Lecture 14: Regularization

CS 109B, STAT 121B, AC 209B, CSE 109B

Mark Glickman and Pavlos Protopapas

Lecture 3
Regularization

Regularization is any modification we make to a learning algorithm that is intended to reduce its generalization error but not its training error

Outline

- Norm Penalties
- Early Stopping
- Data Augmentation
- Bagging
- Dropout

- Regularisation, bagging to avoid overfitting
- If billions of data point, won’t worry about overfitting as difficult to overfit in such a case

Norm Penalties

- Optimize:

$$J(\theta;\ X, y)\ +\ \alpha\,\Omega(\theta)$$

Biases not penalized

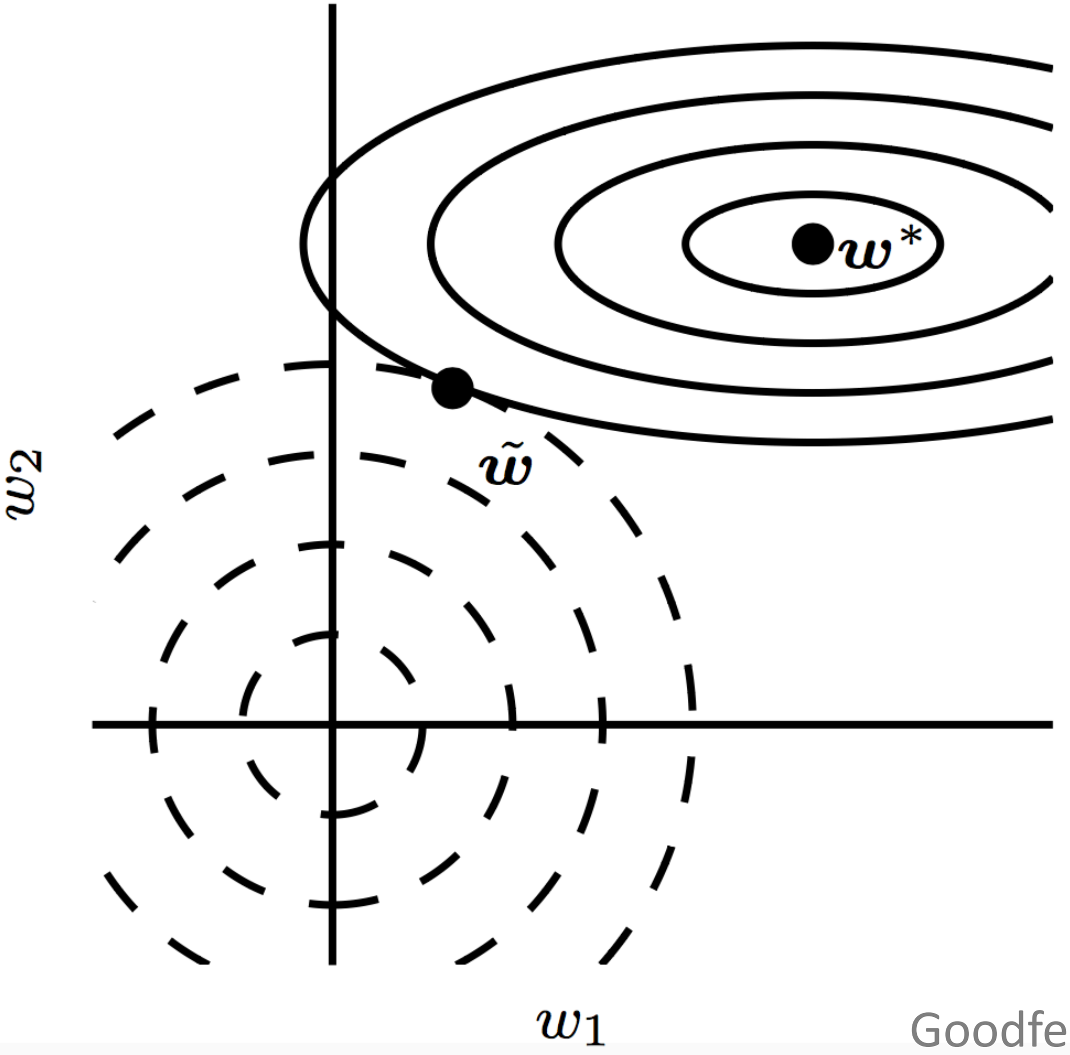
- L_2 regularization:
  - – decays weights
  - – MAP estimation with Gaussian prior

