RocPy | Rochester Data Science Meetup Group

Neural Networks Demystified

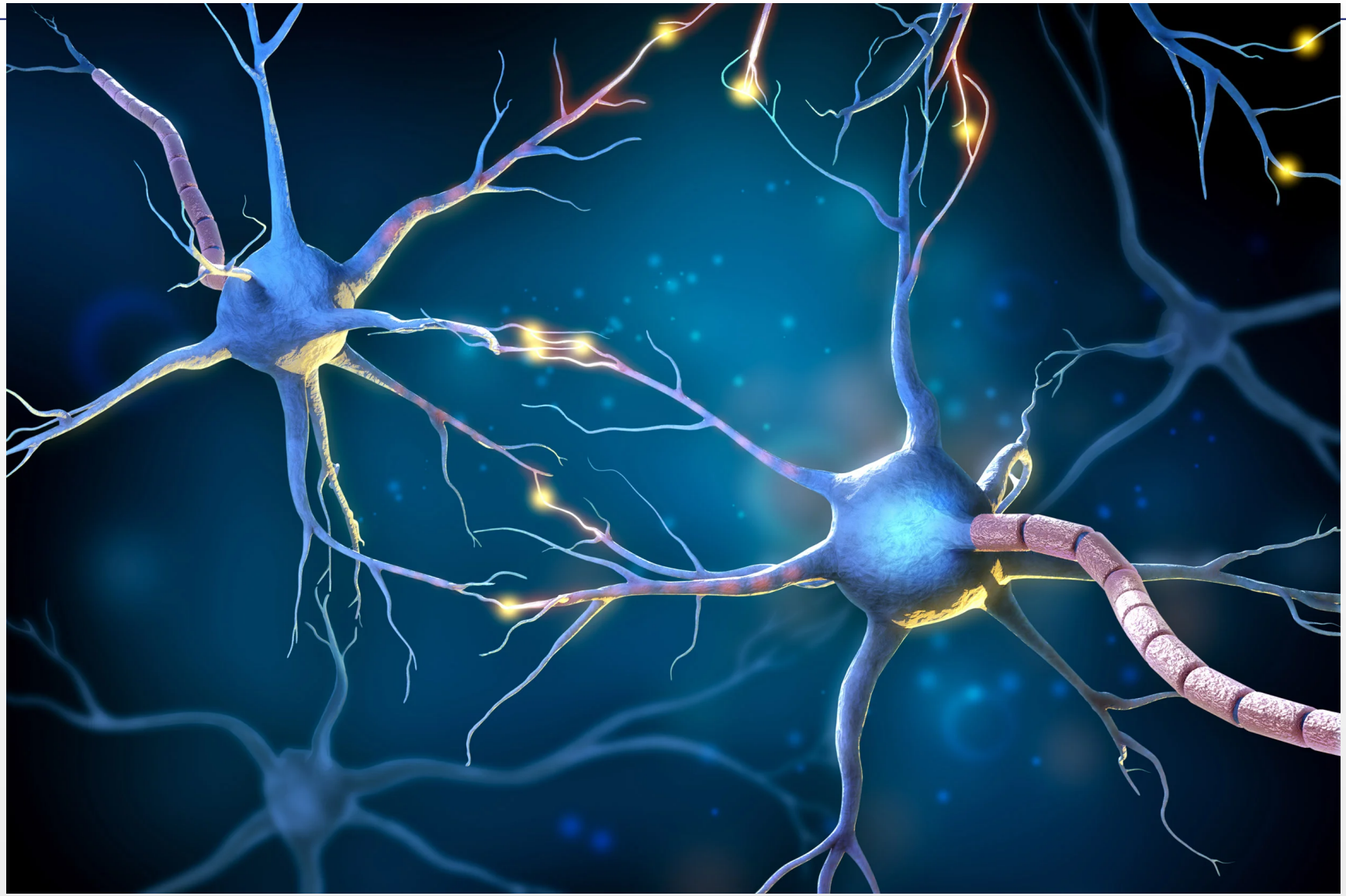
April 10th, 2025

Evan Raw

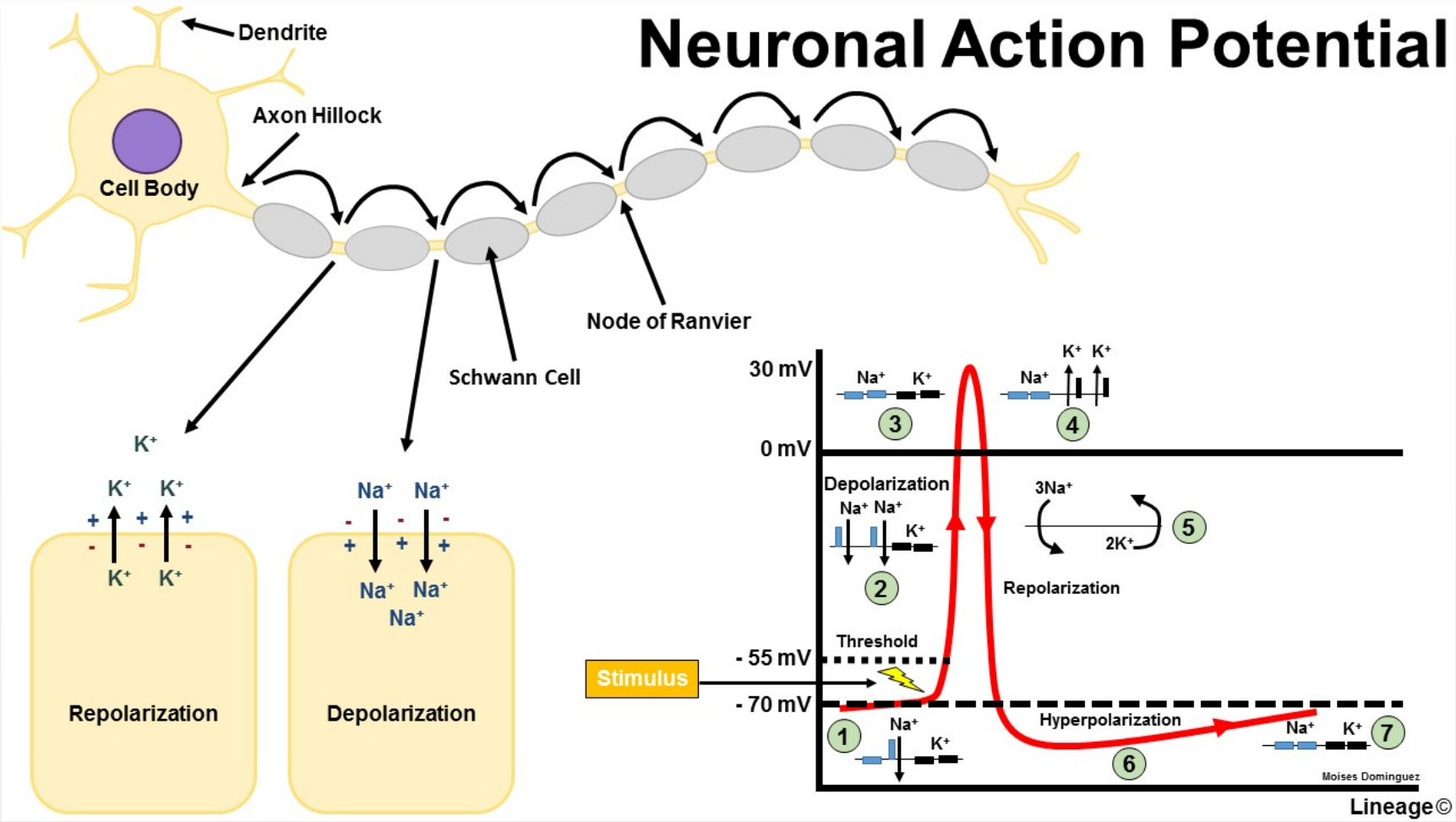
Table of Contents

Get the Slides

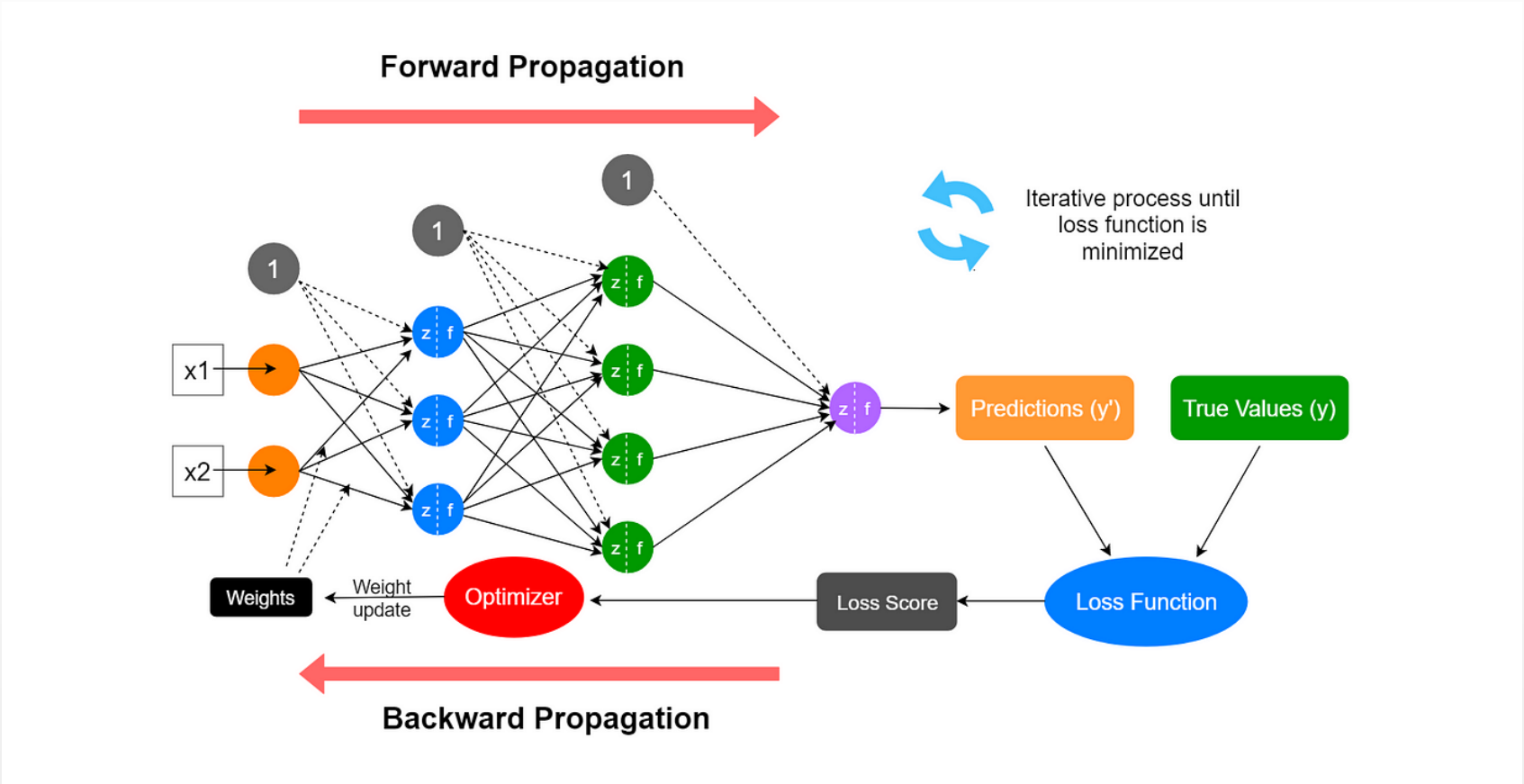
Biological Inspiration



