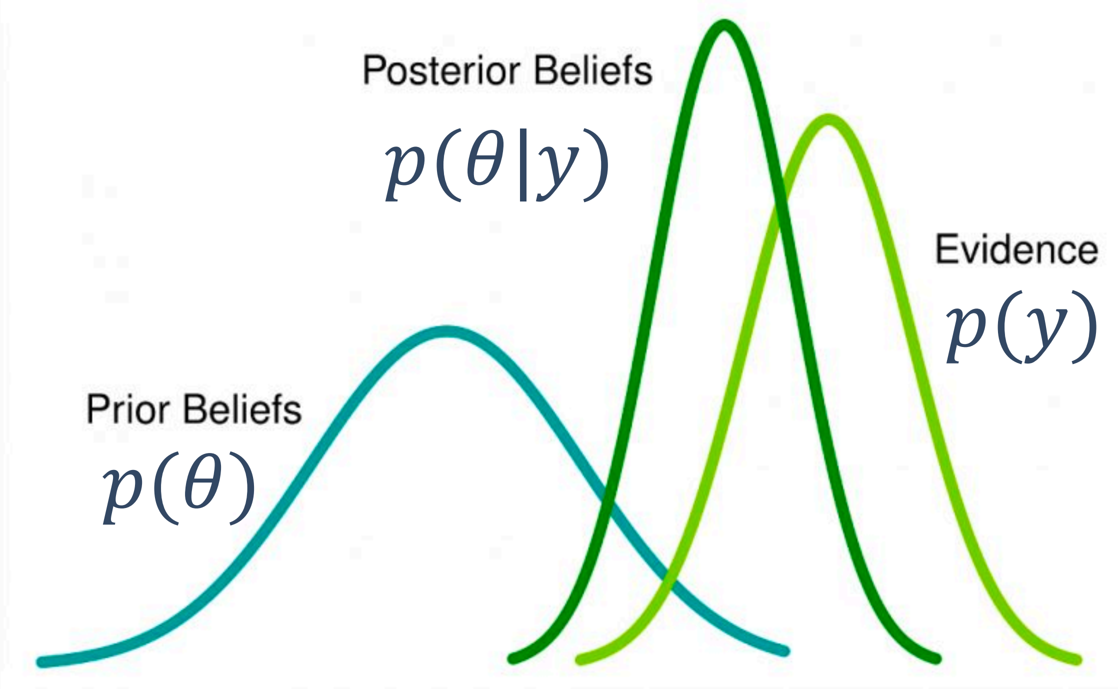
$$p(\theta|y) \propto p(y|\theta)p(\theta)$$

Model   Data



Bayesian Inference

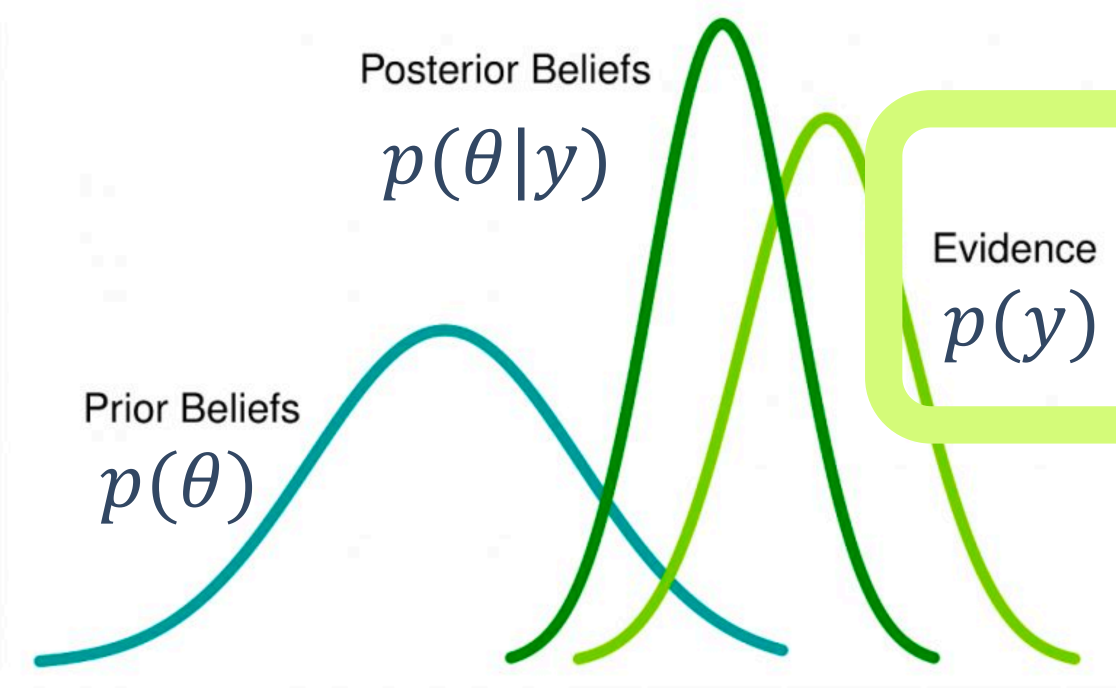
$$\boxed{p(\theta|y) \propto p(y|\theta)p(\theta)}$$



"When the facts change, I change my mind. What do you do, sir? "John Maynard Keynes

Bayesian Inference

$$p(\theta|y) \propto p(y|\theta)p(\theta)$$



$p(\theta|y)$

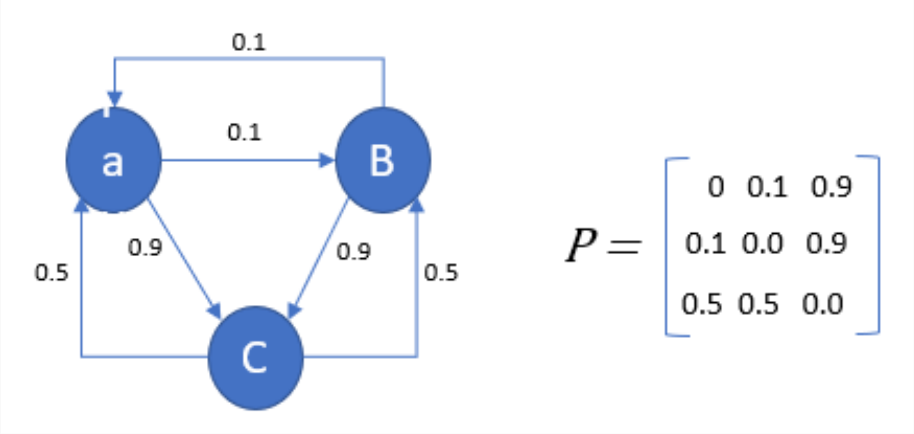
$p(\theta)$

Intractable

$$p(y) = \int_\theta p(y|\theta)p(\theta)d\theta$$

"When the facts change, I change my mind. What do you do, sir? "John Maynard Keynes

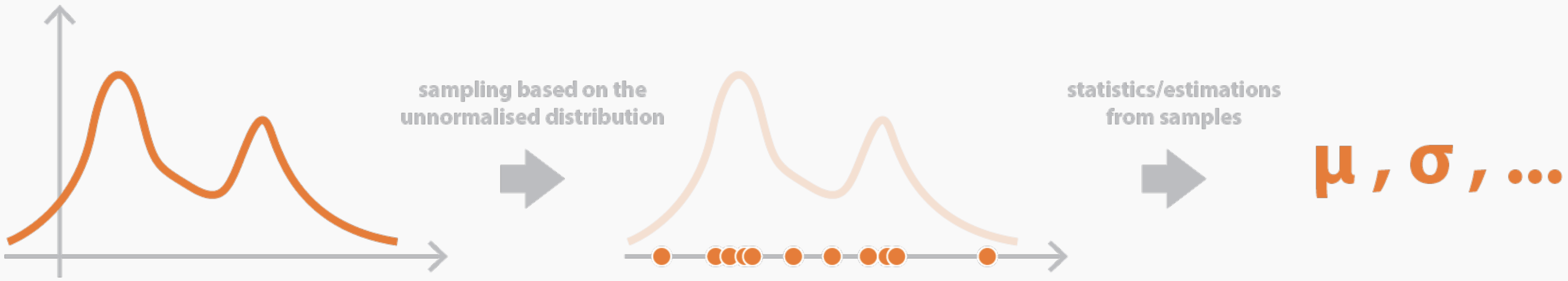
MCMC: Markov Chains



$$p(z^{(m+1)}|z^{(1)},\ldots,z^{(m)}) = p(z^{(m+1)}|z^{(m)})$$

$$p(z^{(m+1)}) = \sum_{z^{(m)}} p(z^{(m+1)}|z^{(m)})p(z^{(m)})$$

MCMC: Sampling method



Unnormalised distribution
whose normalisation factor
computation is intractable

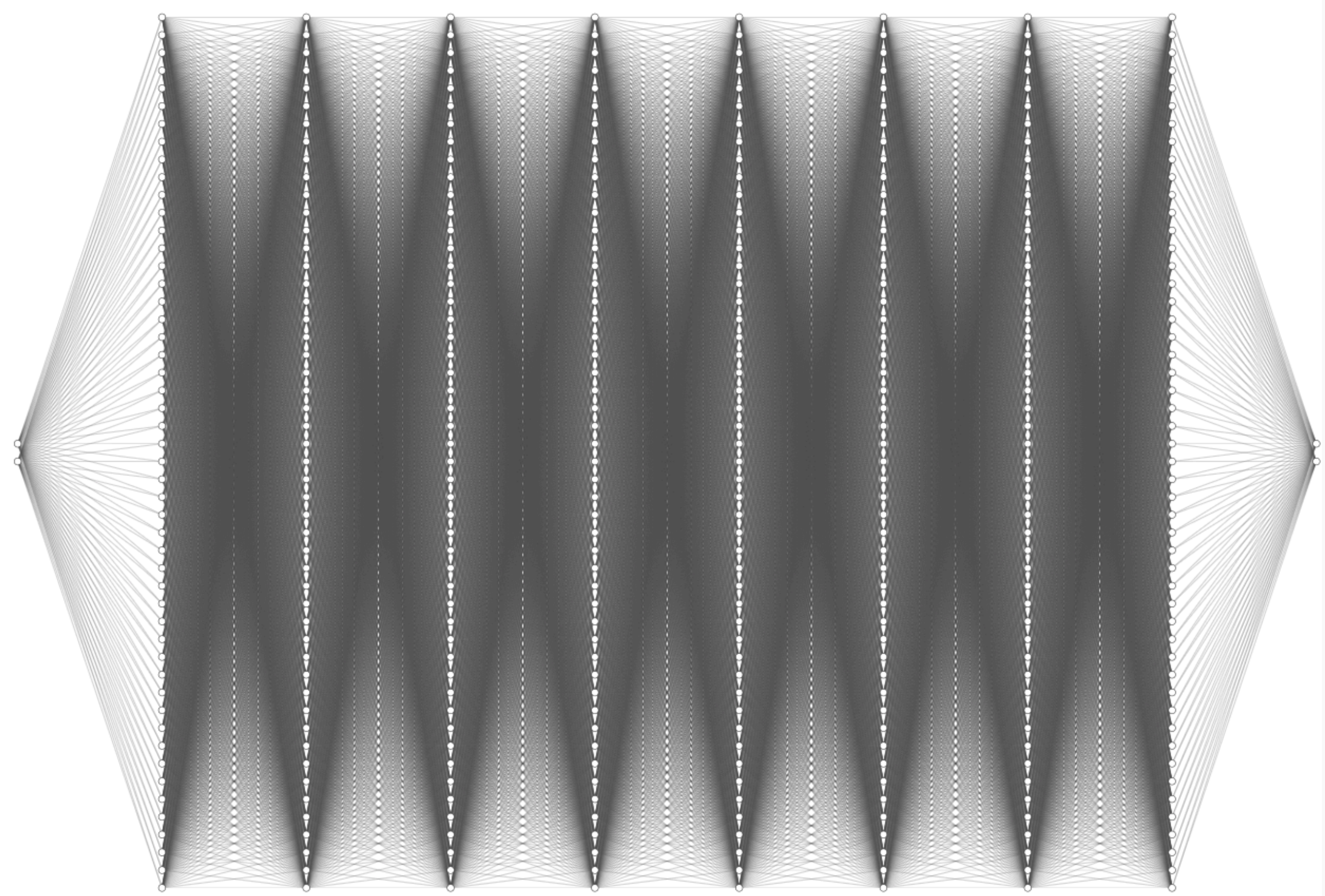
Samples
that can be obtained with MCMC and
without proceeding to the normalisation