$$\Omega(\theta) = \frac{1}{2}\left\|\mathbf{w}\right\|_2^2$$

- L_1 regularization:
  - – encourages sparsity
  - – MAP estimation with Laplacian prior

$$\Omega(\theta) = \left\|\mathbf{w}\right\|_1$$

L_2 Regularization



Goodfellow et al. (2016)

Norm Penalties as Constraints

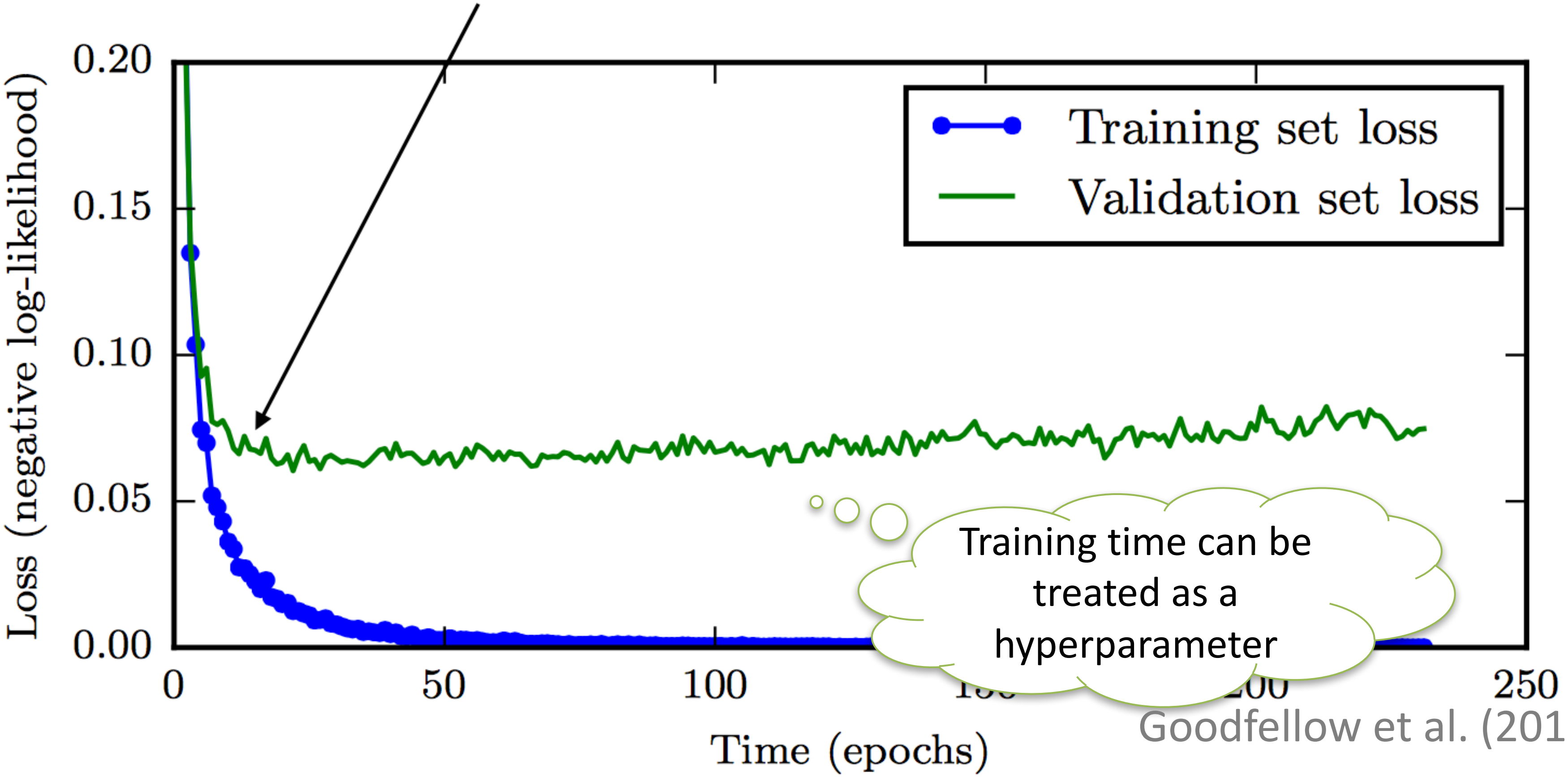
$$\min_{\Omega(\theta) \leq K} J(\theta;\ X, y)$$