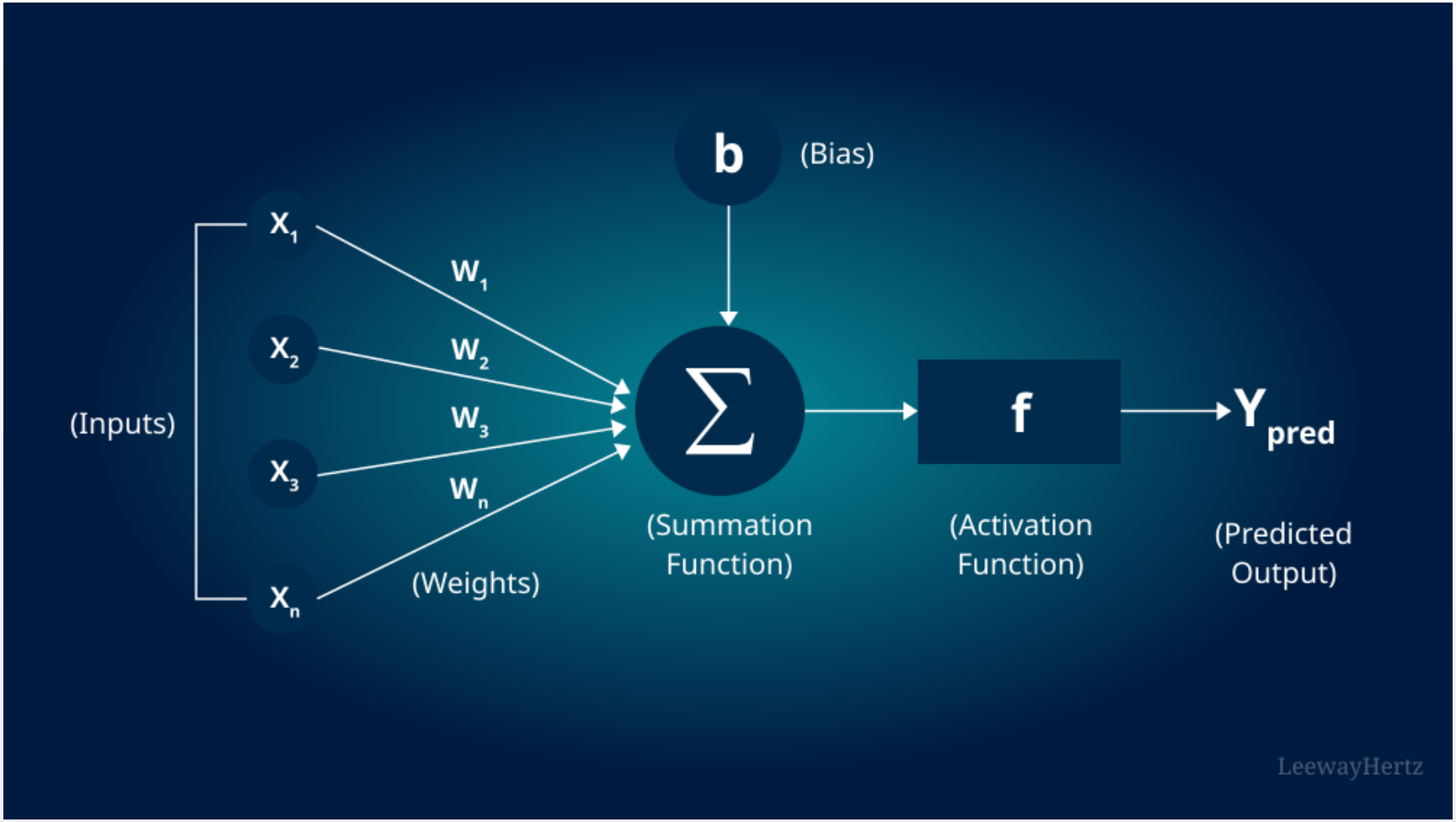
Neuron


Neuronal Action Potential
Dendrite
Axon Hillock
Cell Body
Node of Ranvier
Schwann Cell
K+
Repolarization
Depolarization
30 mV
0 mV
- 55 mV
- 70 mV
Threshold
Stimulus
Depolarization
Repolarization
Hyperpolarization
3Na+
2K+
Moises Dominguez
Lineage©

