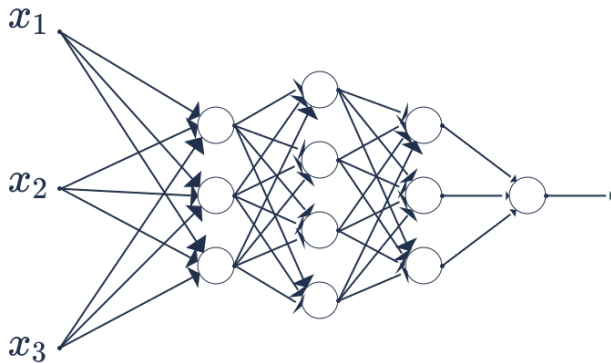


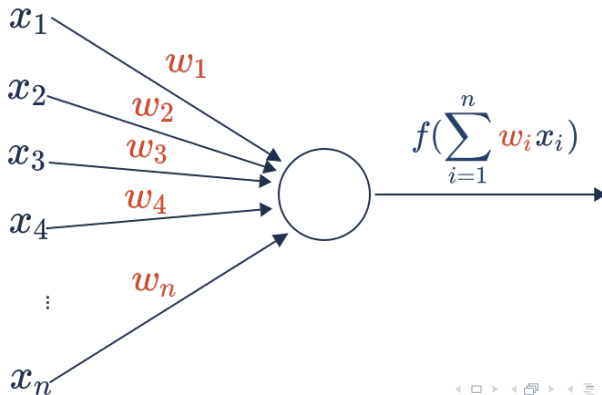


# Deep Learning

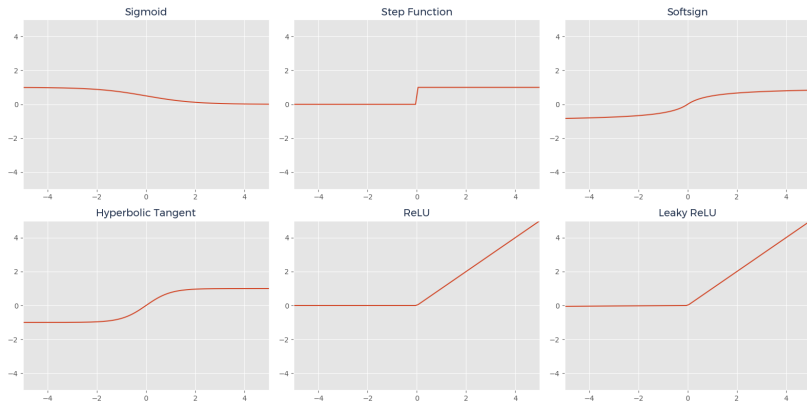


# Neuron

$$\mathbf{y} = f\left(\sum_{i=1}^n w_i x_i\right) = f(\mathbf{w}^T \mathbf{x}),$$

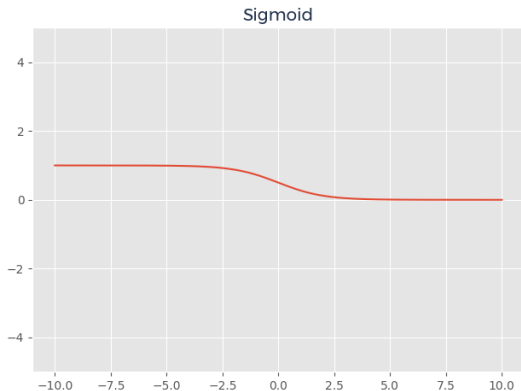


# Activation Functions



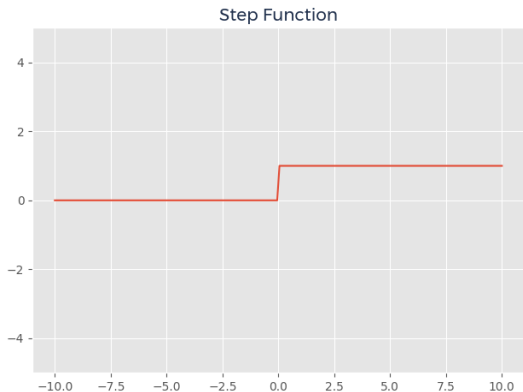
# Sigmoid

$$f_{\text{sigmoid}}(x) = \frac{1}{1 + e^{-x}}, \quad f'_{\text{sigmoid}}(x) = f_{\text{sigmoid}}(x)(1 - f_{\text{sigmoid}}(x)).$$