Statistics or estimations
that can be computed based on
the generated samples

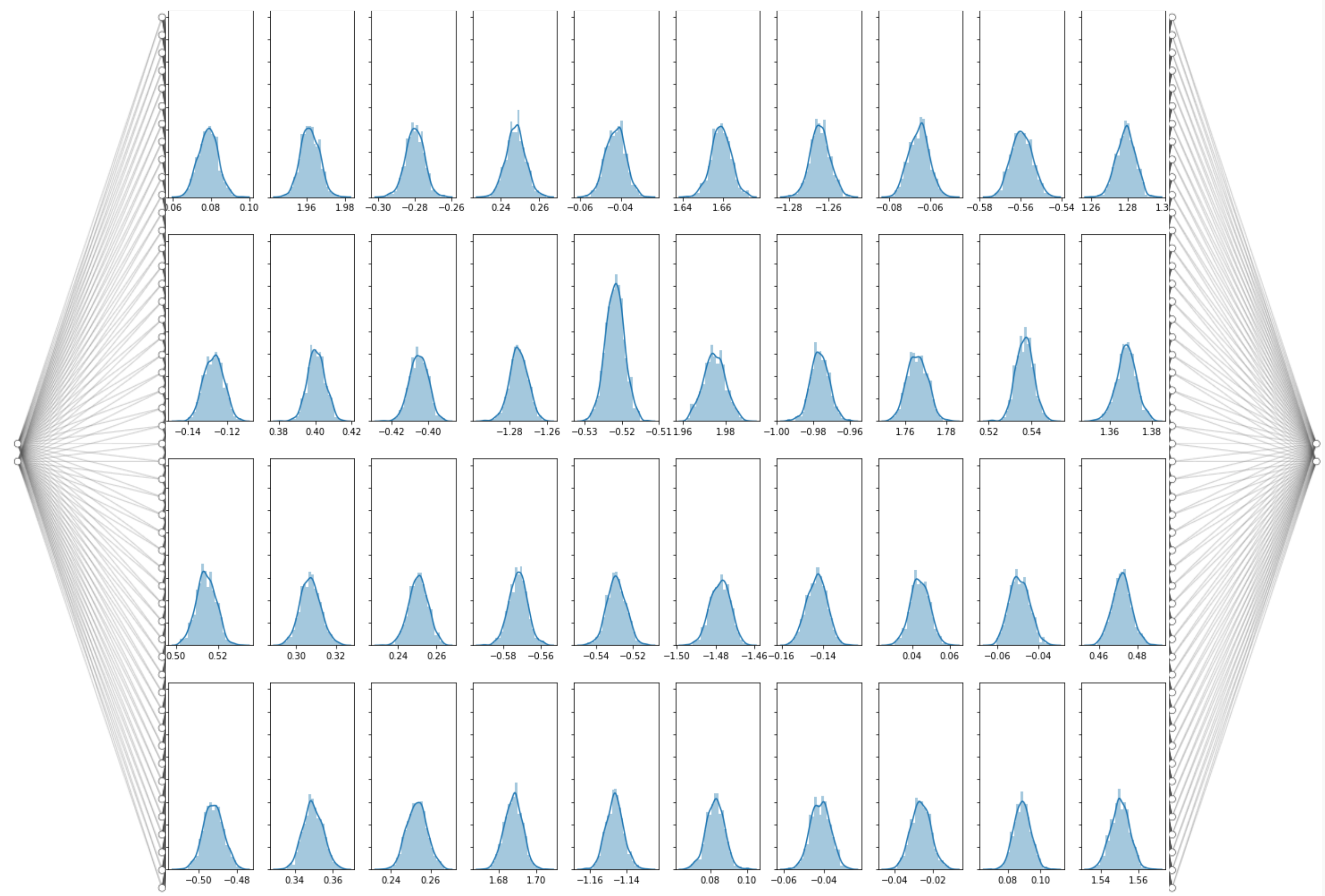
MCMC

Credit: Towards Data Science

Bayesian Neural Networks: FCNN

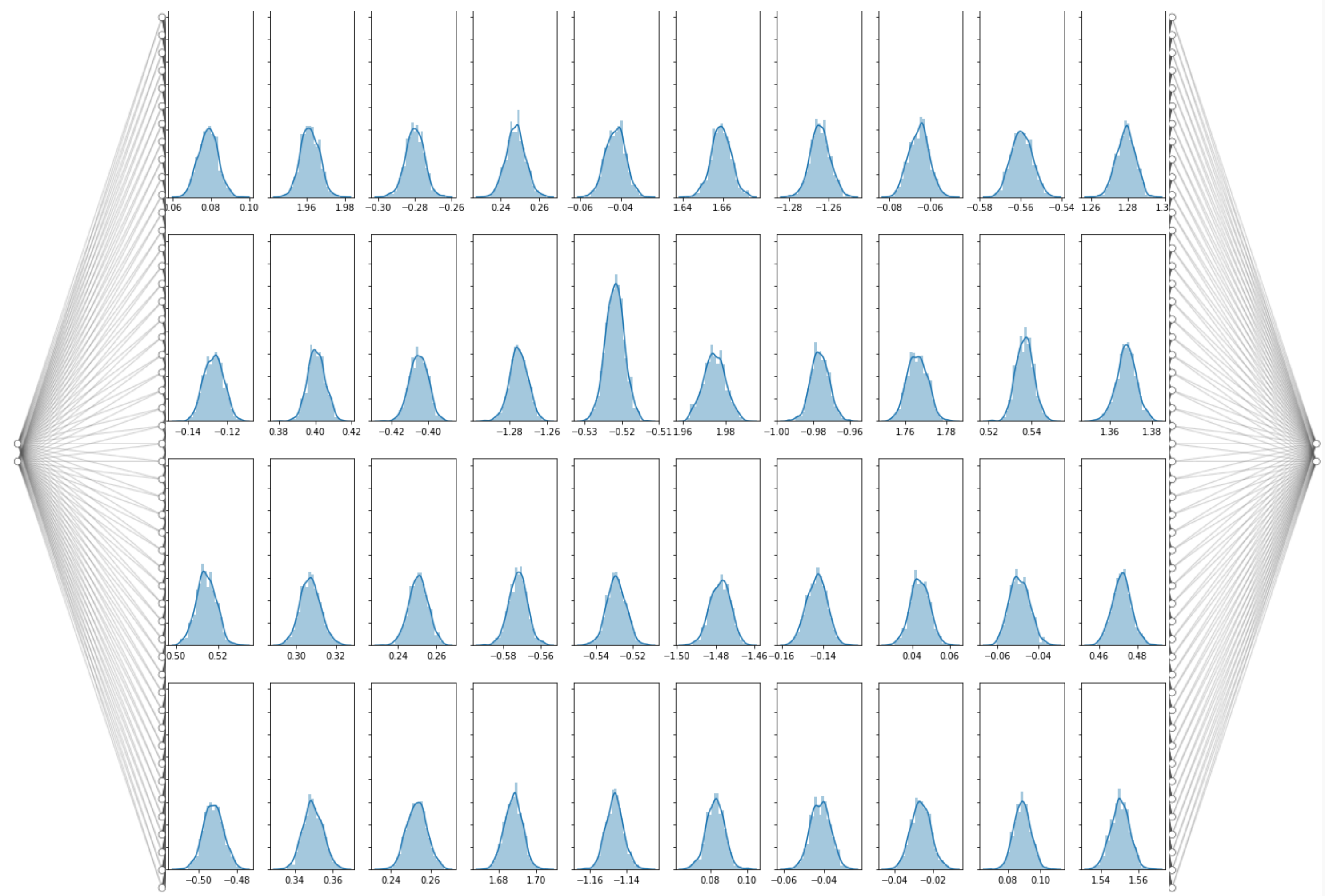
Input →  → Output

Bayesian Neural Networks: FCNN

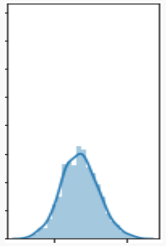
Input →  → Output

Bayesian Neural Networks

Input



Output



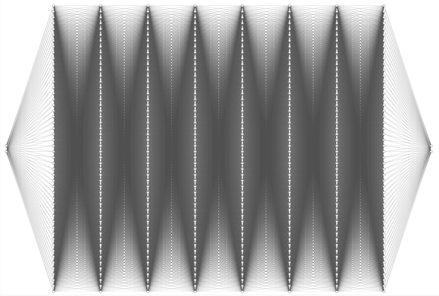
Bayesian Neural Networks

Priors

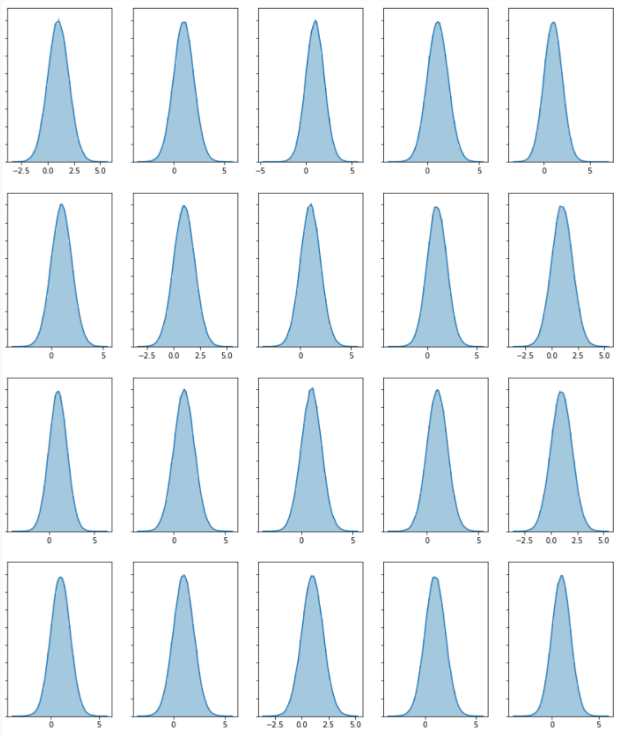
$$p(\theta) \quad \times \quad p(y|\theta) \quad \propto \quad p(\theta|y)$$

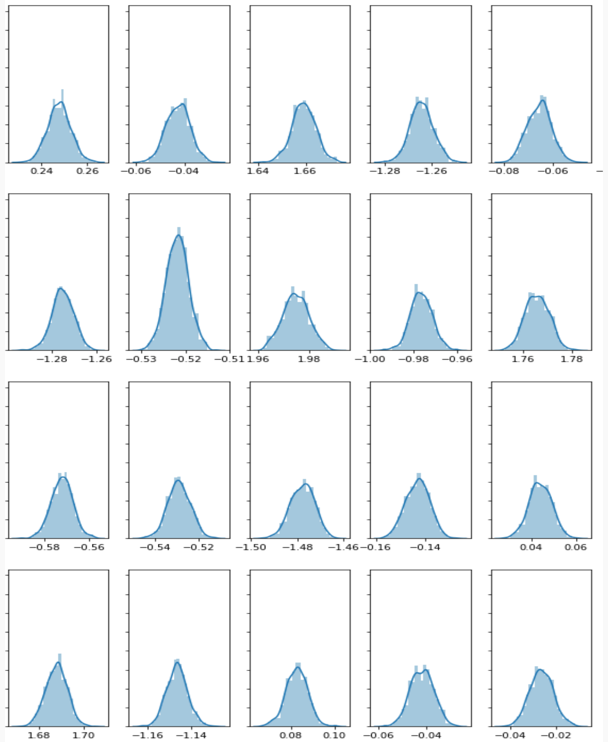
Means

FCNN



& Scale





Bayesian Neural Networks

$$p(\theta) \quad \times \quad p(y|\theta) \quad \propto \quad p(\theta|y)$$

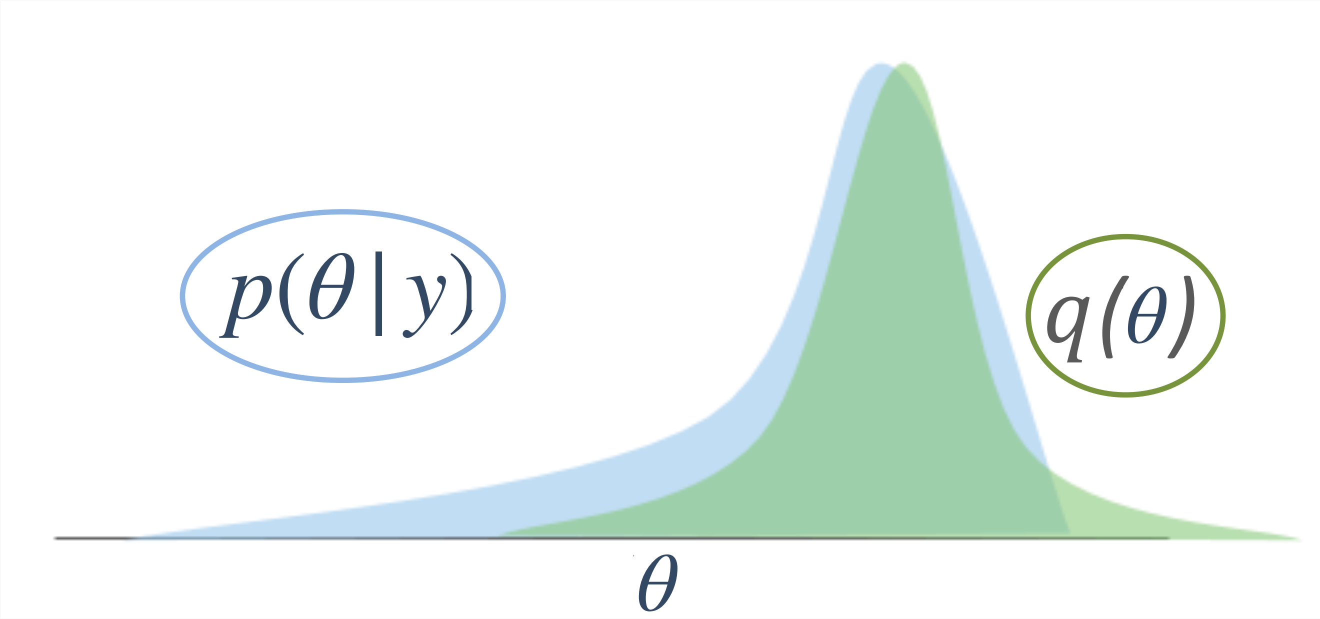
MCMC is eventually accurate, but not scalable to large models