Neural Network



Perceptron Diagram

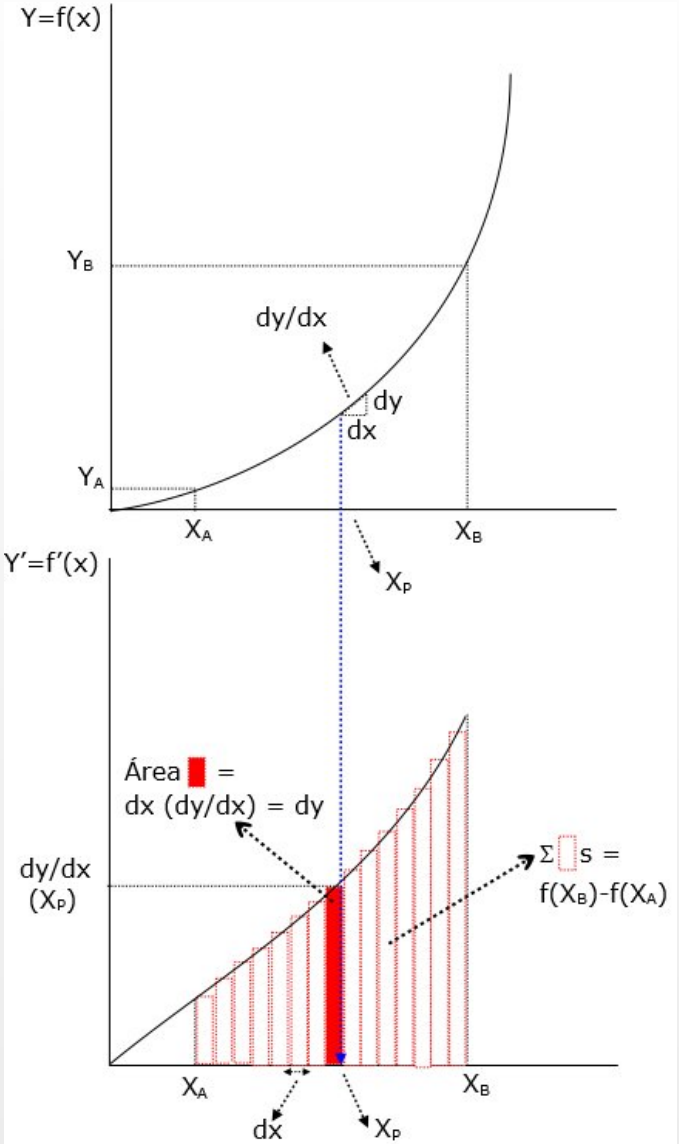


Perceptron

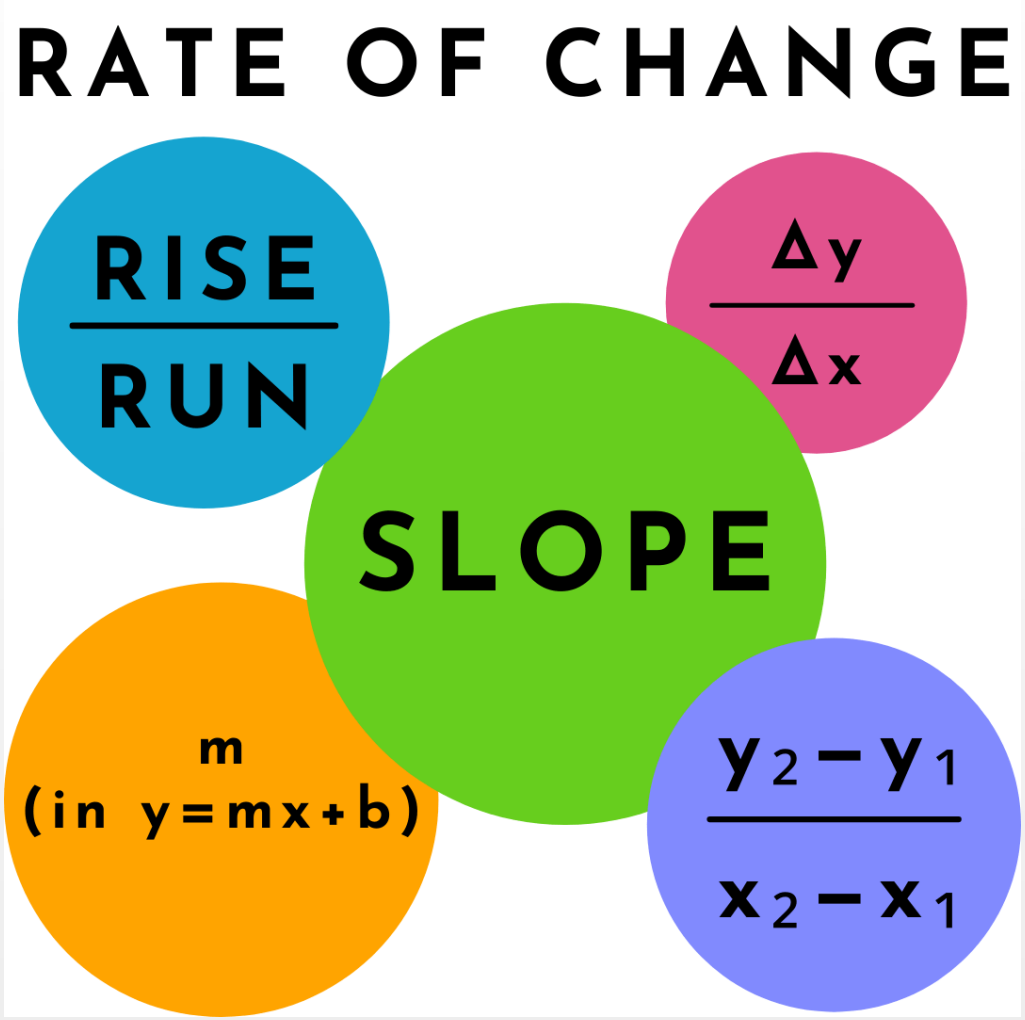
$$y = \sigma\left(\sum_{i=1}^{n} w_i x_i + b\right)$$

```python
xs = [1.0, 2.0, 3.0, 4.0, 5.0] # inputs
ws = [0.5, 0.2, 0.1, 0.7, 0.4] # weights
b  = 3.                        # bias

Z  = b
for x, w in zip(xs, ws):
    Z += x * w

y = min(0, Z) # ReLU activation
```

Calculus


Y=f(x)
Y_B
dy/dx
dy
dx
Y_A
X_A
X_B
X_P
Y'=f'(x)
Área = dx (dy/dx) = dy
dy/dx (X_P)
Σ s = $f(X_B)-f(X_A)$
X_A
X_B
dx
X_P

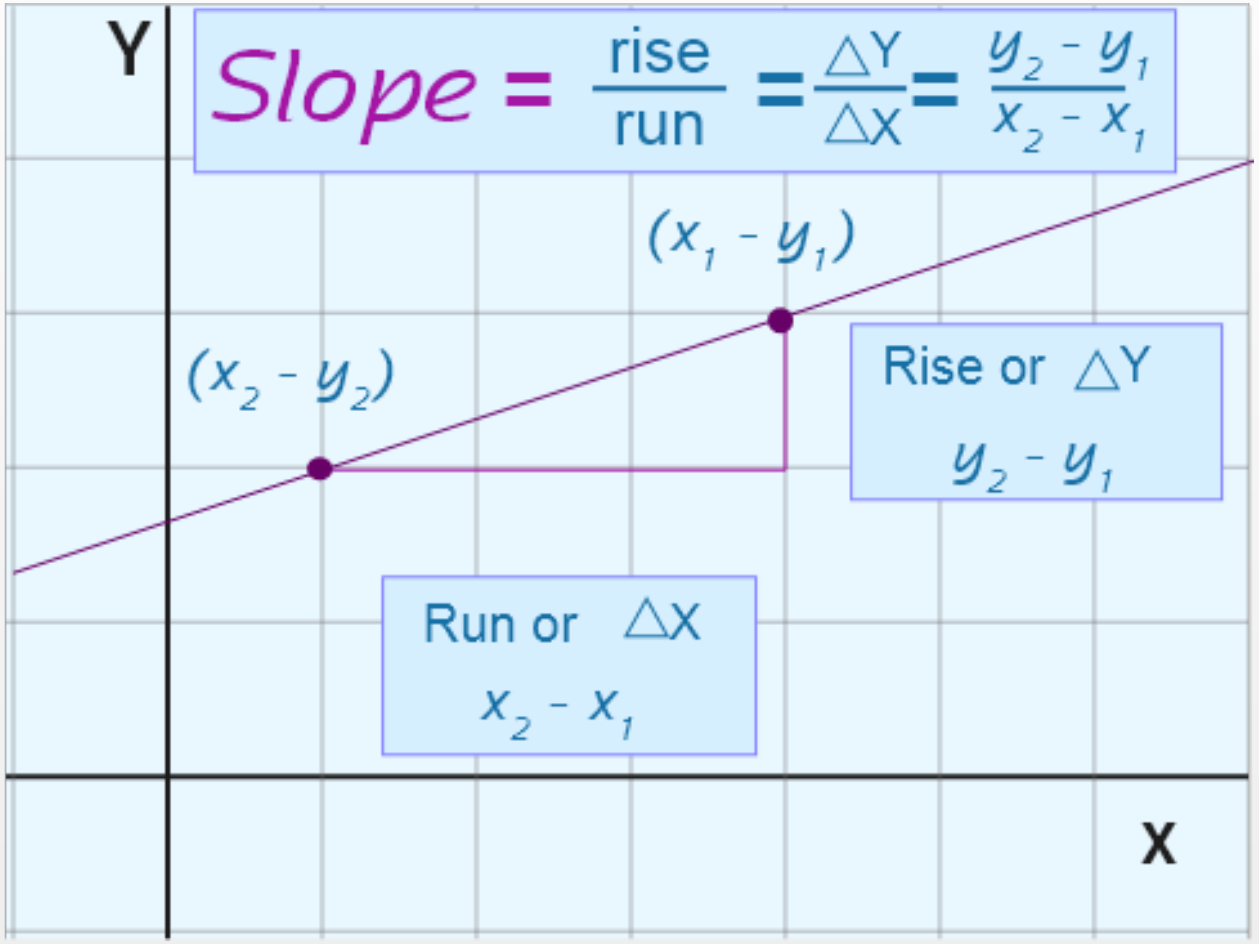
Derivatives



Derivatives Are Ubiquitous

- How fast is your internet? (bits / second)
- How fast is your car going? (distance / time)
- How much are you paid per hour/year? (currency / time)
- More or less anytime a measurement is represented as (thing1 / thing2)