# Step

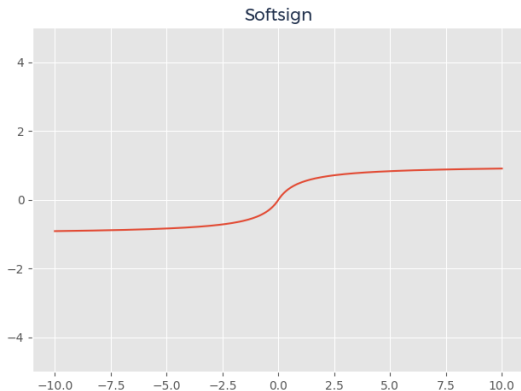
$$f_{\text{step}}(x) = \begin{cases} 0 & x < 0, \\ 1 & x \geq 0, \end{cases} \quad f'_{\text{step}}(x) = \begin{cases} 0 & x \neq 0, \\ \text{undefined} & x = 0. \end{cases}$$



# Softsign

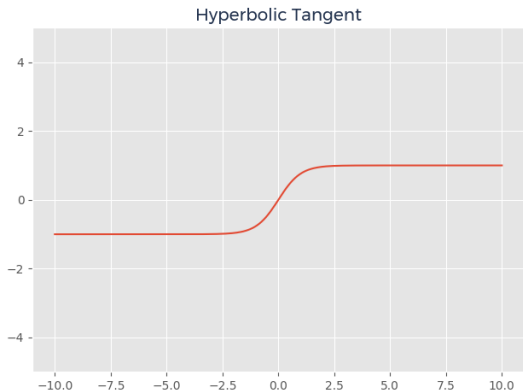
$$f_{\text{softsign}}(x) = \frac{x}{1 + |x|},$$

$$f'_{\text{softsign}}(x) = \frac{x}{(1 + |x|)^2}.$$



# Hyperbolic Tangent

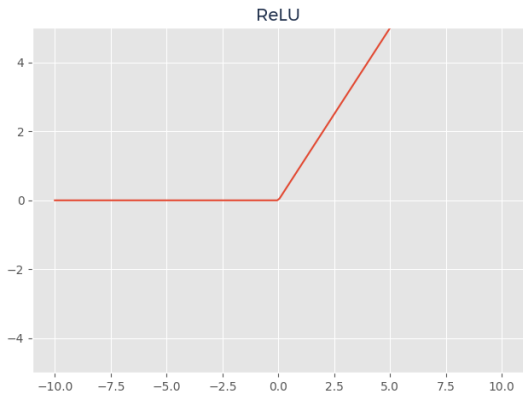
$$f_{\text{hyp. tangent}}(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}, \quad f'_{\text{hyp. tangent}}(x) = 1 - f_{\text{hyp. tangent}}(x)^2.$$





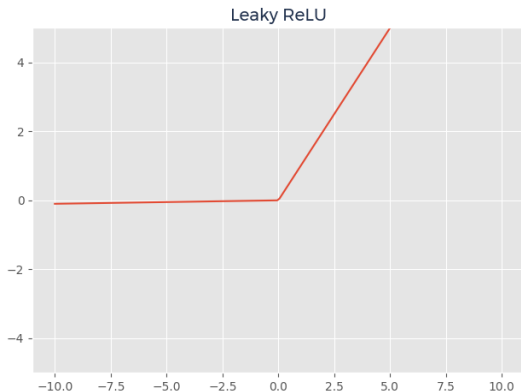
# ReLU

$$f_{\text{ReLU}}(x) = \max(0, x), \quad f'_{\text{ReLU}}(x) = \begin{cases} 0 & x < 0, \\ 1 & x \geq 0 \end{cases}.$$

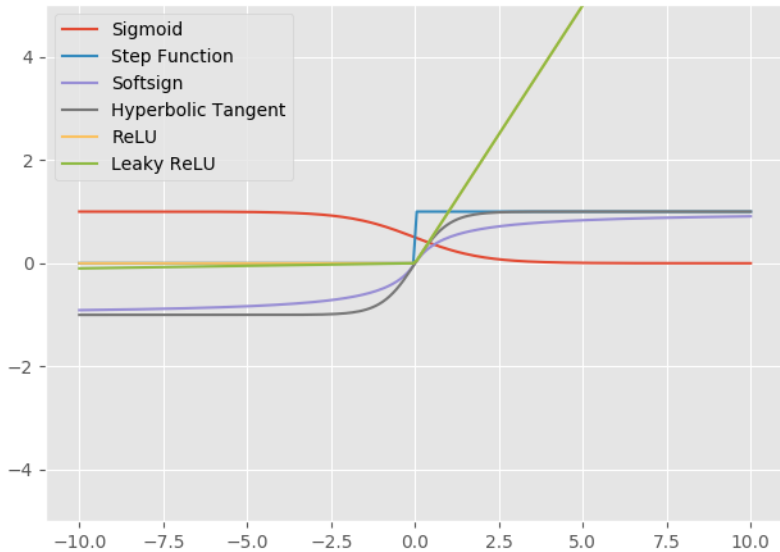


# Leaky ReLU

$$f_{\text{Leaky ReLU}}(x) = \begin{cases} 0.01x & x < 0, \\ x & x \geq 0, \end{cases} \quad f'_{\text{Leaky ReLU}}(x) = \begin{cases} 0.01 & x \neq 0, \\ 1 & x = 0, \end{cases}.$$