Approximate Bayesian Inference: Variational Inference

Variational Inference

Optimization approach -> Q a family of “nice” distributions

$$p(\theta | y) = \frac{p(y | \theta)\, p(\theta)}{\int p(y, \theta) d\theta}$$



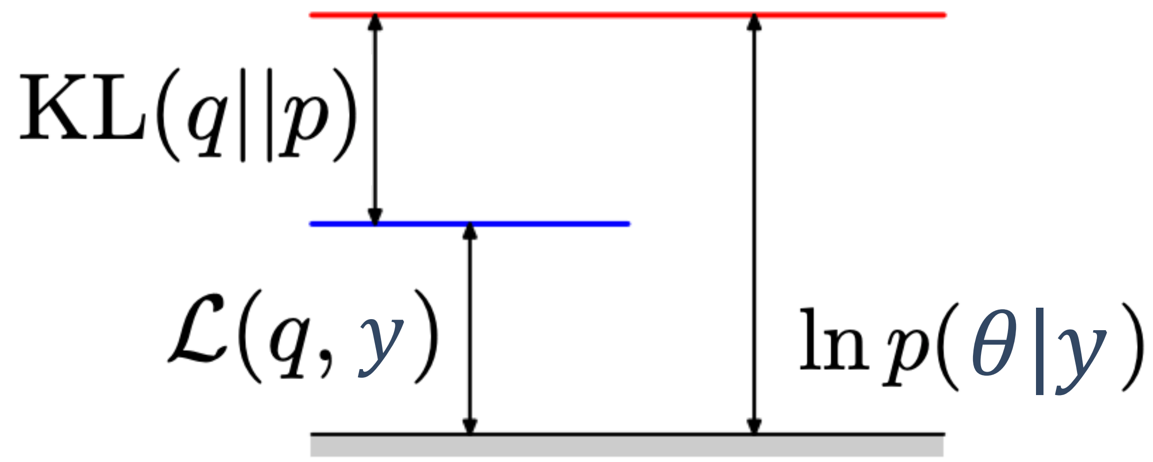
Variational Inference

$$p(\theta|y) = \frac{p(y|\theta)p(\theta)}{\int p(y,\theta)d\theta}$$

Kullback-Leibler divergence:

$$p(\theta|y) \approx q* = argmin_{q\in Q} f(q(\theta), p(\theta|y))$$

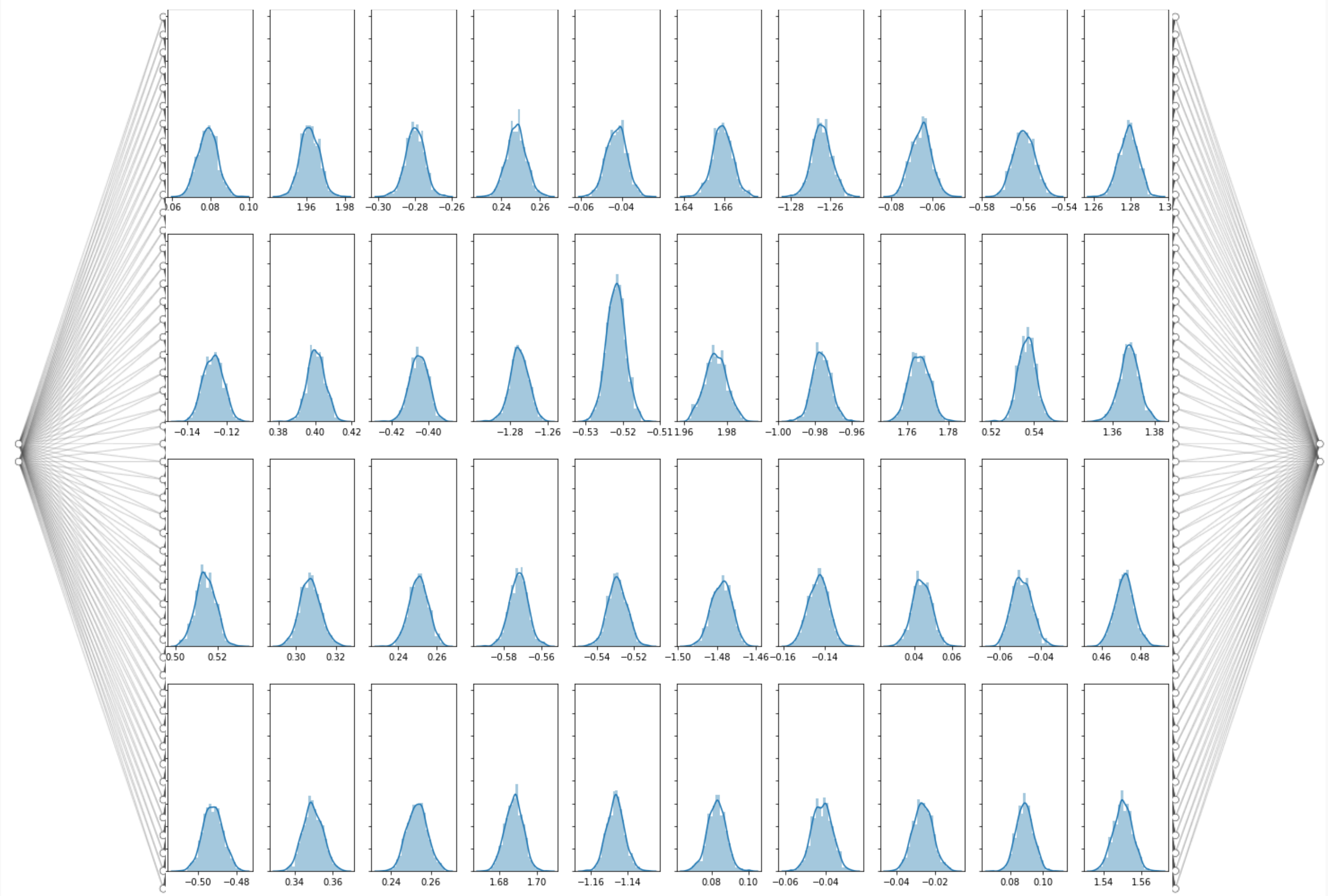
$$argmin_q KL(q,p) \equiv argmax_q ELBO$$



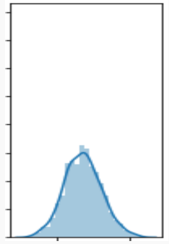
Bishop

Variational Inference

Input



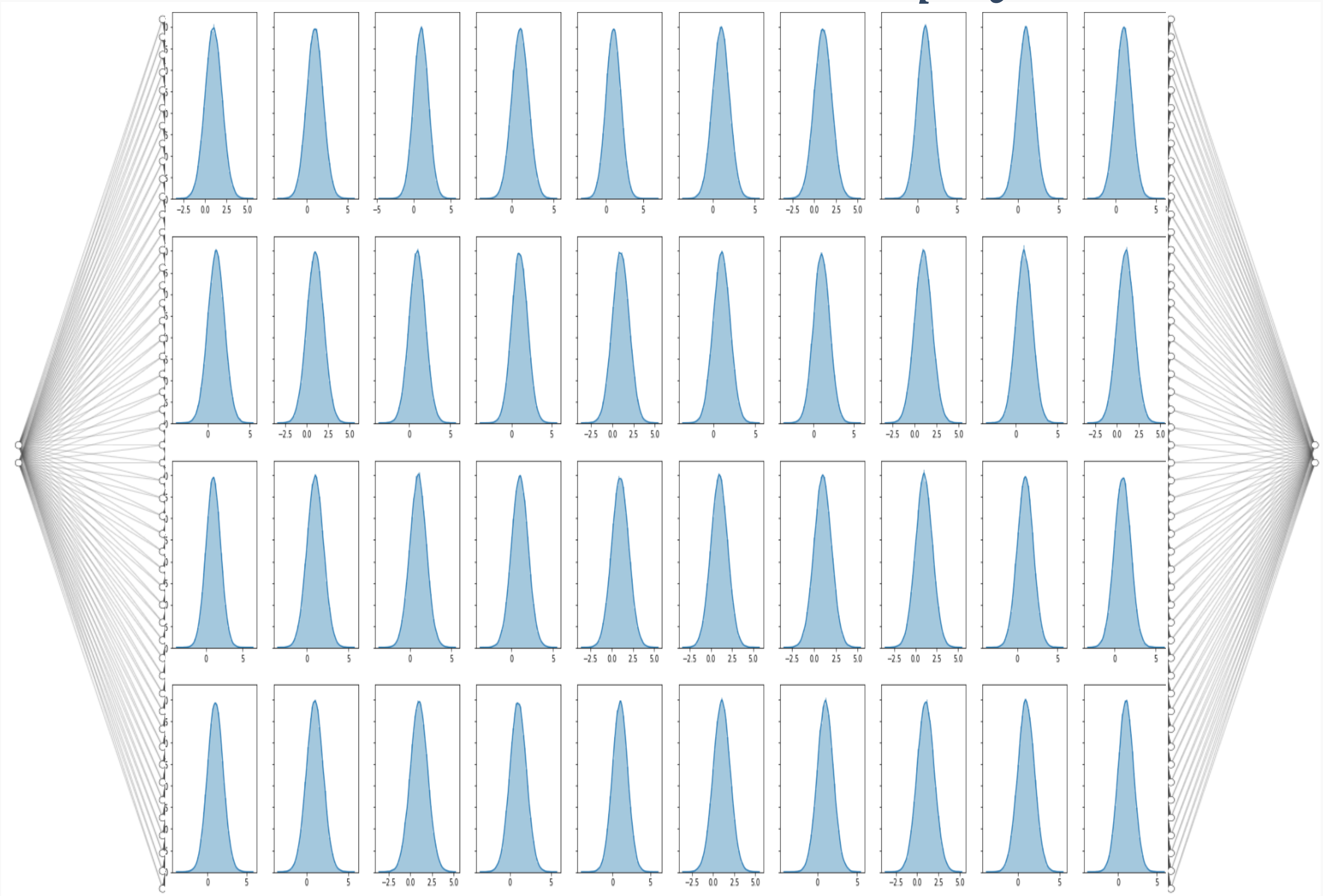
Output



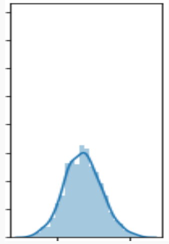
Variational Inference

$$p(\theta|y) \approx q* = argmax_{q \in Q} ELBO$$

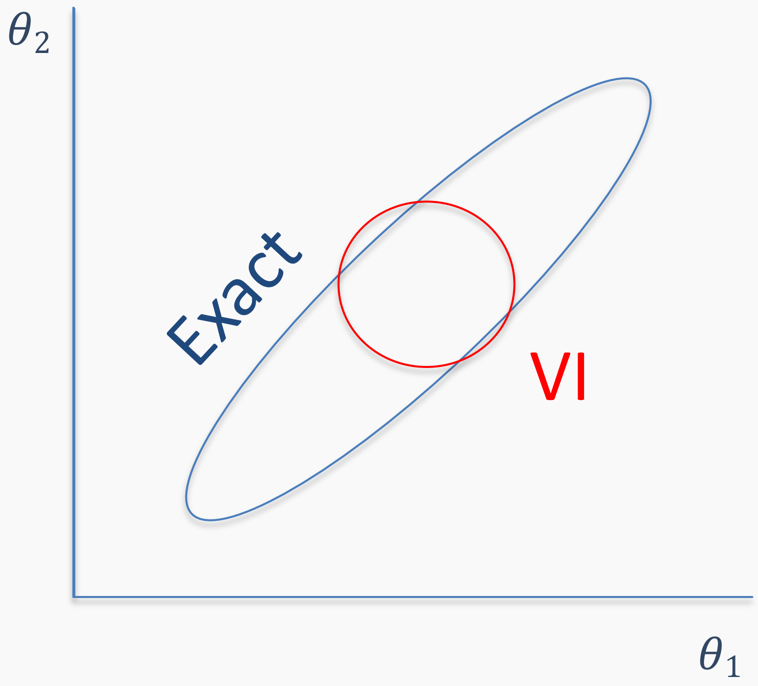
Input →



→ Output



Variational Inference



$$KL(q\,||\,p(\cdot\,|\,x)) = \int_\theta q(\theta)\log\frac{q(\theta)}{p(\theta\,|\,x)}d\theta$$

$$q(\theta) = \prod_{j=1}^{J} q_j(\theta_j)$$

Underestimates variance (sometimes severely)