Slope Formula



Derivative Definition

$$\frac{dy}{dx} = \lim_{h \to 0} \frac{f(x+h) - f(x)}{h}$$

$$m = \lim_{x \to a} \frac{f(x) - f(a)}{x \to a}$$

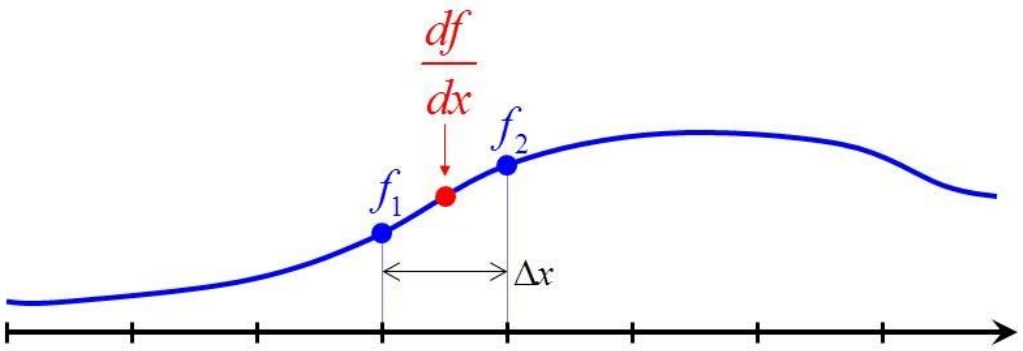
Finite Differences Derivative

The Basic Finite-Difference Approximation

CEM

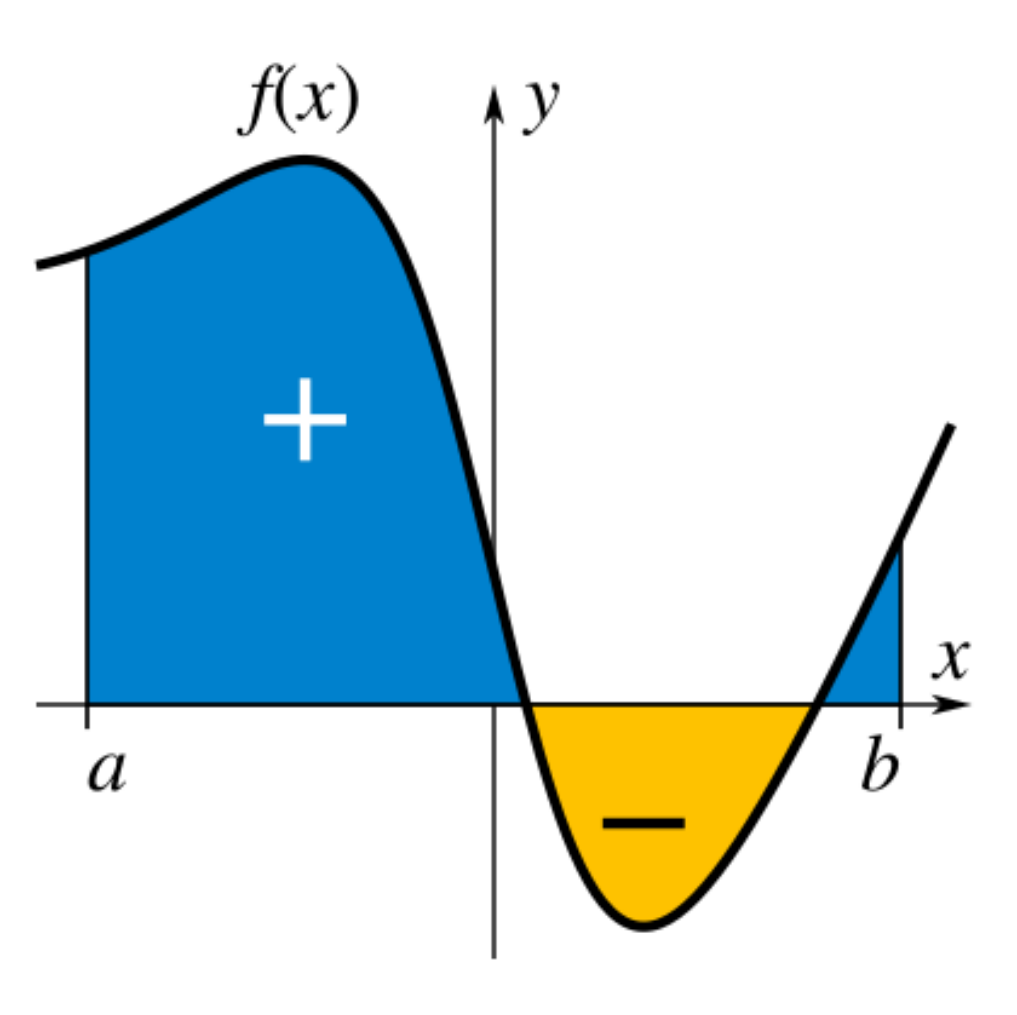
$$\frac{df_{1.5}}{dx} \approx \frac{f_2 - f_1}{\Delta x}$$

second-order accurate
first-order derivative



This is the only finite-difference approximation we will use in this course!

Integrals



Integrals Are Ubiquitous

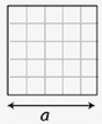
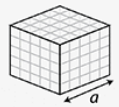
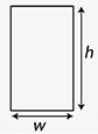
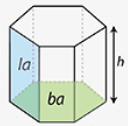
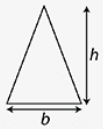
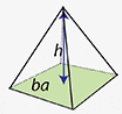
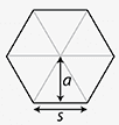
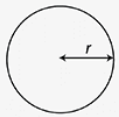
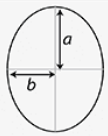
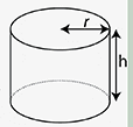
Any analog (non-discrete) sum of values is an integral

- **Area (for square, width * height)**
- **Volume (cup, gallon, liter)**
- **How fast is your car going? (distance / time)**
- **How much are you paid per hour/year? (currency / time)**
- **More or less anytime a non-discrete measurement is represented as (thing1 / thing2)**