- Useful if *K* is known in advance
- Optimization:
  - Construct Lagrangian and apply gradient descent
  - Projected gradient descent

Early Stopping

- Linear Reg: Early stopping not possible as no epochs
- Logistic Reg: Early stopping possible
- Boosting also early stopping possible

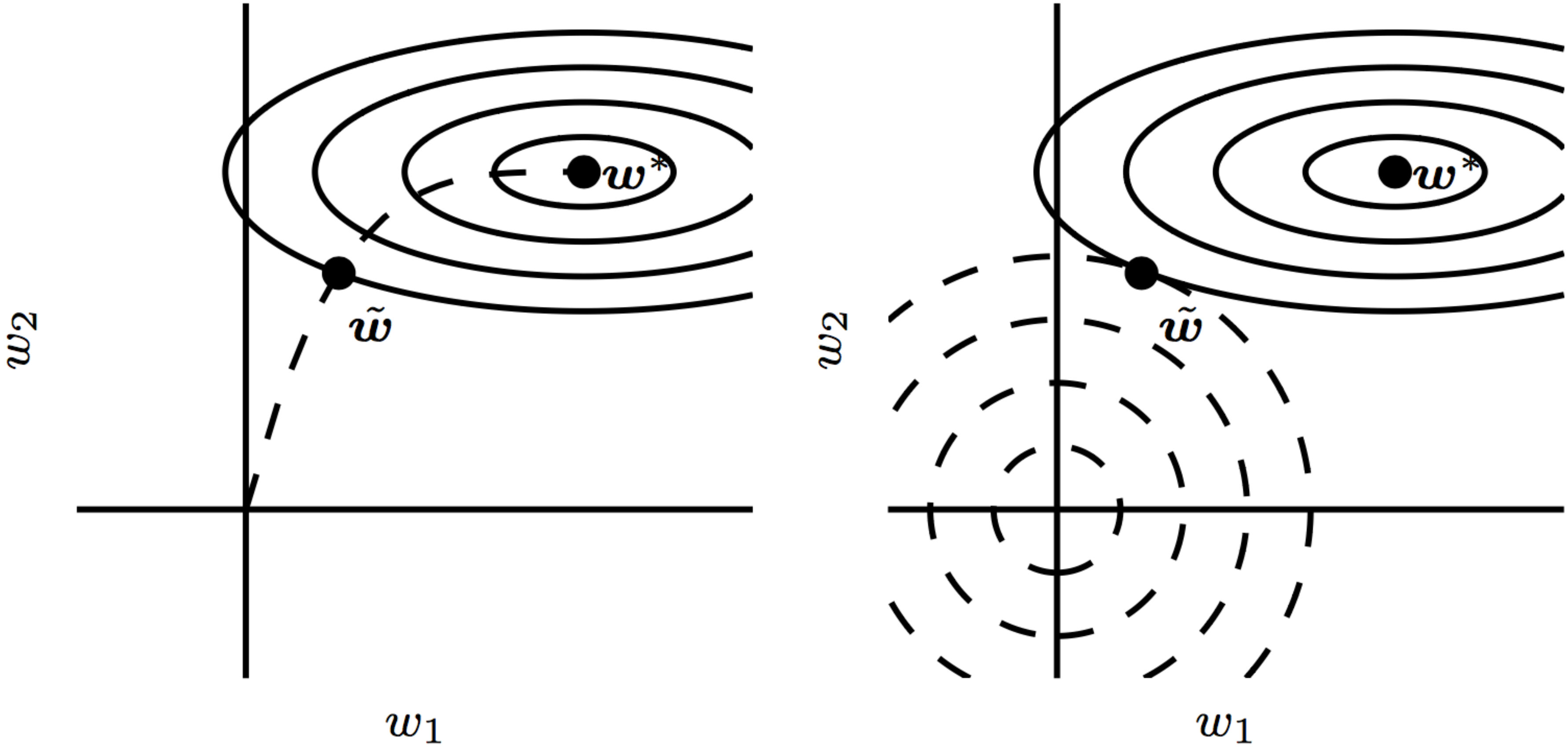
Early stopping: terminate while validation set performance is better