Dropout

Dropout as a Bayesian Approximation:
Representing Model Uncertainty in Deep Learning

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Zoubin Ghahramani ZG201@CAM.AC.UK
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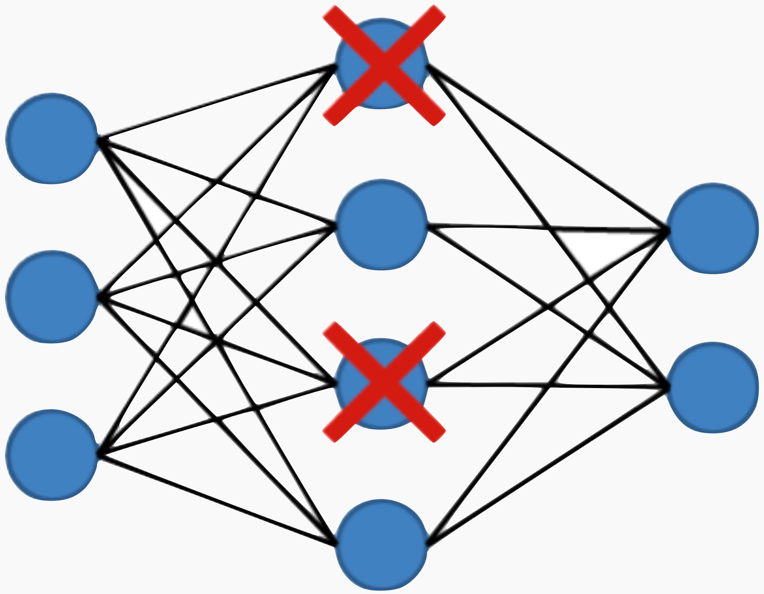
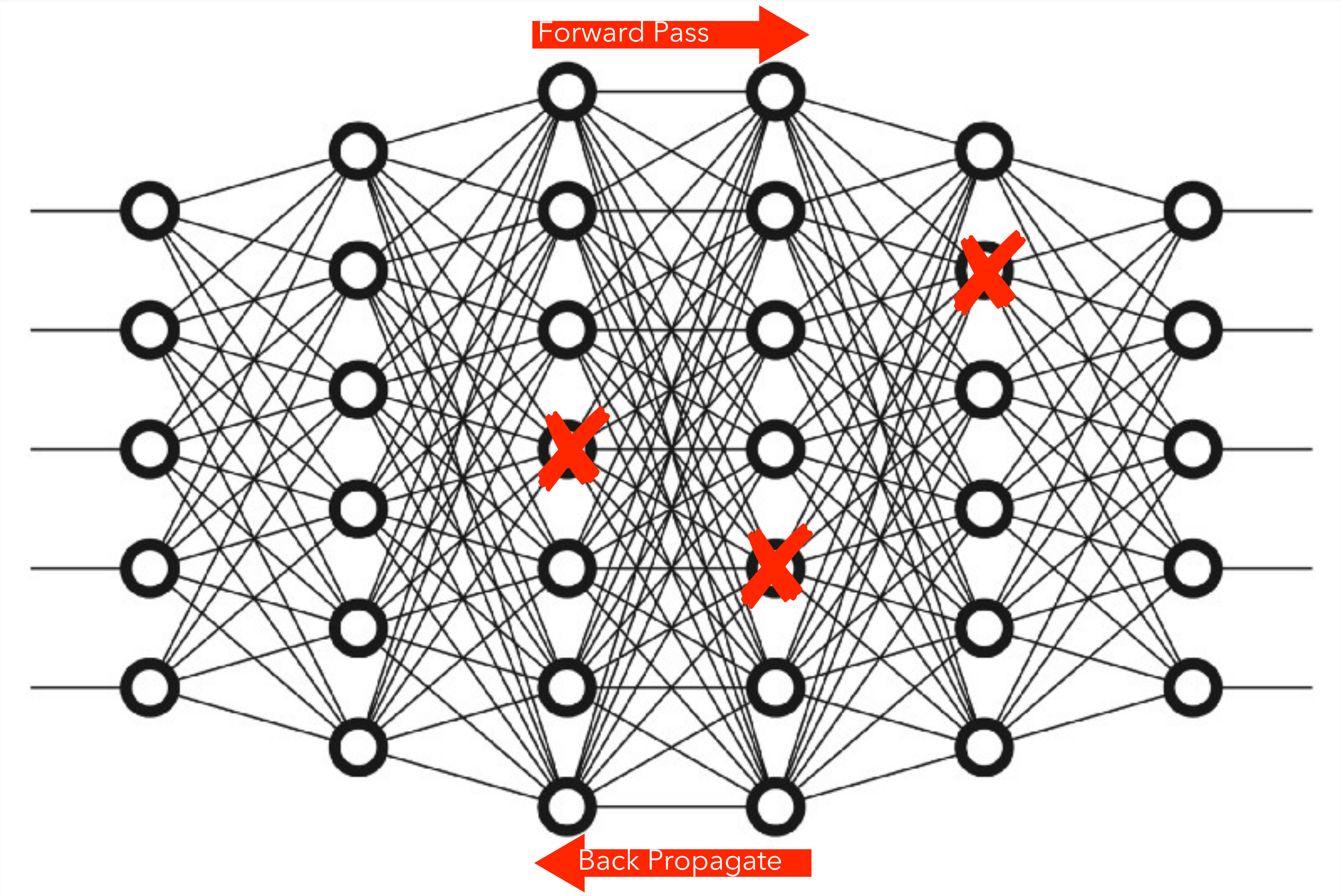
[arXiv:1506.02142](https://arxiv.org/abs/1506.02142)