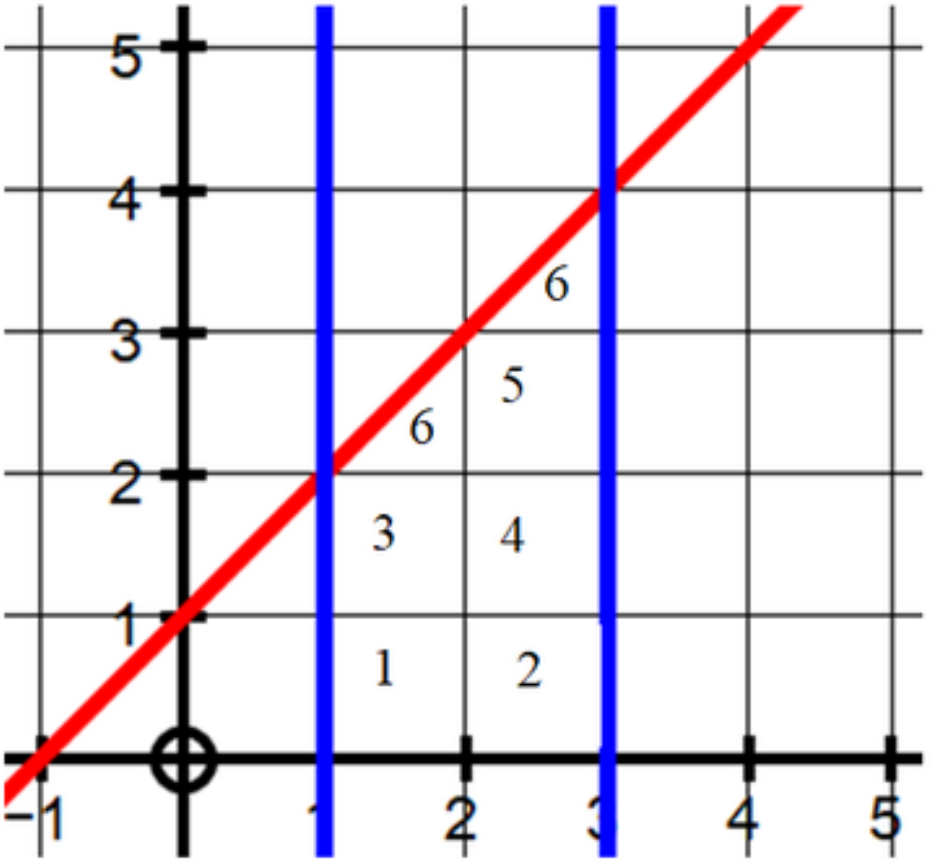
Area/Volume Calculations

SKILLS YOU NEED
Helping You Develop Life Skills

Area, Surface Area & Volume
reference sheet

Two-dimensional plane shapes	**Area** *The measure of how many squares will fit into a shape.* Units²	Three-dimensional solid shapes	**Surface Area** *The measure of the area of all outward facing sides.* Units²	**Volume** *The measure of how many cubes will fit into a shape.* Units³
Square 	Area = a^2 or $a \times a$ **Example:** $a = 5cm$ $Area = 5^2 = 25cm^2$	**Cube** 	Surface Area = $6 \times a^2$ **Example:** $a = 5cm$ $Surface\ Area = 150cm^2$	Volume = a^3 or $a \times a \times a$ **Example:** $a = 5cm.$ $Volume = 125cm^3$
Rectangle 	Area = $w \times h$ **Example:** $w = width = 10cm$ $height = 20cm$ $Area = 10 \times 20 = 200cm^2$	**Prism** 	Surface Area = $2 \times ba + la$ **Example:** $ba = base\ area = 20cm^2$ $la = lateral\ area\ (all\ sides) = 60cm^2$ $Surface\ area =$ $2 \times 20 + 60 = 100cm^2$	Volume = $ba \times h$ **Example:** $ba = base\ area = 20cm^2$ $h = height = 5cm$ $Volume = 20 \times 5 = 100cm^3$
Triangle 	Area = $b \times h \times 0.5$ **Example:** $b = base = 20cm$ $h = vertical\ height = 15cm$ $Area = 20 \times 15 \times 0.5 = 150cm^2$	**Pyramid** 	Surface Area = $ba + la$ **Example:** $ba = base\ area = 16cm^2$ $la = lateral\ area\ (all\ sides) = 60cm^2$ $Surface\ area = 16 + 60 = 76cm^2$	Volume = $ba \times h \times 1/3$ **Example:** $ba = base\ area = 16cm^2$ $h = height = 9cm$ $Volume = 16 \times 9 \times 1/3 = 48cm^3$
Reg Polygon 	Area = $n \times s \times a \times 0.5$ **Example:** $n = number\ of\ sides = 6$ $length\ of\ side = 5cm$ $a = apothem = 15cm$ $Area = 6 \times 5 \times 15 \times 0.5 = 225cm^2$	**R. Polyhedron** 	Surface Area = $fa \times s$ **Example:** $fa = area\ of\ one\ side = 200cm^2$ $s = number\ of\ sides = 12$ $Surface\ area = 200 \times 12 = 2400cm^2$	**Example:** *There is no simple generic formula for working out the volume of a regular polyhedron.*
Circle 	Area = $\pi \times r^2$ **Example:** $\pi = pi = 3.14$ $r = radius = 5cm$ $Area = 3.14 \times 5^2 = 3.14 \times 5 \times 5 = 78.5cm^2$	**Sphere** 	Surface Area = $4 \times \pi \times r^2$ **Example:** $r = radius = 4.5cm$ $Surface\ area = 4 \times 3.14 \times 20.25$ $= 254.5\ cm^2\ (Approx)$	Volume = $4/3 \times \pi \times r^3$ **Example:** $r = radius = 4.5cm$ $Volume = 4/3 \times 3.14 \times 4.5^3$ $= 381.5cm^3\ (Approx)$
Ellipse 	Area = $\pi \times a \times b$ **Example:** $\pi = pi = 3.14$ $a = radius\ of\ long\ axis = 6$ $b = radius\ short\ axis = 4$ $Area = 3.14 \times 6 \times 4 \times 5 = 75.36cm^2$	**Cylinder** 	Surface Area = $2\pi rh + 2\pi r^2$ **Example:** $r = radius = 5cm$ $h = height = 10cm$ $Surface\ area = 2 \times 3.14 \times 5 \times 10$ $+ 2 \times 3.14 \times 25 = 471cm^2$	Volume = $\pi \times r^2 \times h$ **Example:** $r = radius = 5cm$ $h = height = 10cm$ $Volume = 3.14 \times 25 \times 10$ $= 785cm^3\ (Approx)$