Training time can be treated as a hyperparameter

Goodfellow et al. (2016)

Early Stopping ≈ Weight Decay



Goodfellow et al. (2016)

Sparse Representations

- Weight decay *on activations* instead of parameters

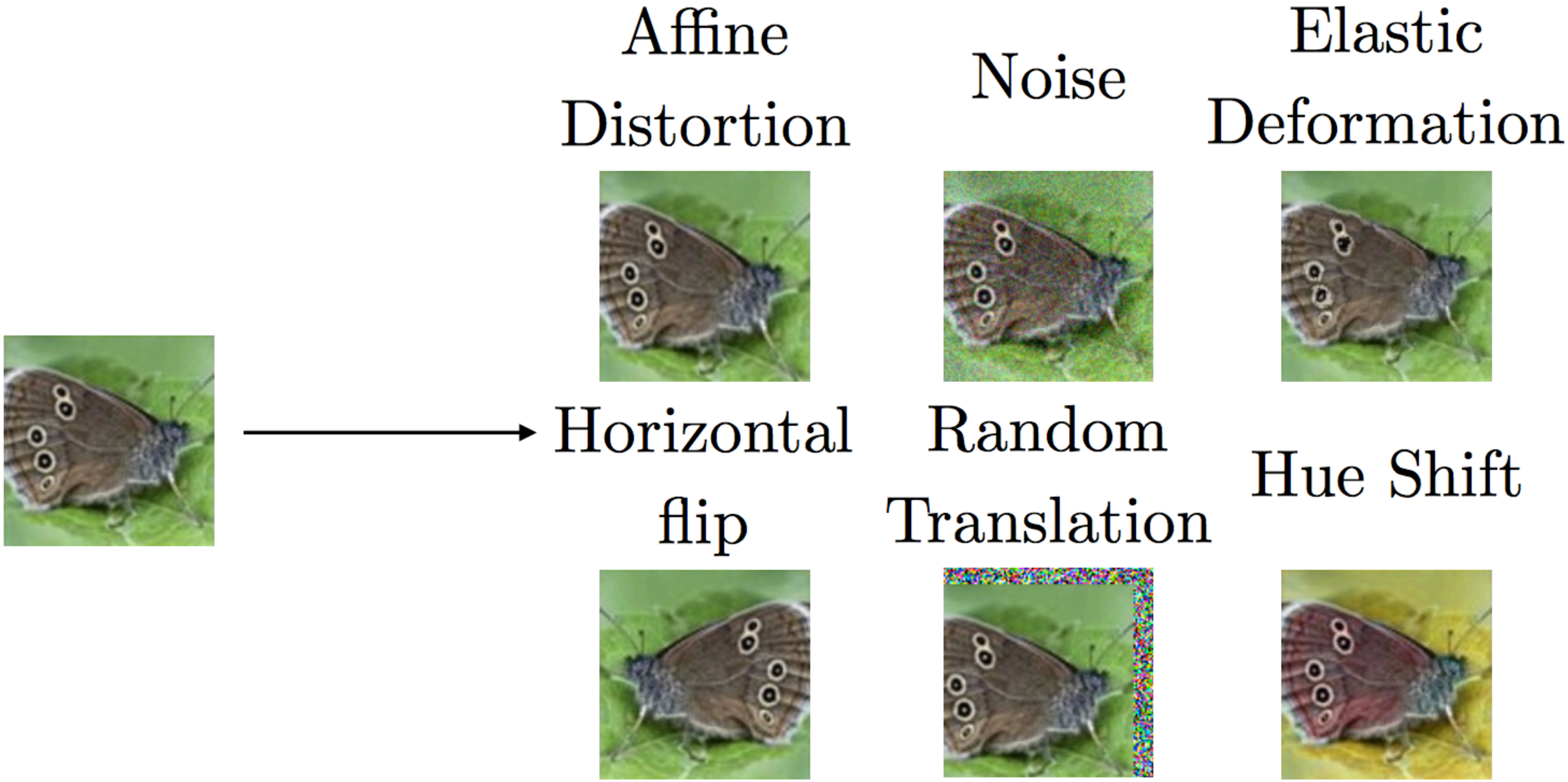
Output of hidden layer

$$\underset{\boldsymbol{y} \in \mathbb{R}^m}{\begin{bmatrix} -14 \\ 1 \\ 19 \\ 2 \\ 23 \end{bmatrix}} = \underset{\boldsymbol{B} \in \mathbb{R}^{m \times n}}{\begin{bmatrix} 3 & -1 & 2 & -5 & 4 & 1 \\ 4 & 2 & -3 & -1 & 1 & 3 \\ -1 & 5 & 4 & 2 & -3 & -2 \\ 3 & 1 & 2 & -3 & 0 & -3 \\ -5 & 4 & -2 & 2 & -5 & -1 \end{bmatrix}} \underset{\boldsymbol{h} \in \mathbb{R}^n}{\begin{bmatrix} 0 \\ 2 \\ 0 \\ 0 \\ -3 \\ 0 \end{bmatrix}}$$