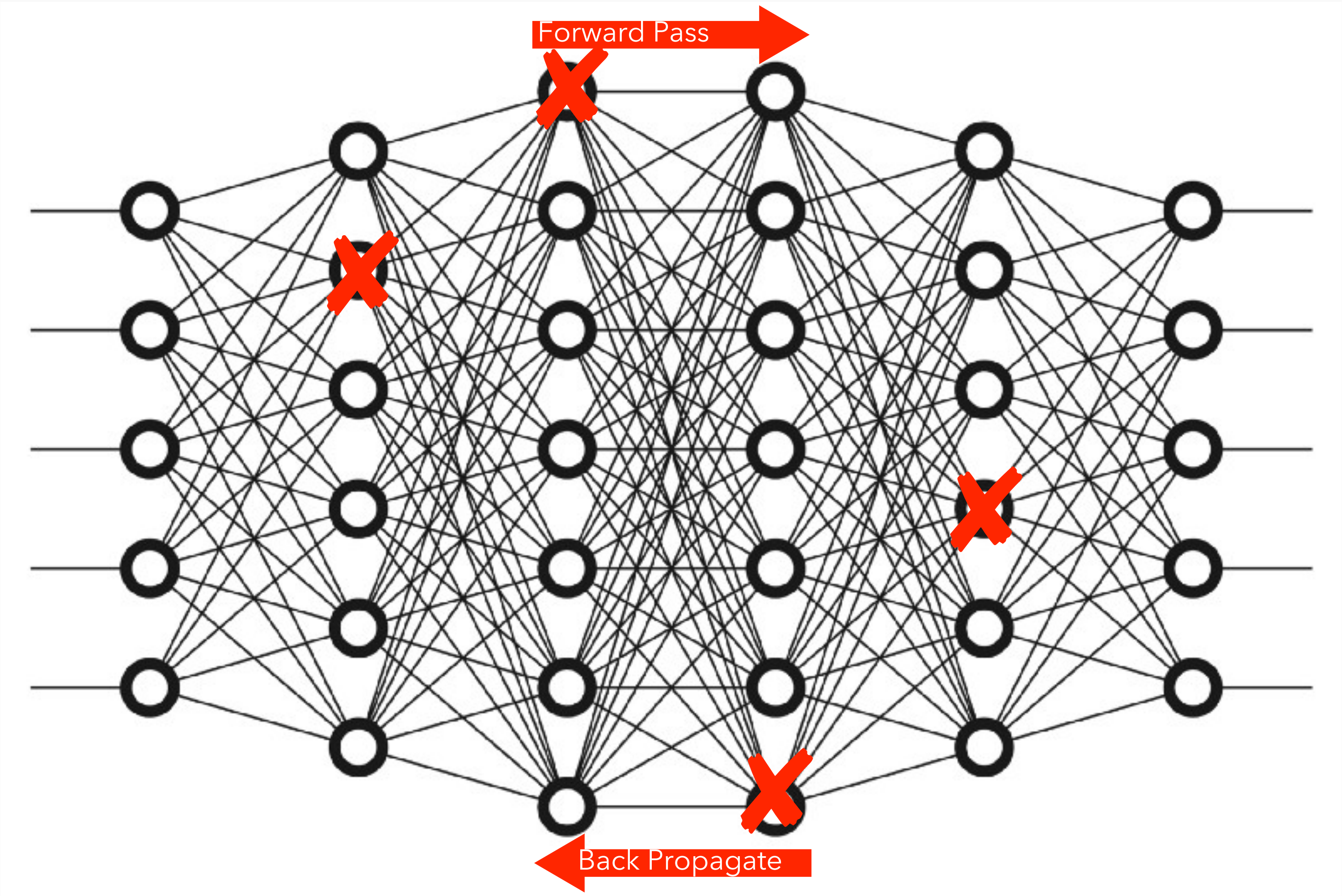


Dropout: train



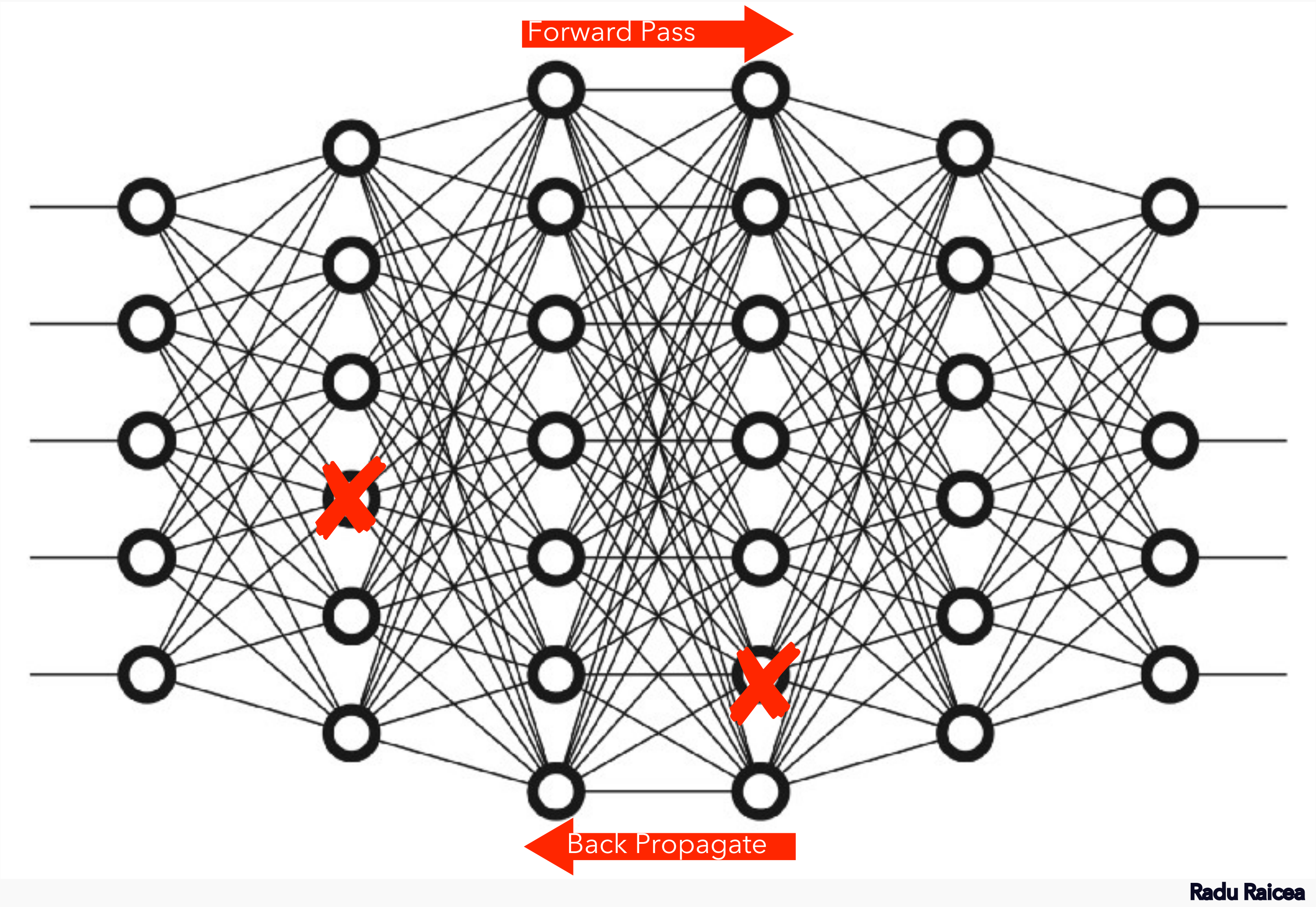
Radu Raicea

Dropout: train

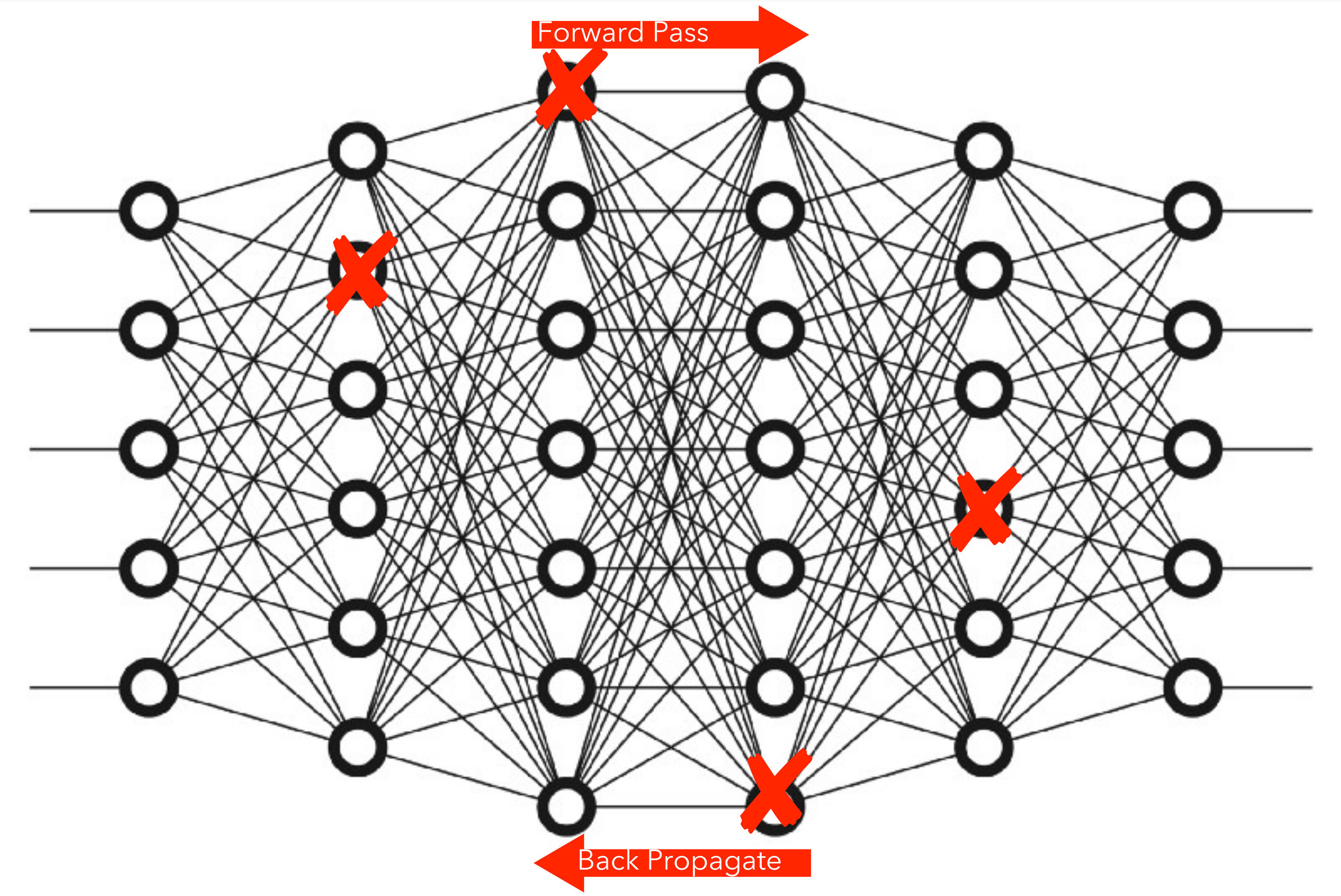


Radu Raicea

Dropout: train

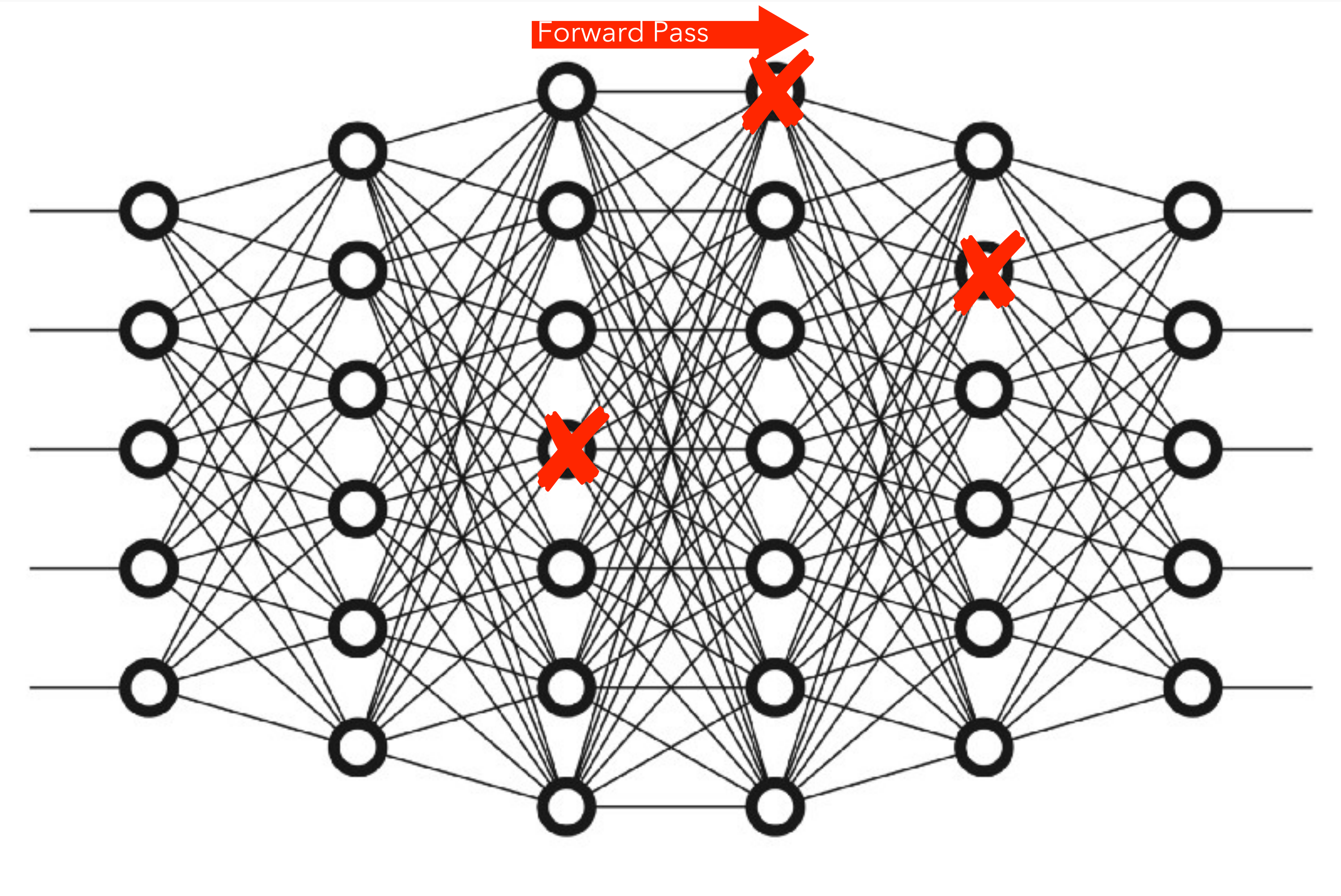


Dropout: train



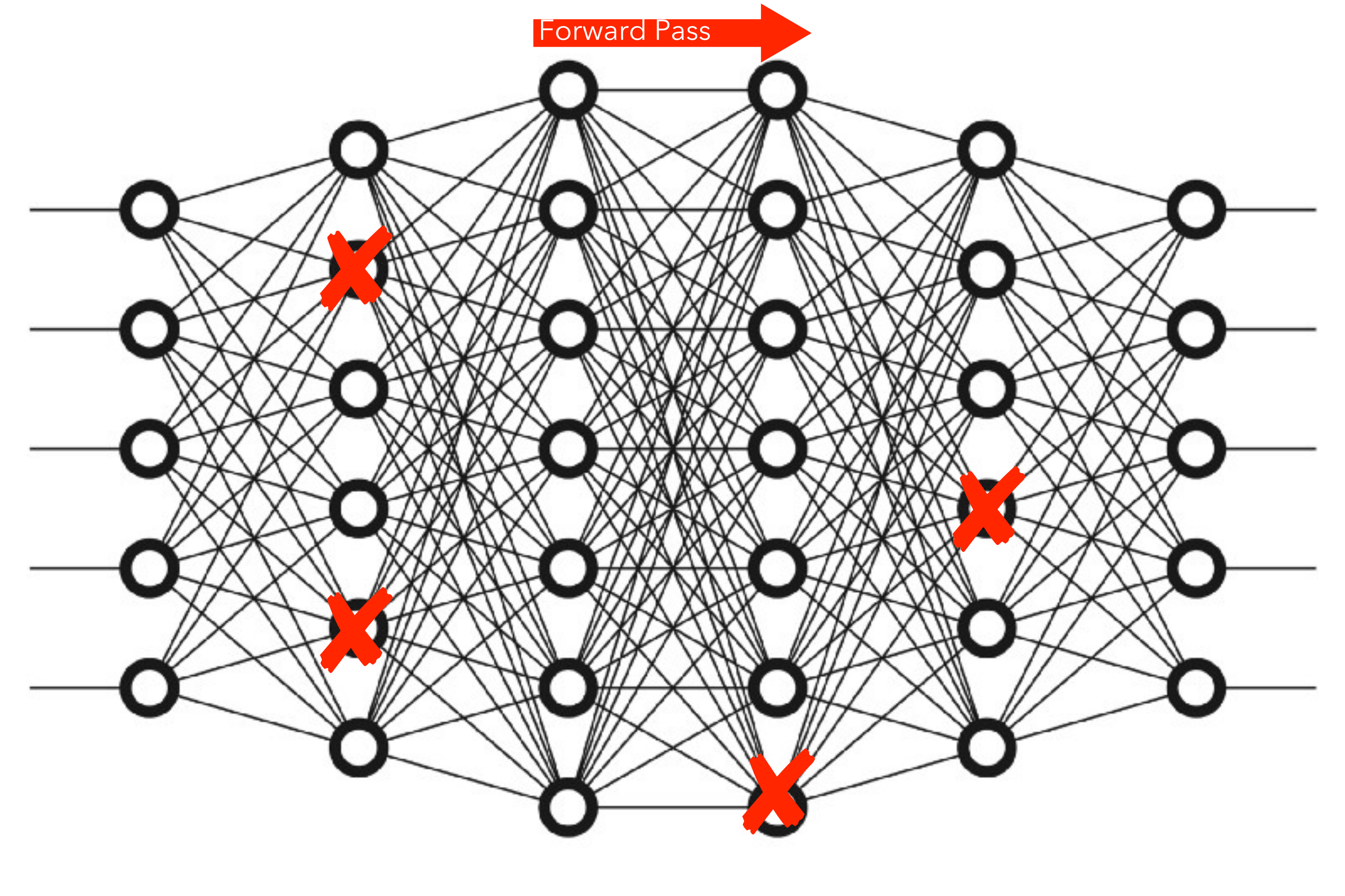
Radu Raicea

Dropout: evaluate

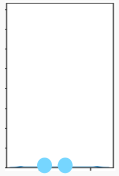


Radu Raicea

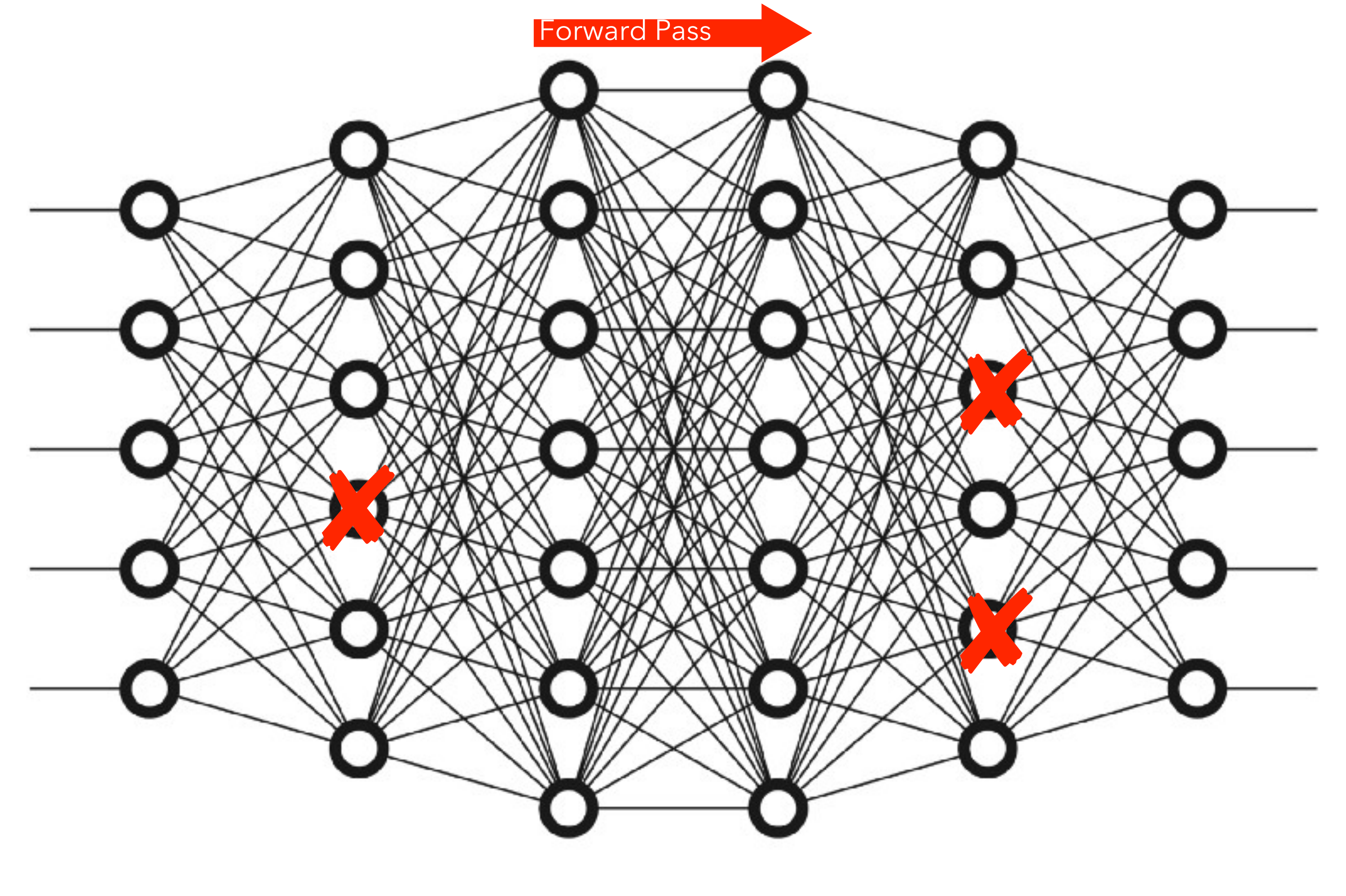
Dropout: evaluate