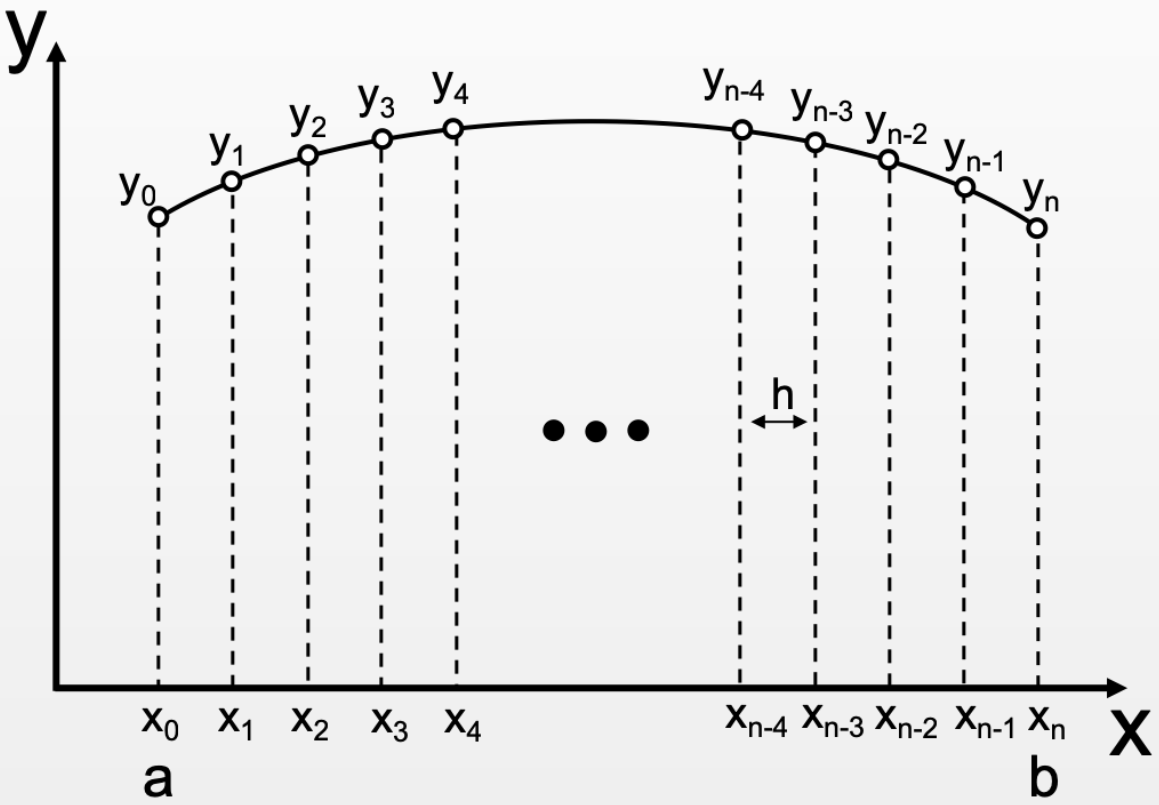
Integral Approximation



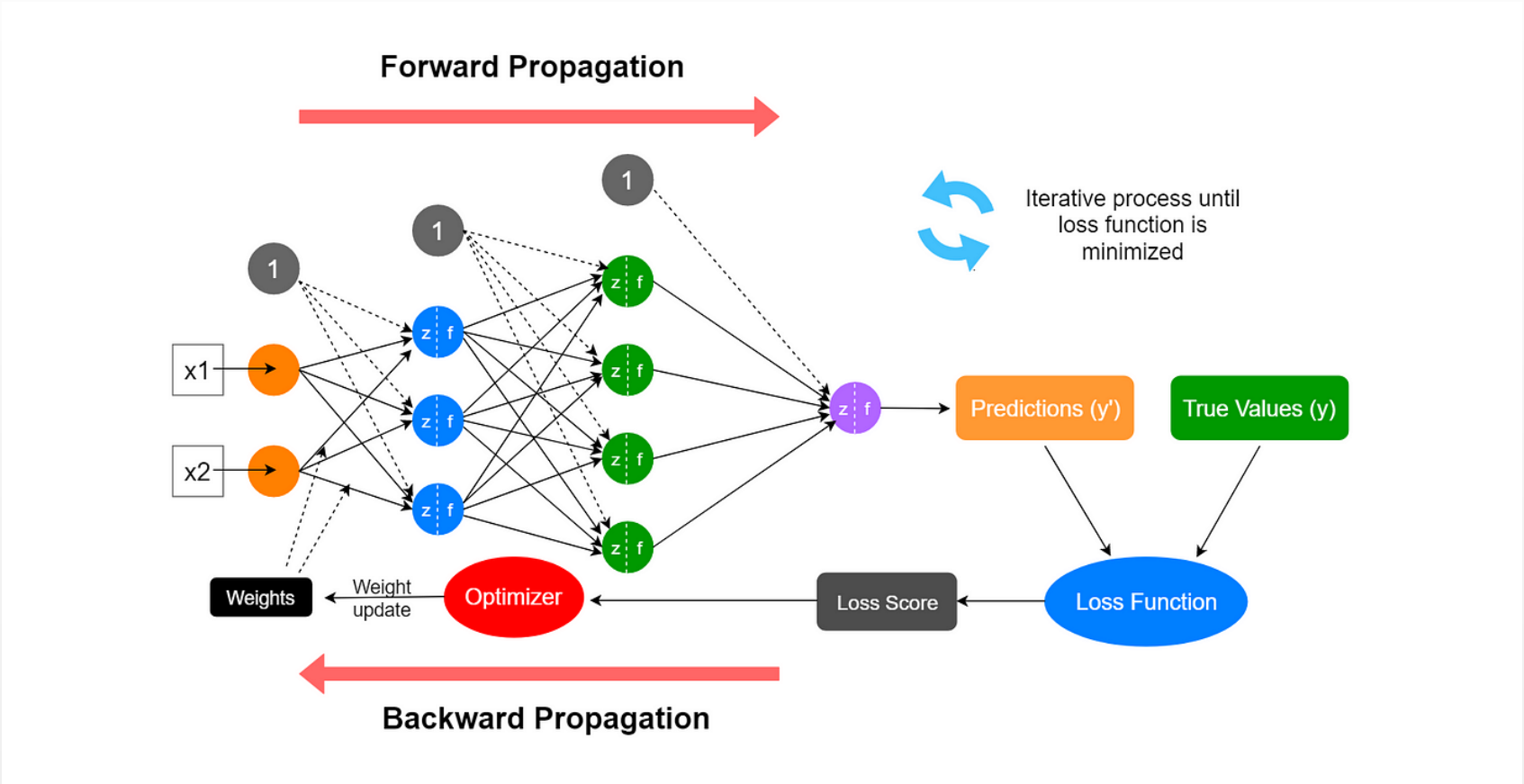
Area = 6 squares

Just count them!

Finite Differences Integral



Neural Network

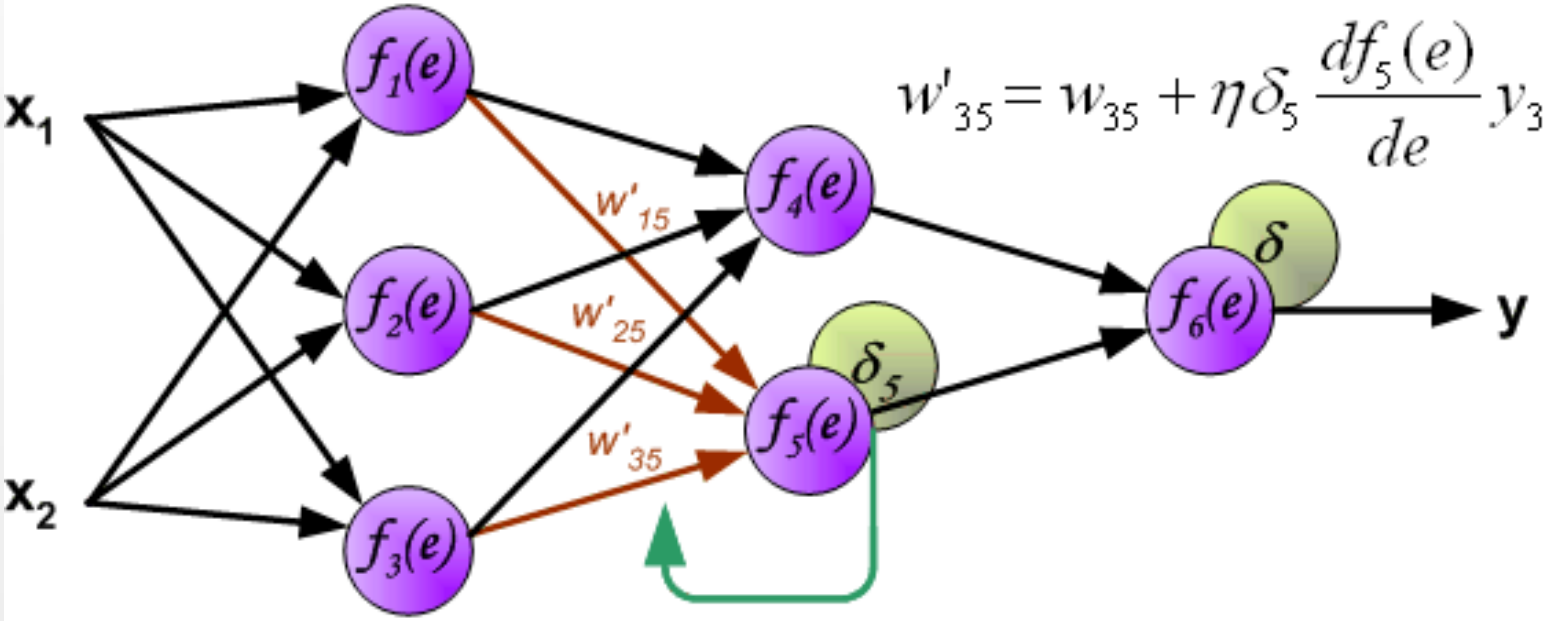


Backpropogation

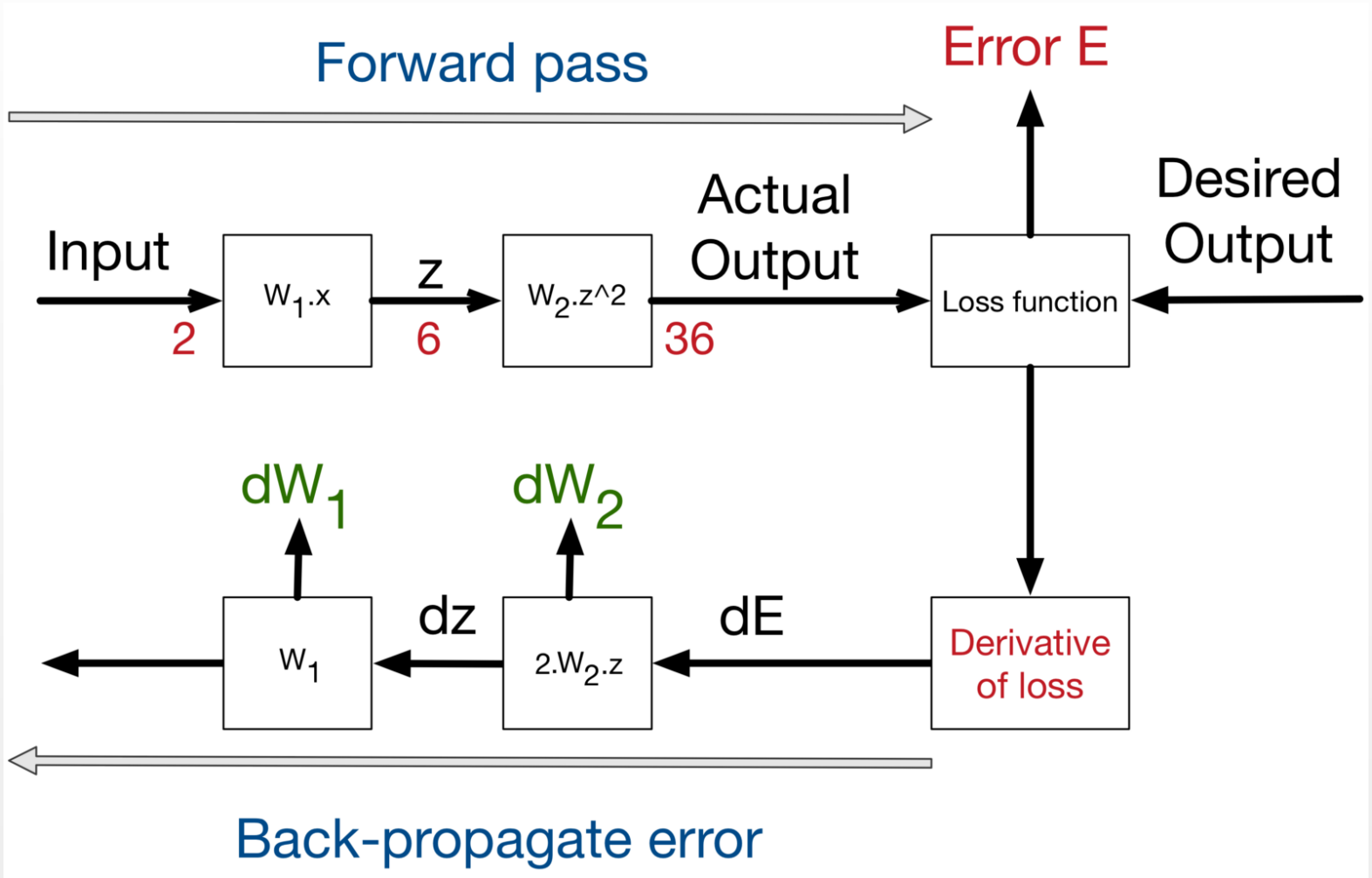
$$w'_{15} = w_{15} + \eta \delta_5 \frac{df_5(e)}{de} y_1$$