## Activation Function Comparison



# Training - Cost / Error Function

$$\epsilon_i = \|\hat{y}_i - y_i\|_2.$$

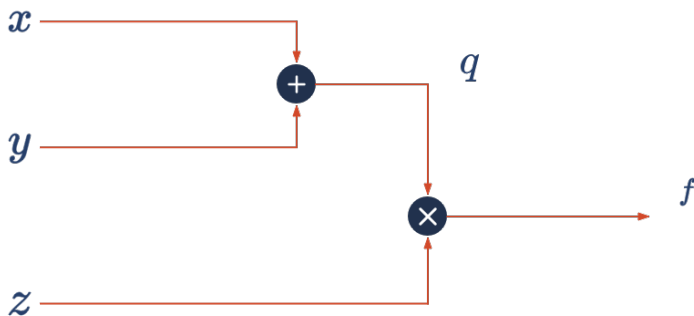
# Training - Gradient Descent

$$\mathbf{w}_{t+1} = \mathbf{w}_t - \alpha \nabla \epsilon$$

$$\frac{\partial z}{\partial x} = \frac{\partial z}{\partial y} \times \frac{\partial y}{\partial x}.$$

# Backpropagation Example

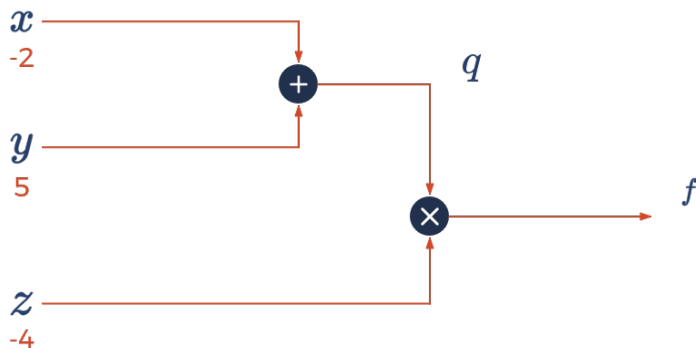
$$f(x, y, z) = (x + y)z$$



# Backpropagation Example

$$x = -2, y = 5, z = -4$$

$$f(x, y, z) = (x + y)z$$

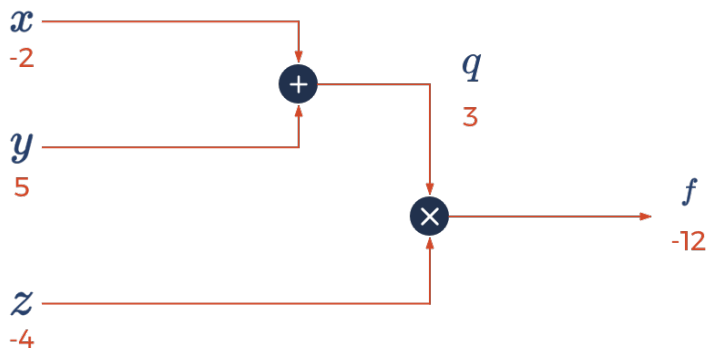




# Backpropagation Example

$$x = -2, y = 5, z = -4$$

$$f(x, y, z) = (x + y)z$$



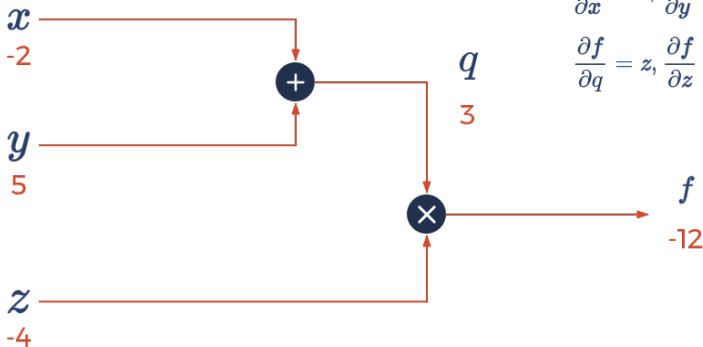
# Backpropagation Example

$$x = -2, y = 5, z = -4$$

$$f(x, y, z) = (x + y)z$$

$$\frac{\partial q}{\partial x} = 1, \frac{\partial q}{\partial y} = 1.$$

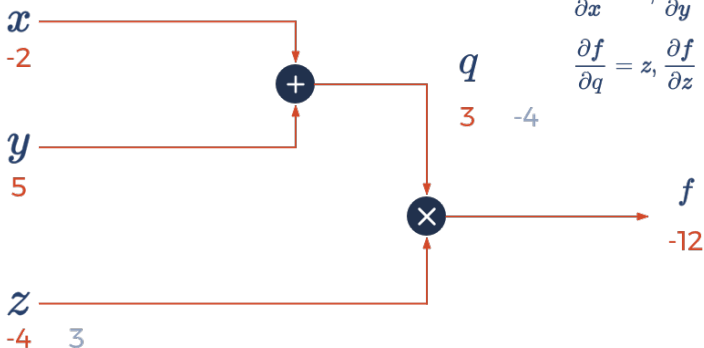
$$\frac{\partial f}{\partial q} = z, \frac{\partial f}{\partial z} = q,$$