Weights in output layer

$$J(\theta;\ X, y)\ +\ \alpha\,\Omega(h)$$

Data Augmentation



Affine Distortion

Noise

Elastic Deformation

Horizontal flip

Random Translation

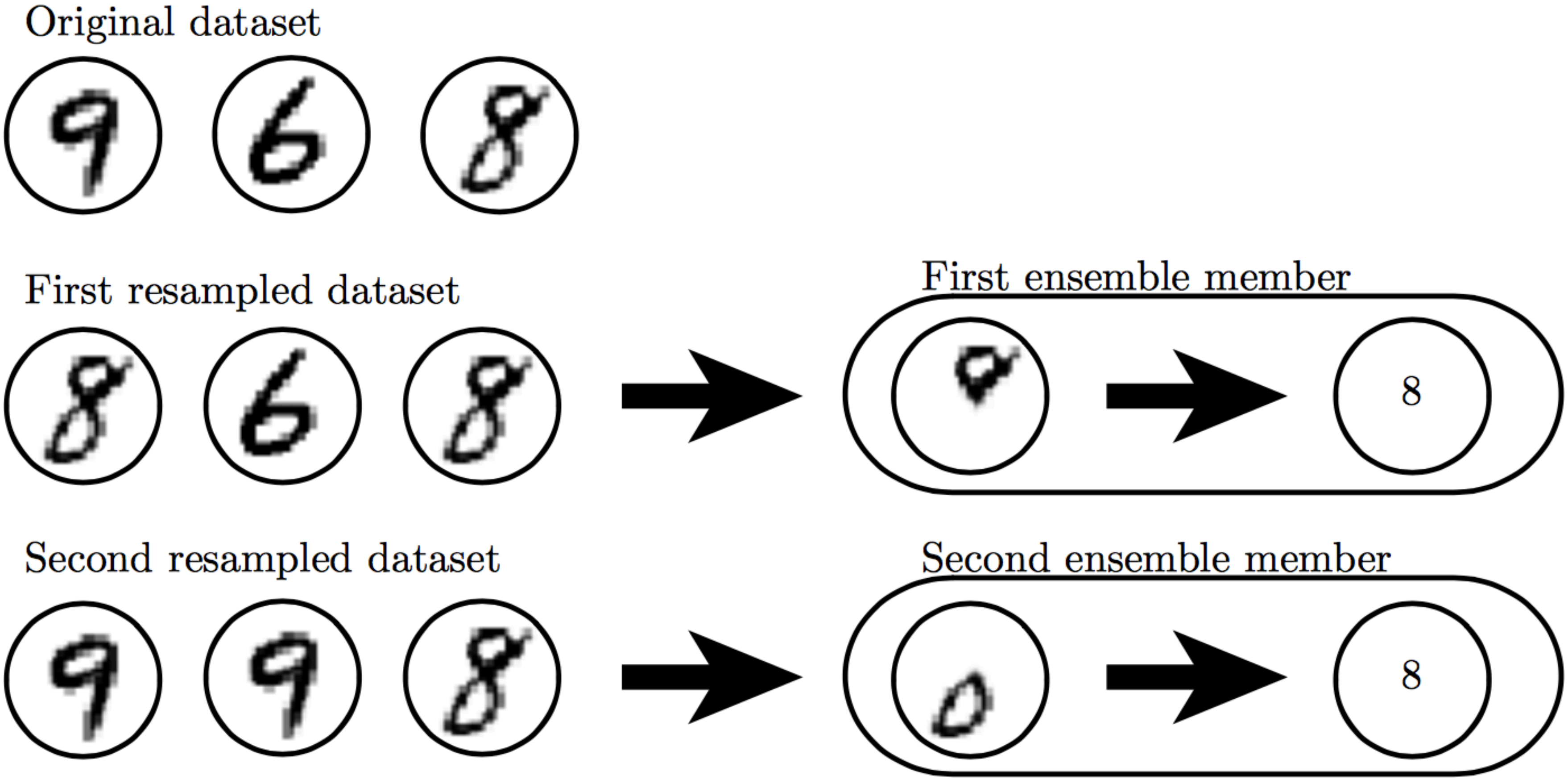
Hue Shift

deeplearningbook.org

Noise Robustness

- Random perturbation of network weights
  - Gaussian noise: Equivalent to minimizing loss with regularization term $\mathbf{E}\left[\left\|\nabla_W y(x)\right\|\right]$
  - Encourages smooth function: small perturbation in weights leads to small changes in output
- Injecting noise in output labels
  - Better convergence: prevents pursuit of hard probabilities