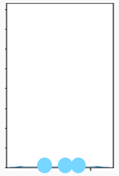
Radu Raicea



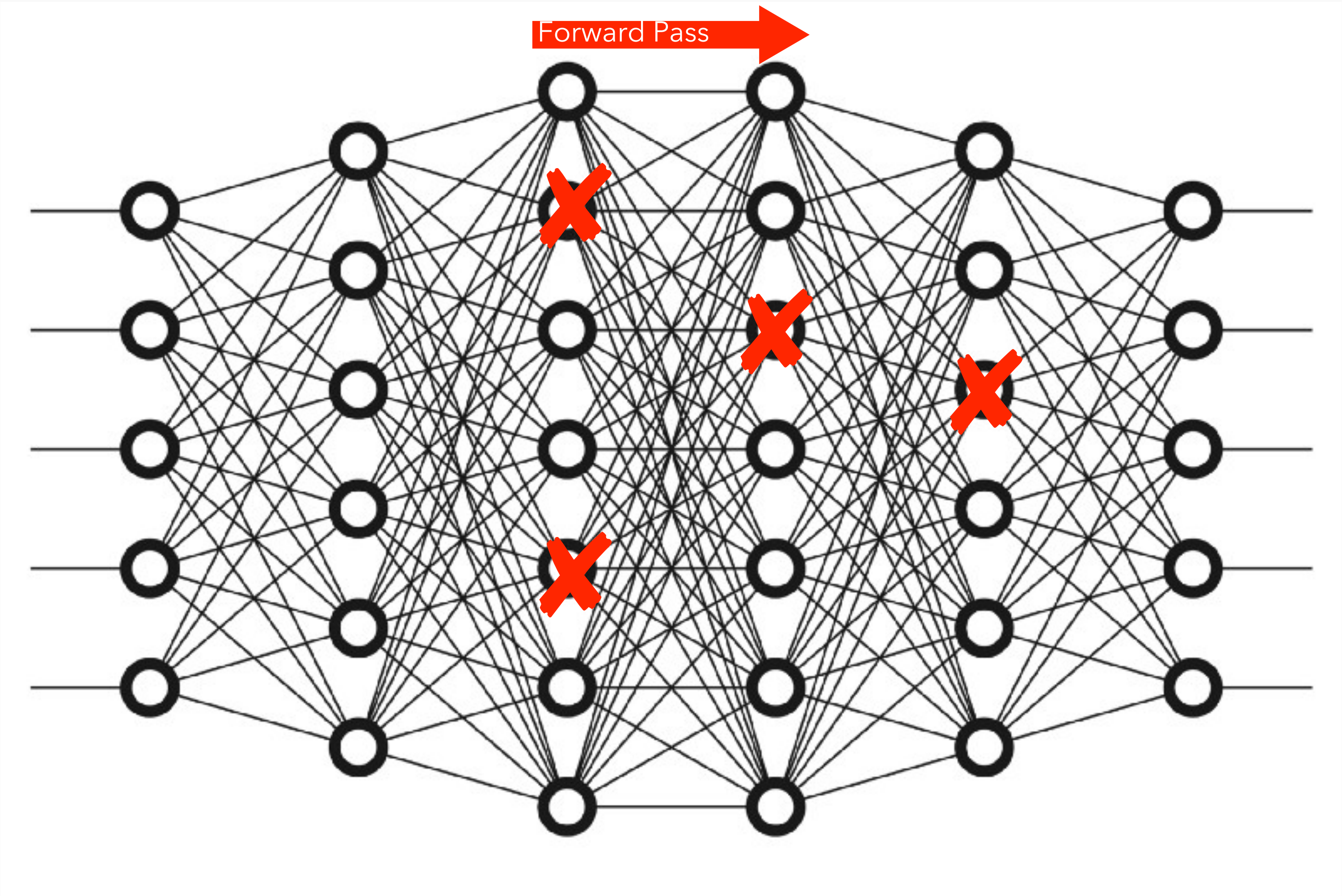
Dropout: evaluate

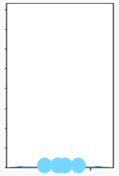


Radu Raicea



Dropout: evaluate





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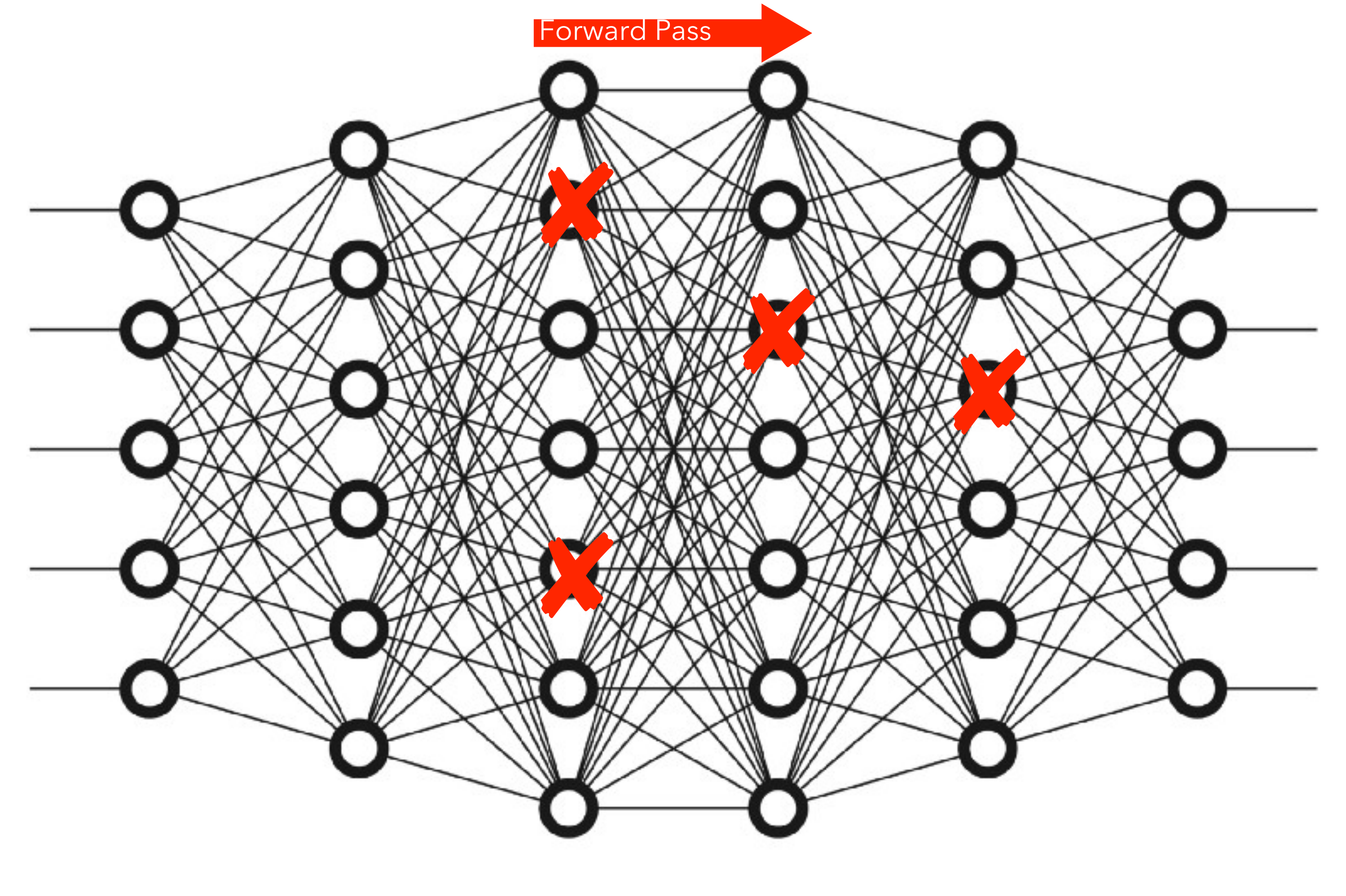
Dropout: evaluate



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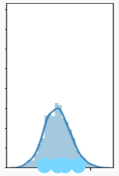
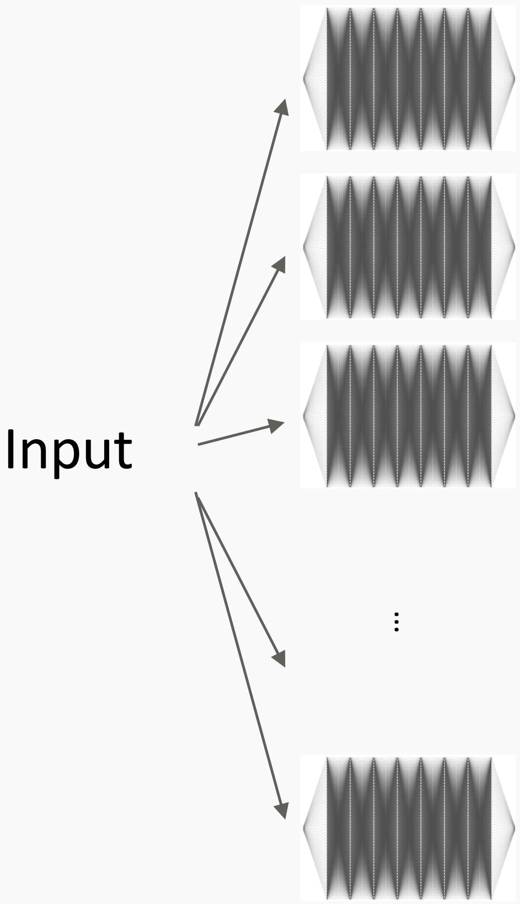
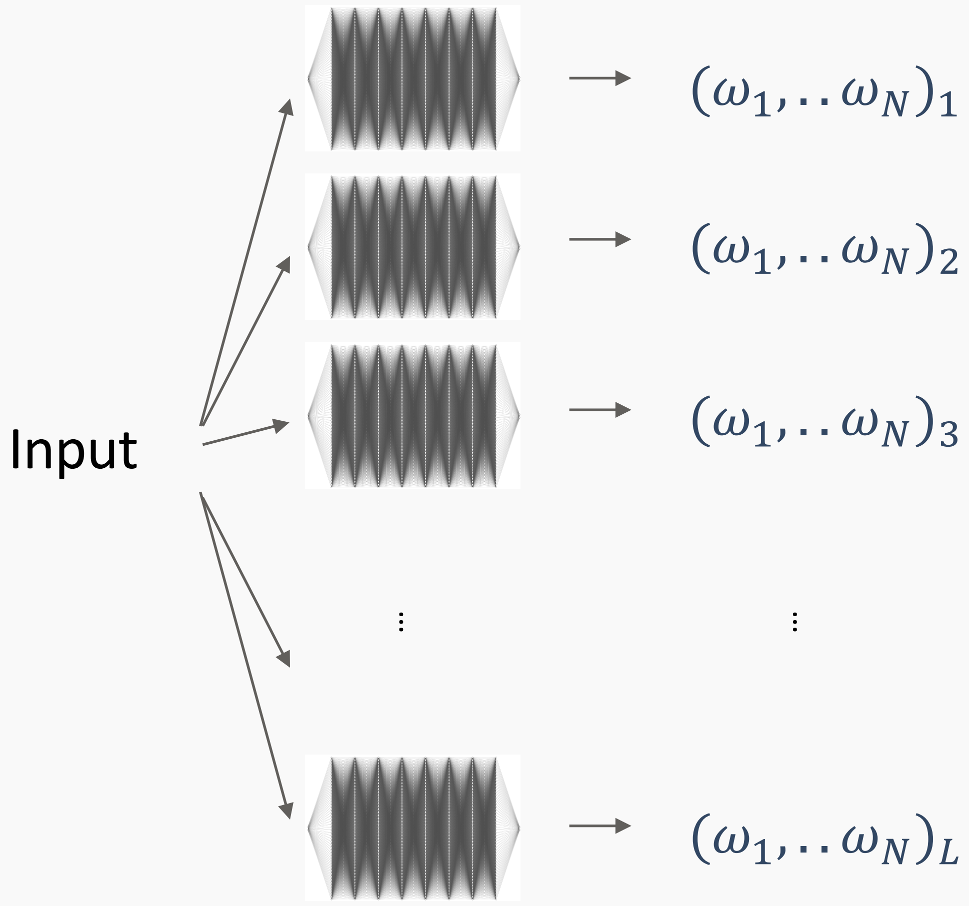