# Backpropagation Example

$$x = -2, y = 5, z = -4$$

$$f(x, y, z) = (x + y)z$$



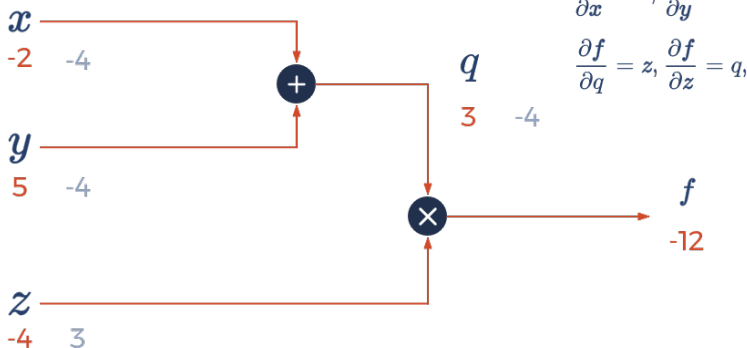
$$\frac{\partial q}{\partial x} = 1, \frac{\partial q}{\partial y} = 1.$$

$$\frac{\partial f}{\partial q} = z, \frac{\partial f}{\partial z} = q,$$

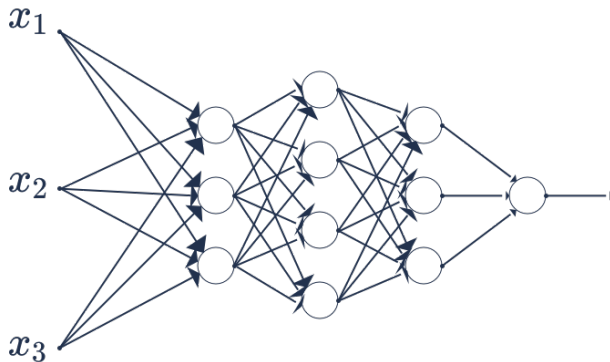
# Backpropagation Example

$$x = -2, y = 5, z = -4$$

$$f(x, y, z) = (x + y)z$$



# Feed Forward Neural Network

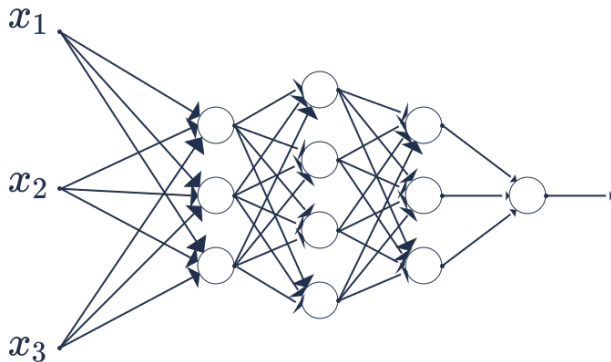


# Overfitting - Regularization

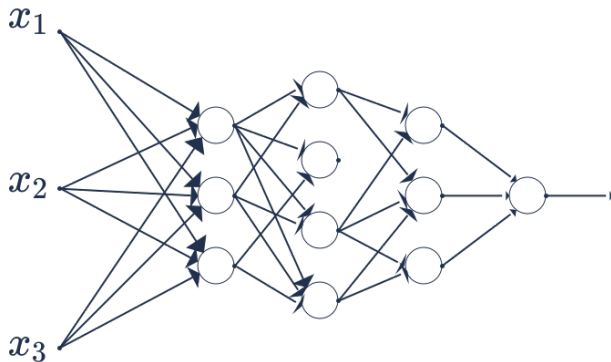
$$\epsilon = ||\hat{\mathbf{y}} - \mathbf{y}||_2.$$

$$\epsilon = ||\hat{\mathbf{y}} - \mathbf{y}||_2 + ||\mathbf{w}||_p^q.$$

# Overfitting - Dropout



# Overfitting - Dropout





## Demo

# Questions

These slides are designed for educational purposes, specifically the CSCI-470 Introduction to Machine Learning course at the Colorado School of Mines as part of the Department of Computer Science.

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