$$w'_{25} = w_{25} + \eta \delta_5 \frac{df_5(e)}{de} y_2$$

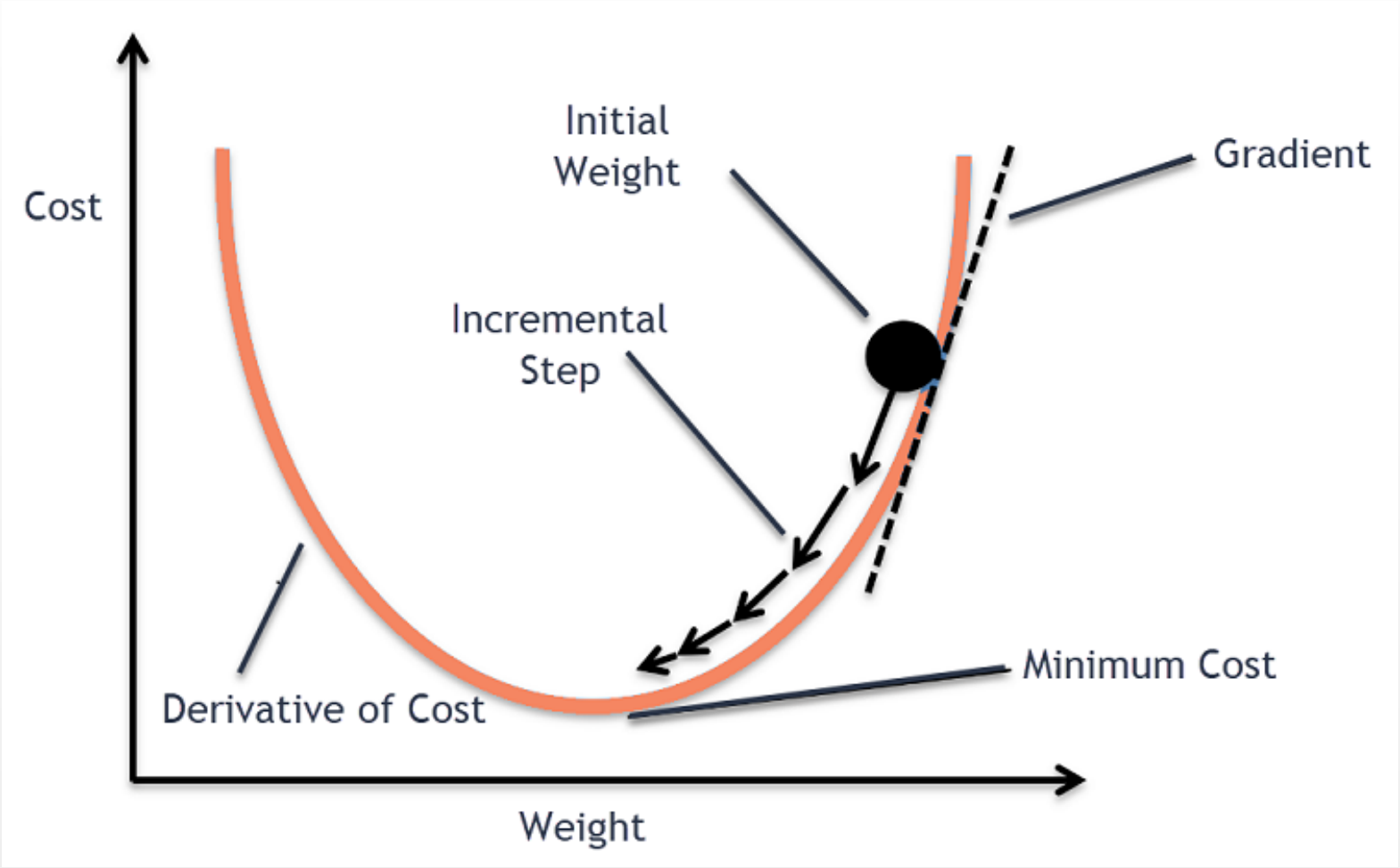
$$w'_{35} = w_{35} + \eta \delta_5 \frac{df_5(e)}{de} y_3$$