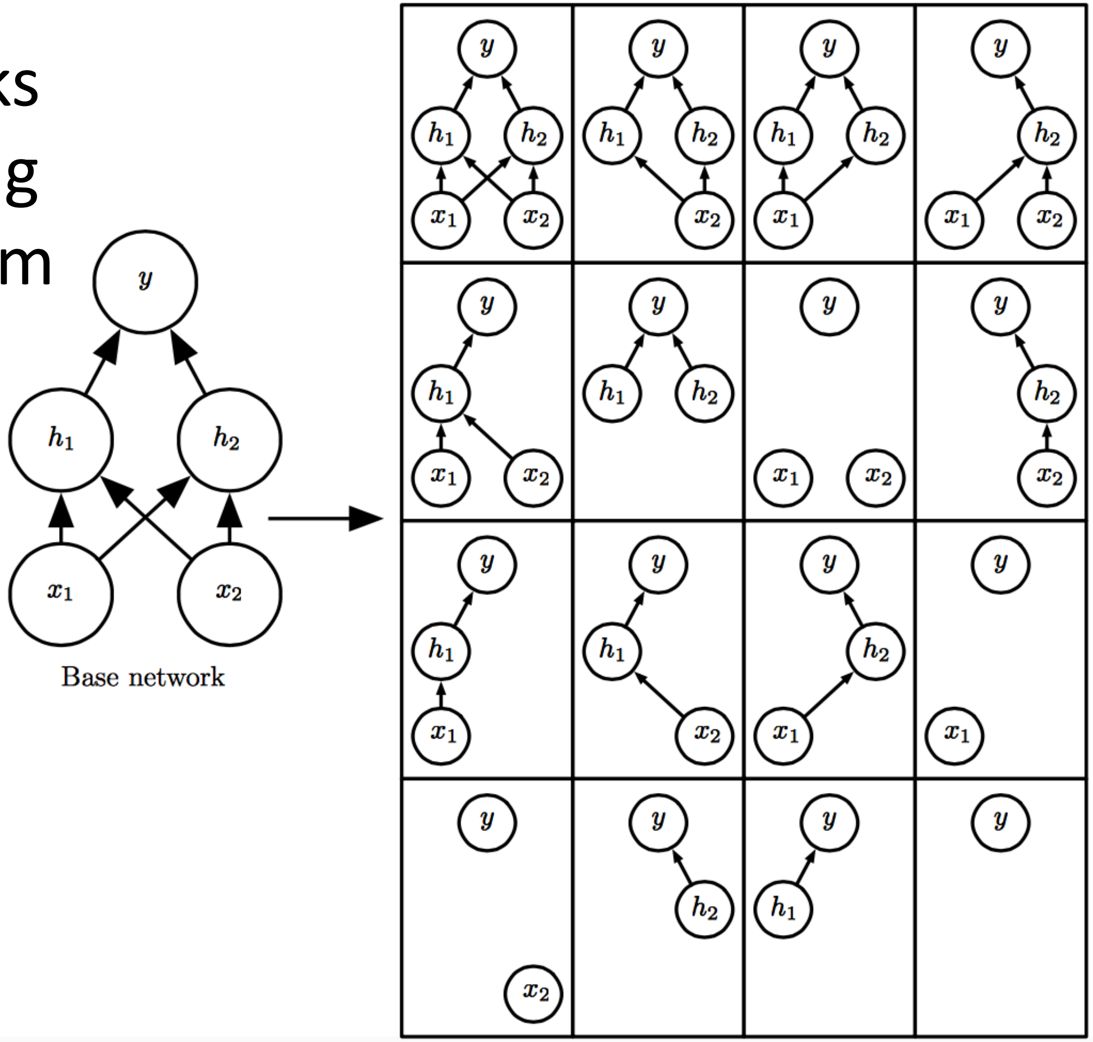
Bagging



deeplearningbook.org

Dropout

Train all sub-networks obtained by removing non-output units from base network



Base network

Ensemble of subnetworks

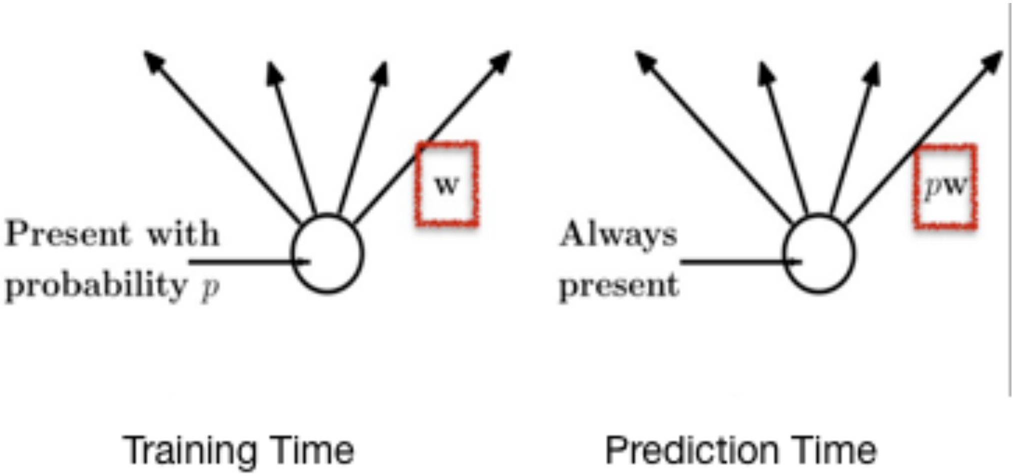
Goodfellow et al. (2016)

Dropout: Stochastic GD

- For each new example/mini-batch:
  - Randomly sample a binary mask μ independently, where μ_i indicates if input/hidden node i is included
  - Multiply output of node i with μ_i, and perform gradient update
- Typically, an input node is included with prob.0.8, hidden node with prob. 0.5

Dropout: Weight Scaling

- During prediction time use all units, but scale weights with probability of inclusion