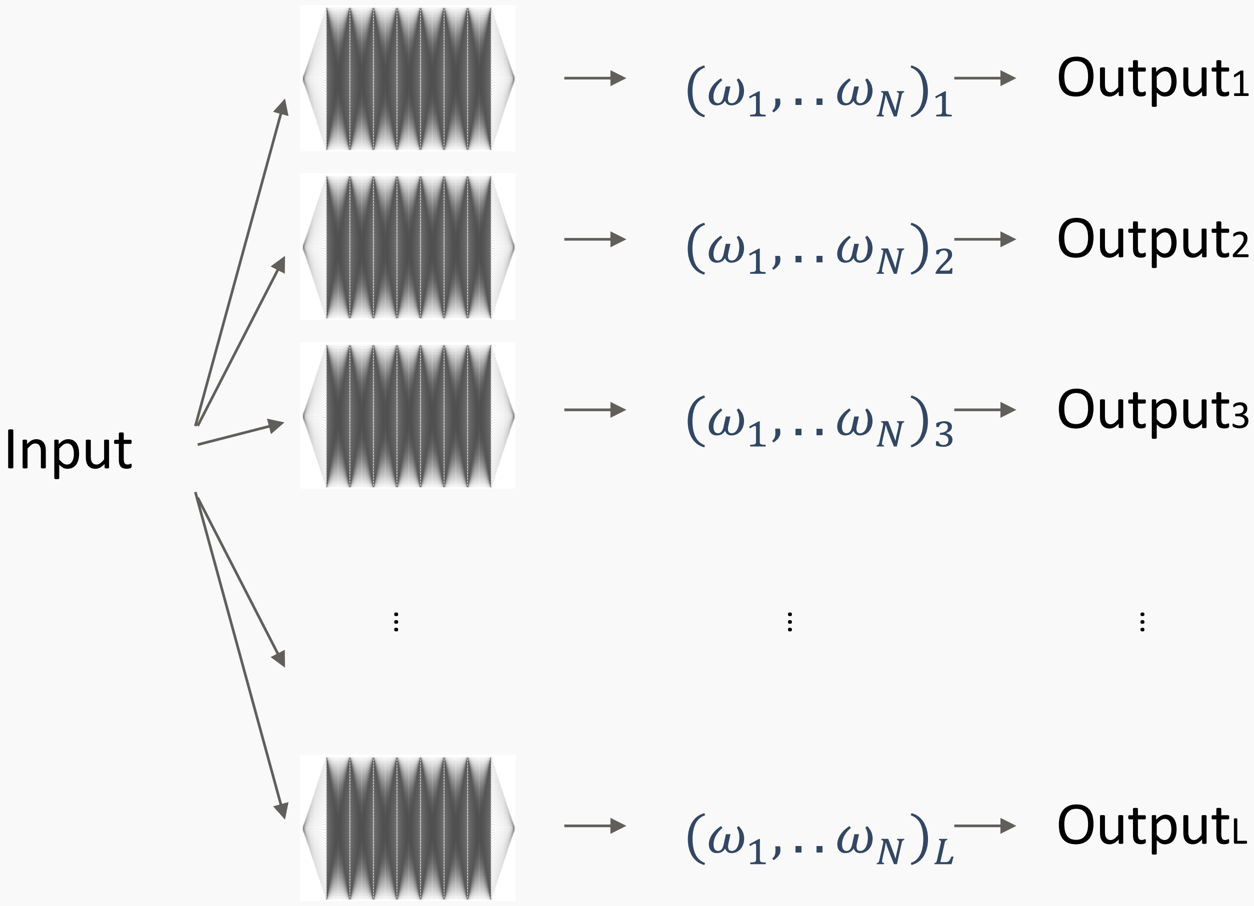
Bootstrap for Inference



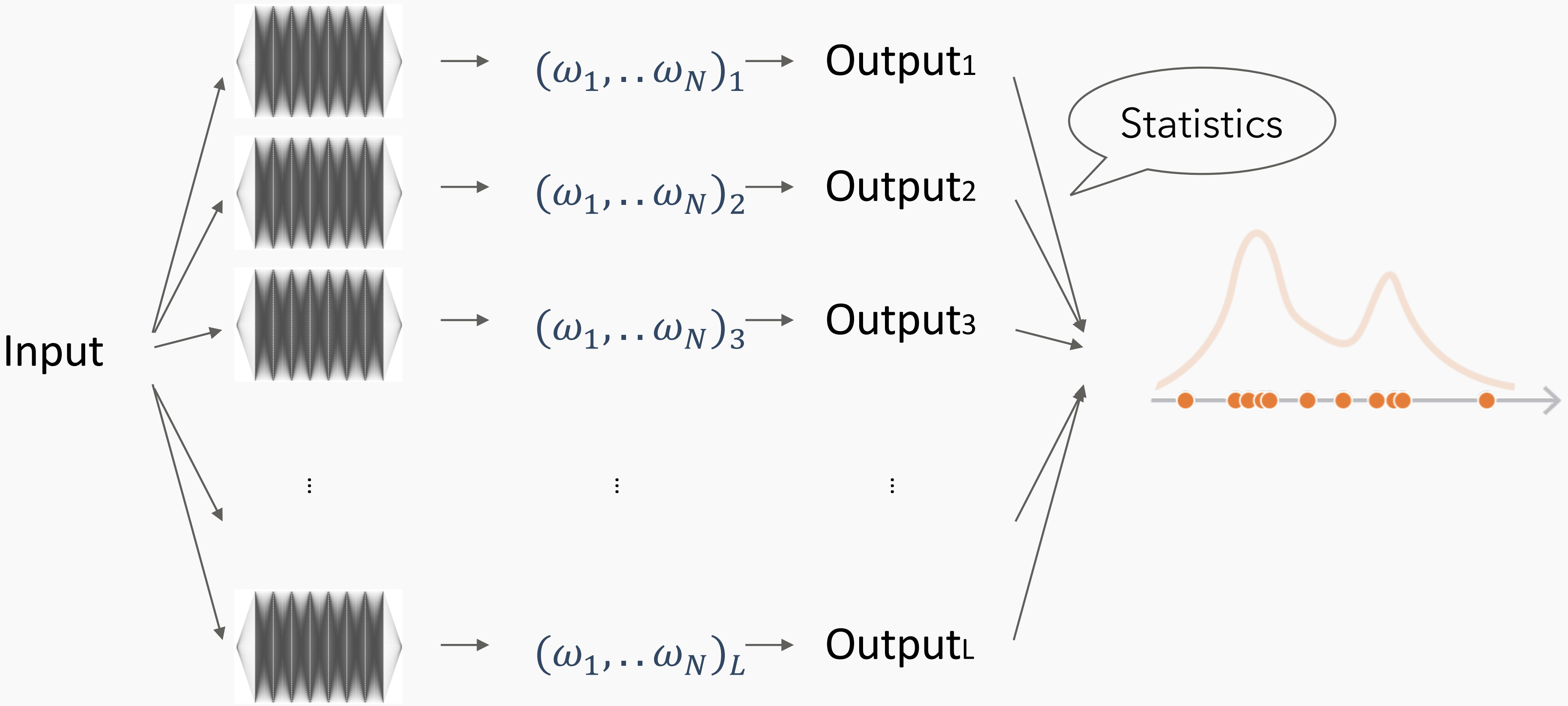
Bootstrap for Inference



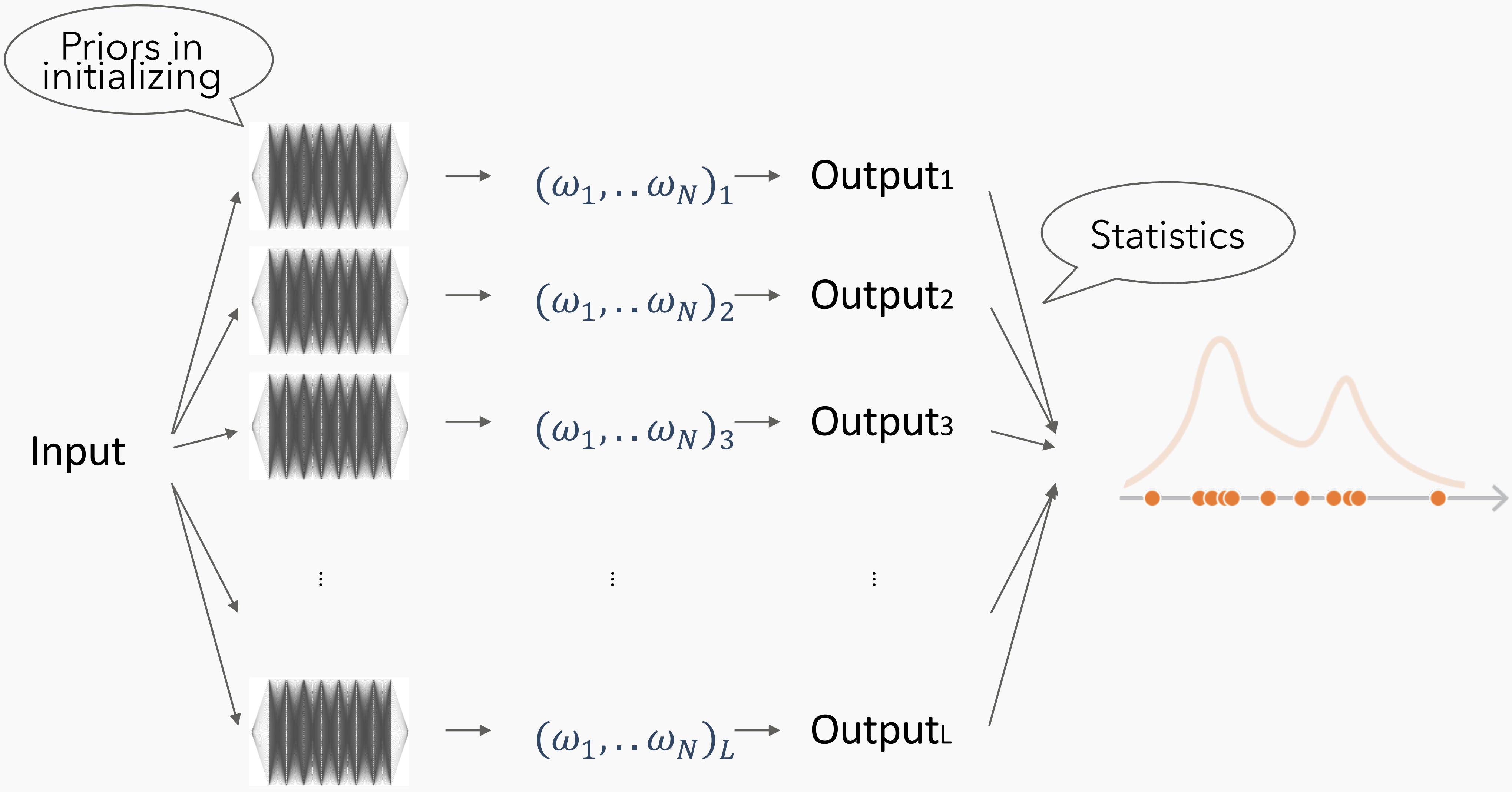
Bootstrap for Inference



Bootstrap for Inference



Bootstrap for Inference



Working Example

Variational Bayesian Inference

The problem

$y = x^3 + N(0,0.25)$

Working Example

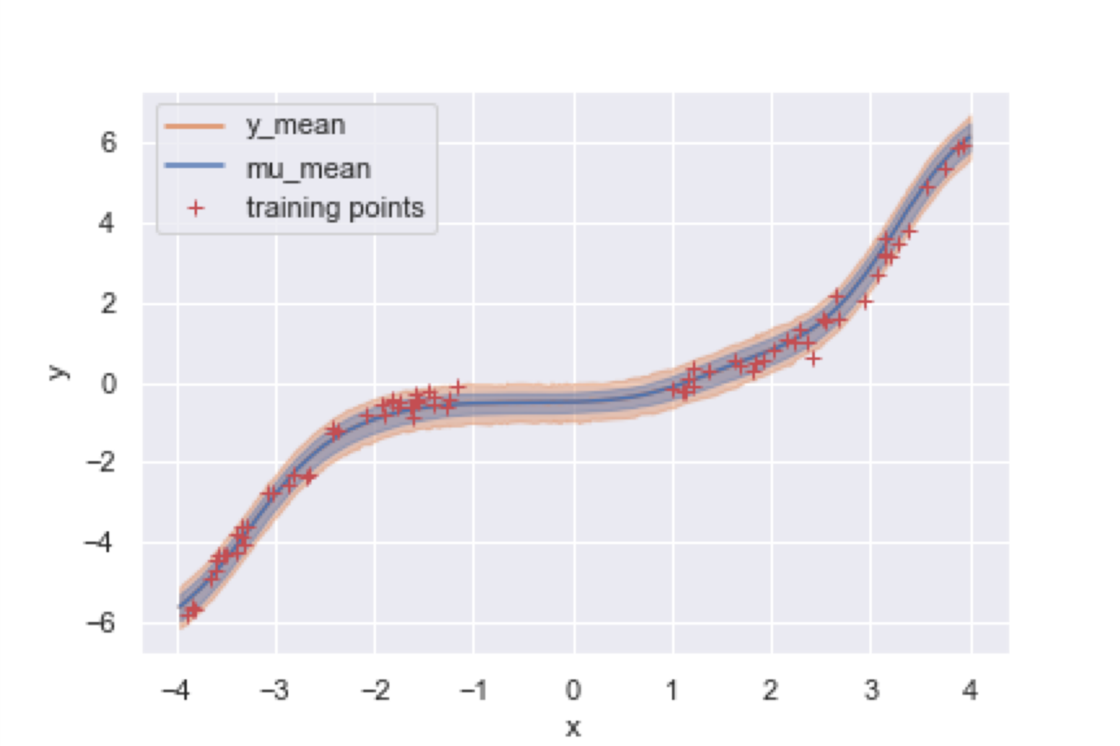
Variational Bayesian Inference

The right solution (MCMC)

Working Example

Variational Bayesian Inference