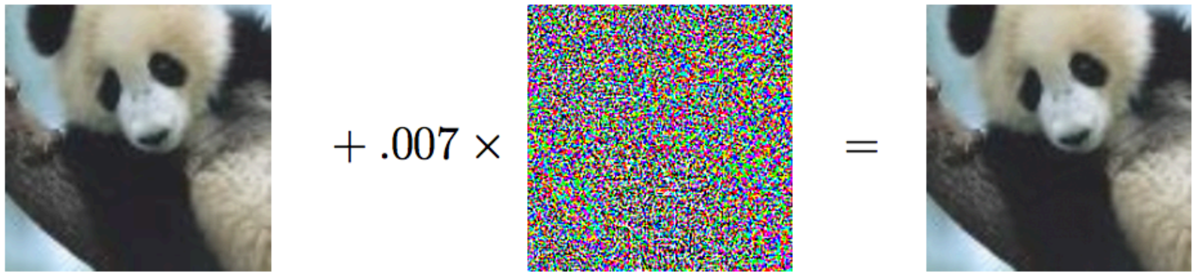


- Approximates the following inference rule:

$$\tilde{p}_{\text{ensemble}}(y \mid \boldsymbol{x}) = \sqrt[2^d]{\prod_{\boldsymbol{\mu}} p(y \mid \boldsymbol{x}, \boldsymbol{\mu})}.$$

Cristina Scheau (2016)

Adversarial Examples



$\boldsymbol{x}$

$y =$"panda"
w/ 57.7%
confidence

$\text{sign}(\nabla_{\boldsymbol{x}} J(\boldsymbol{\theta}, \boldsymbol{x}, y))$

"nematode"
w/ 8.2%
confidence

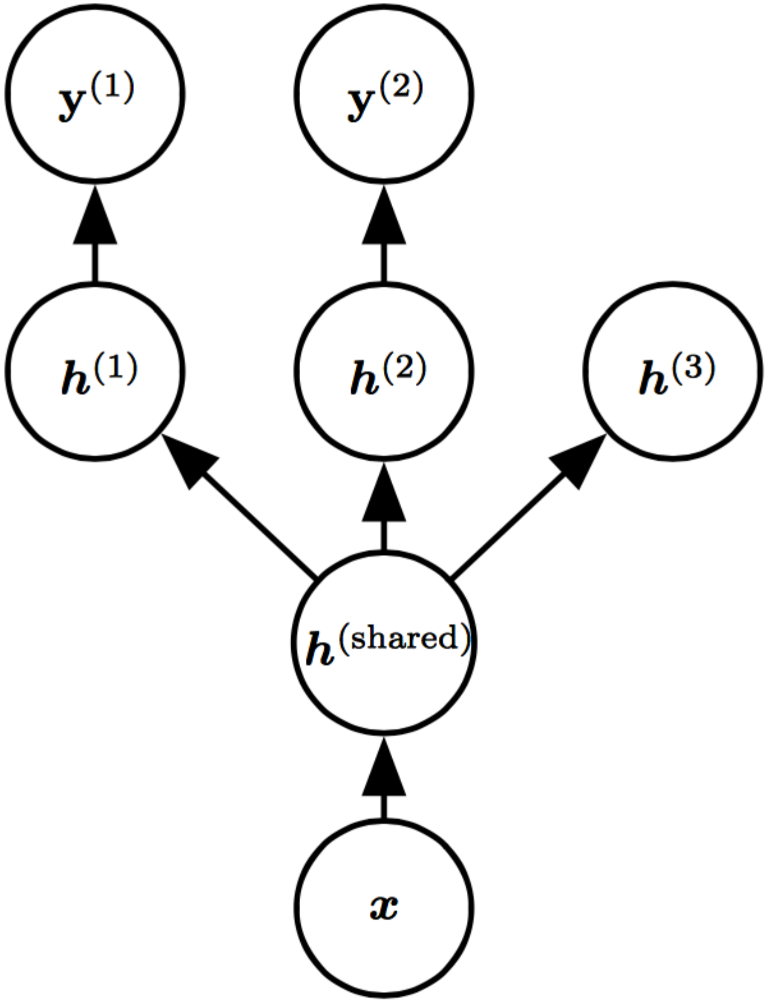
$\boldsymbol{x} +$
$\epsilon\, \text{sign}(\nabla_{\boldsymbol{x}} J(\boldsymbol{\theta}, \boldsymbol{x}, y))$

"gibbon"
w/ 99.3 %
confidence

Training on adversarial examples is mostly intended to improve security, but can sometimes provide generic regularization.

deeplearningbook.org

Multi-task Learning



Goodfellow et al. (2016)