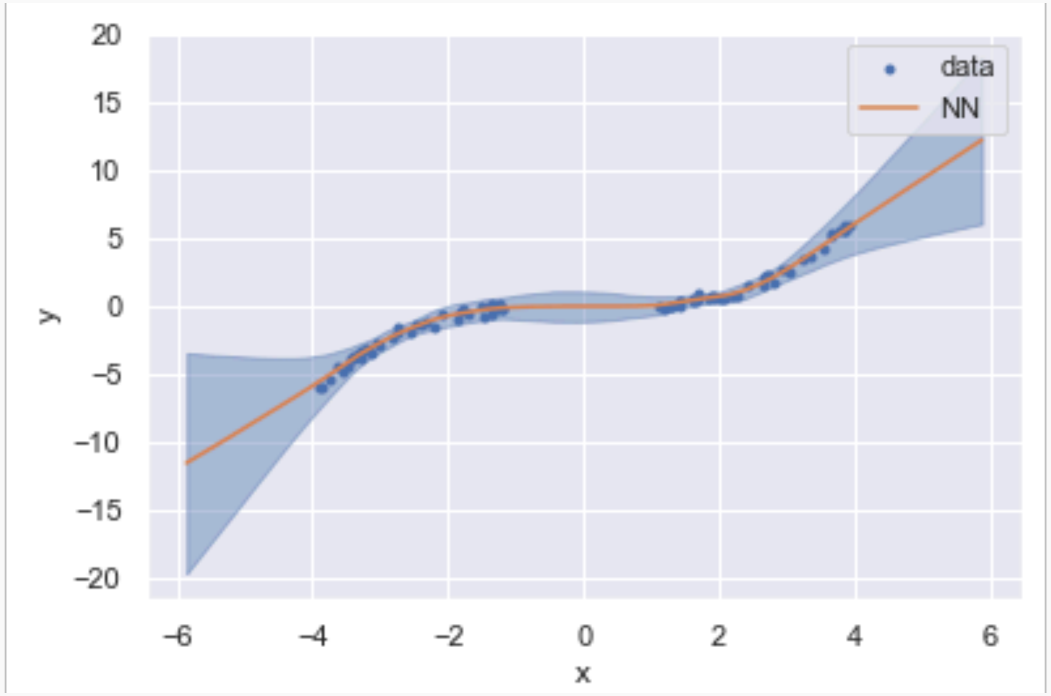
SVI



Working Example

Variational Bayesian Inference
Bootstrap

Model Mean 95% models

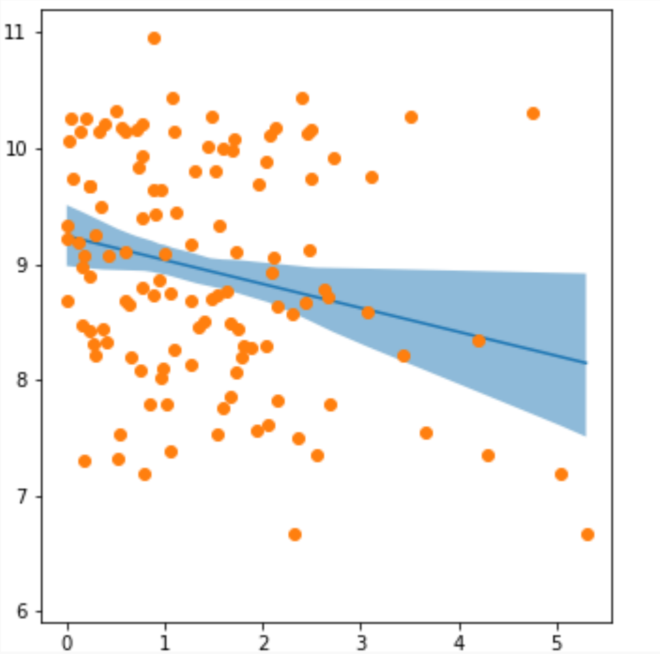


Working Example

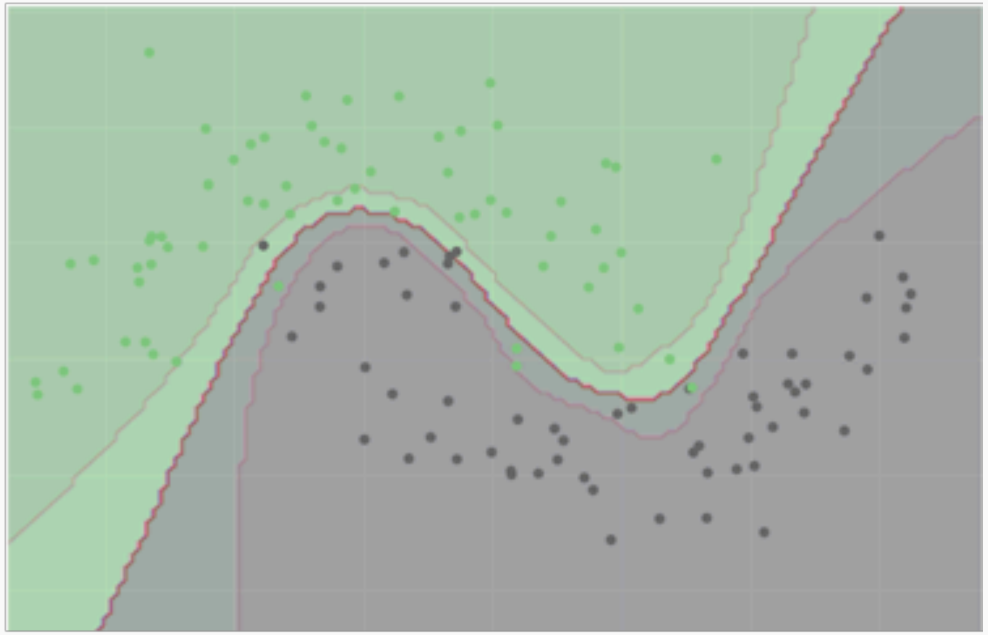
Variational Bayesian Inference
Bootstrap

Model Mean 95% models

Regression



Classification

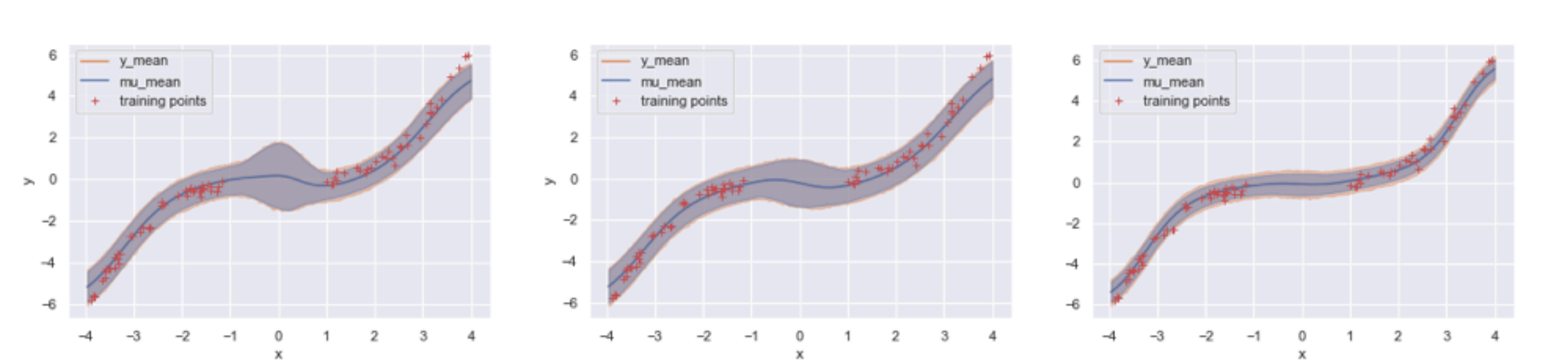


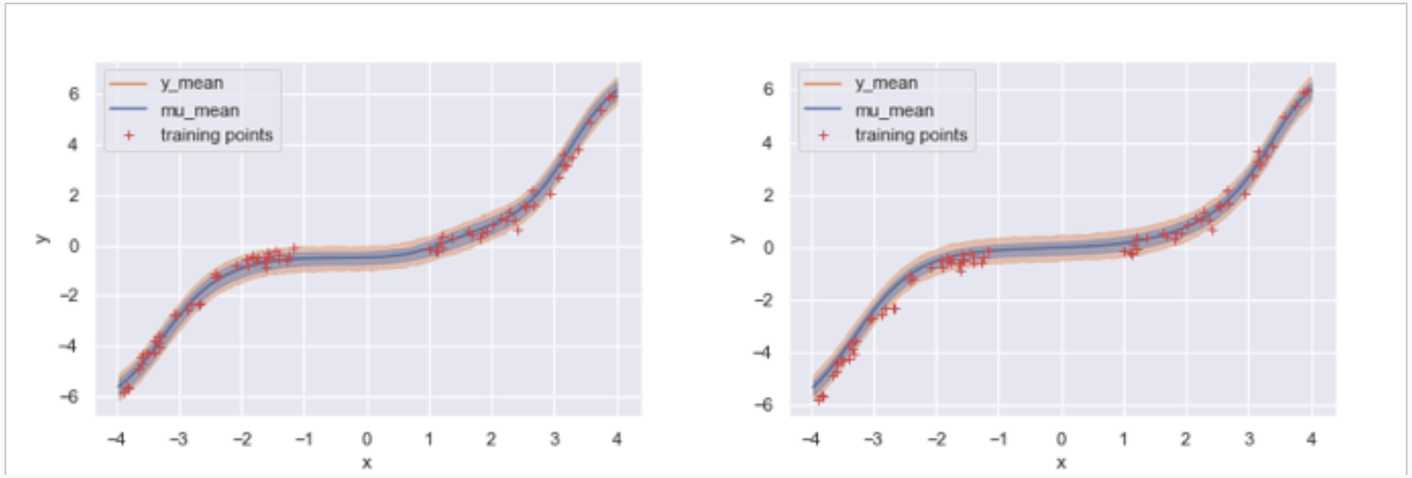
Extra

Working Example

Variational Bayesian Inference

SVI





DONE