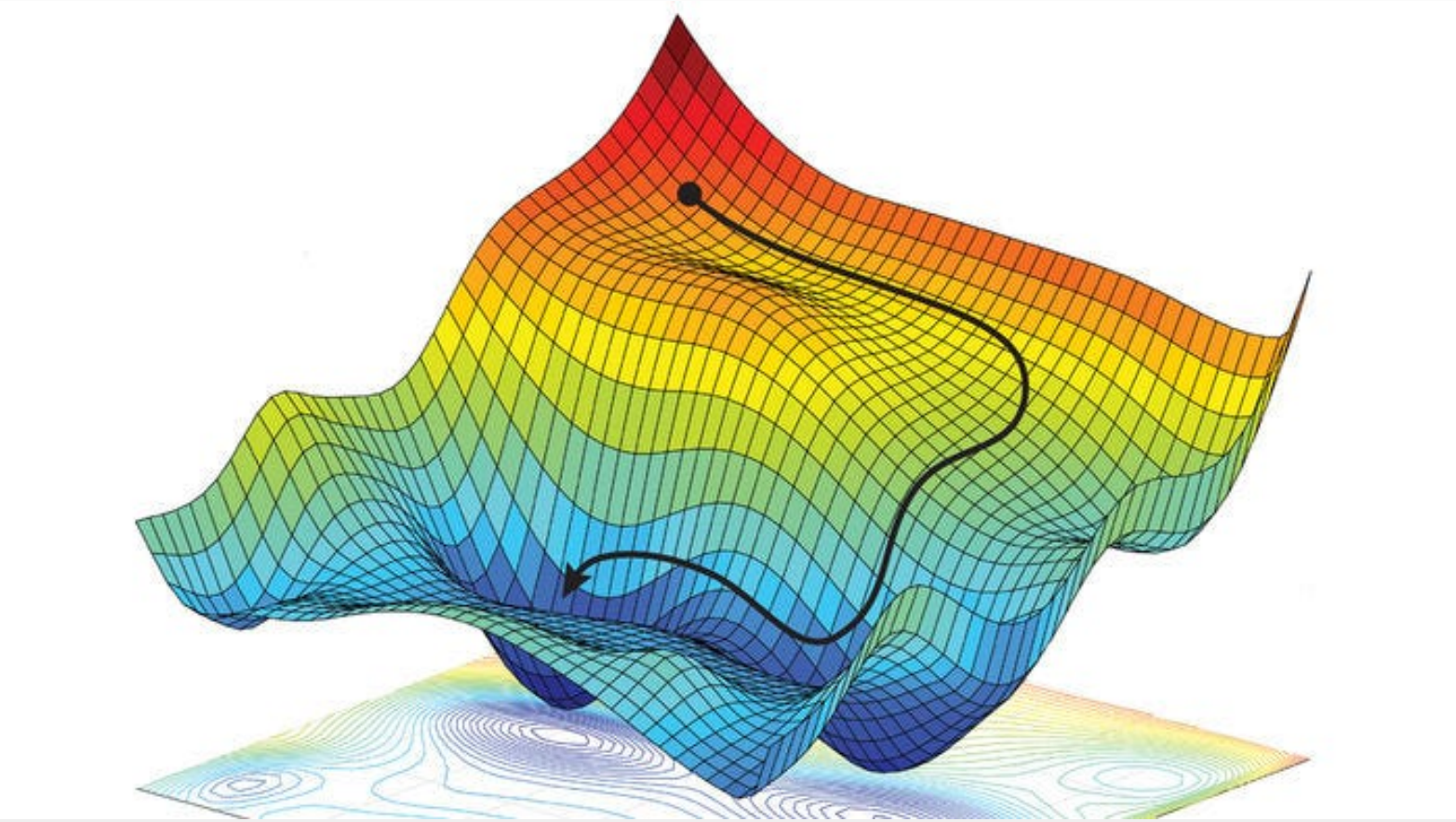
Backpropogating Error



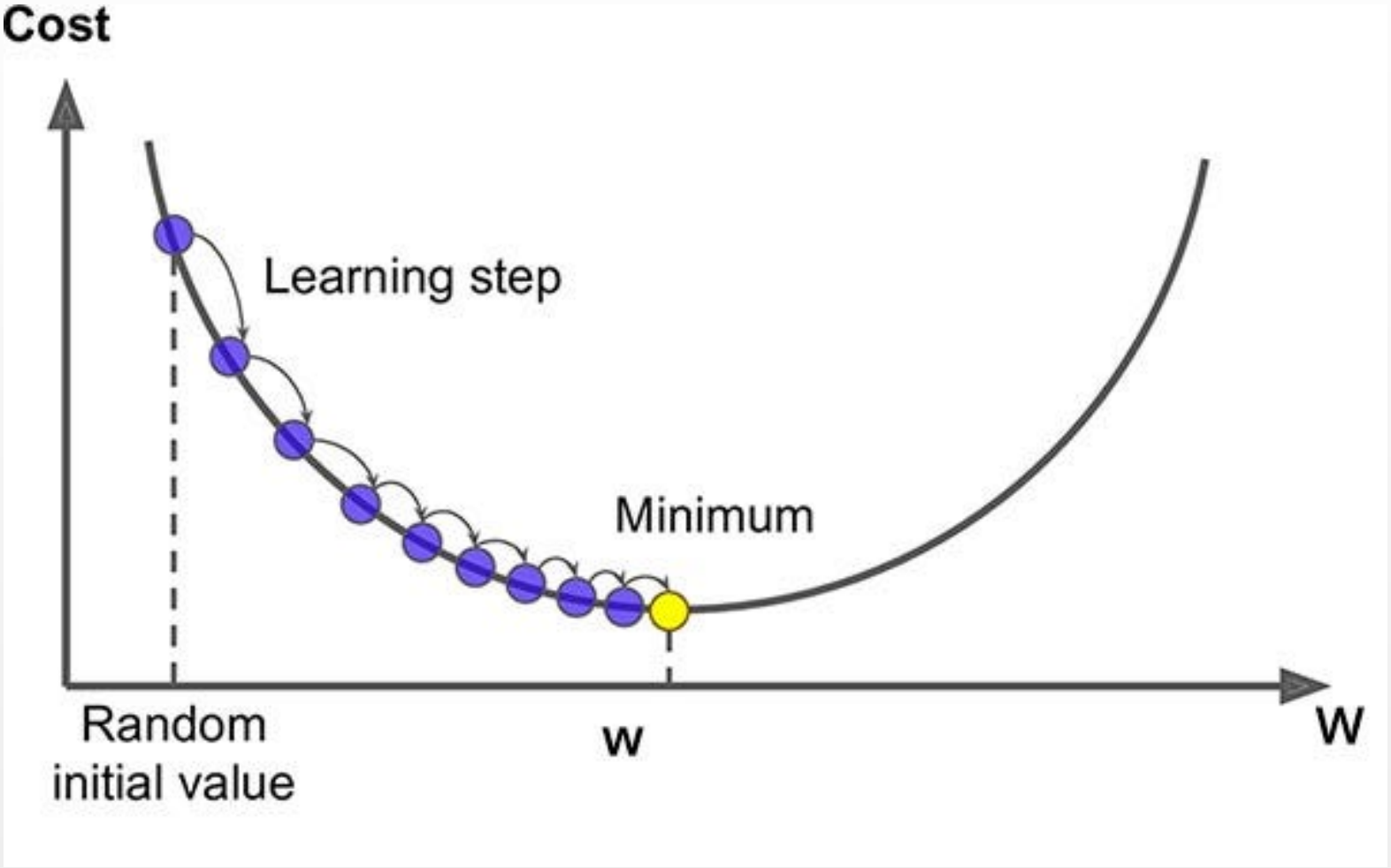
Gradient Descent



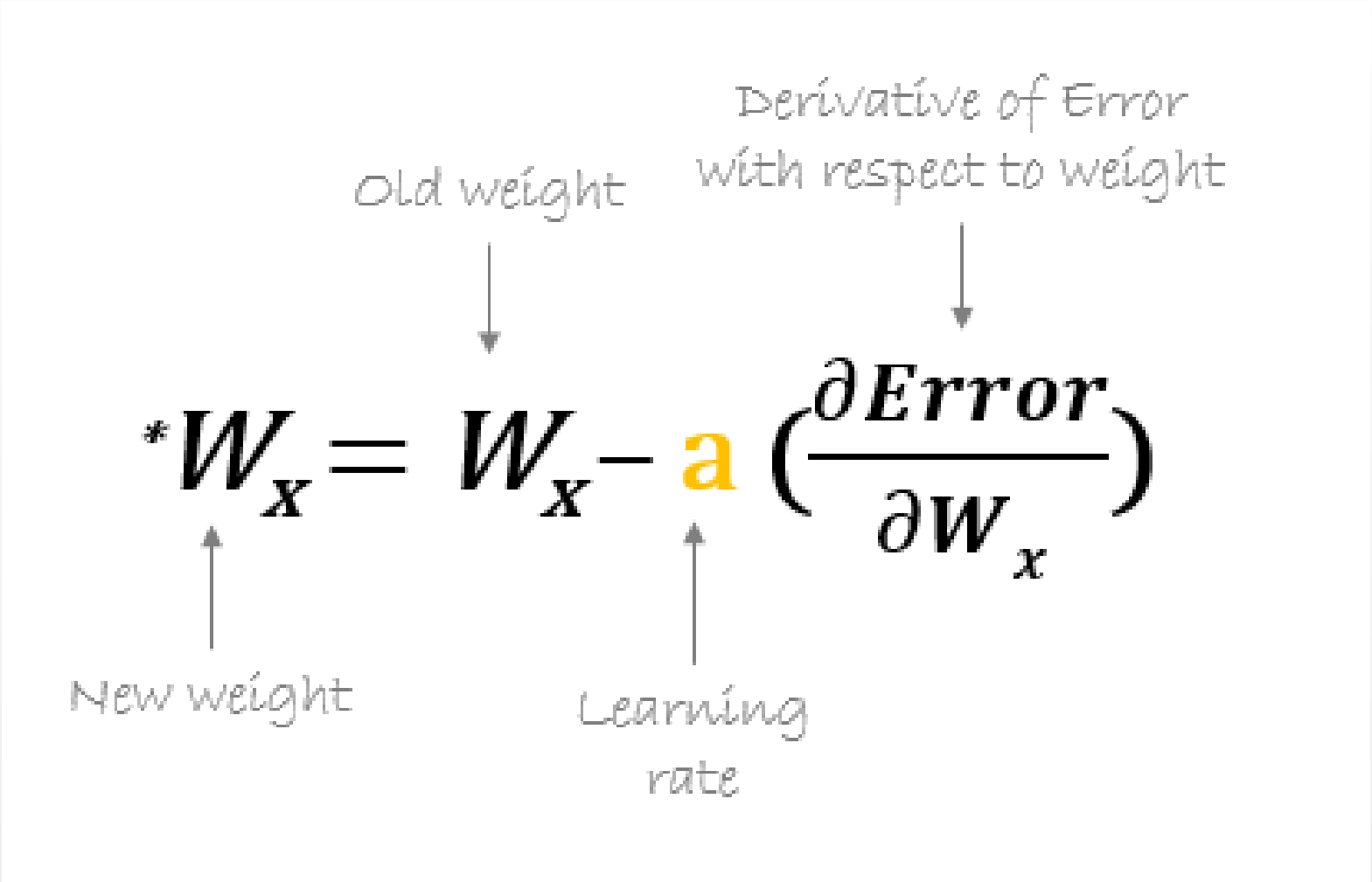
Gradient Descent 2D



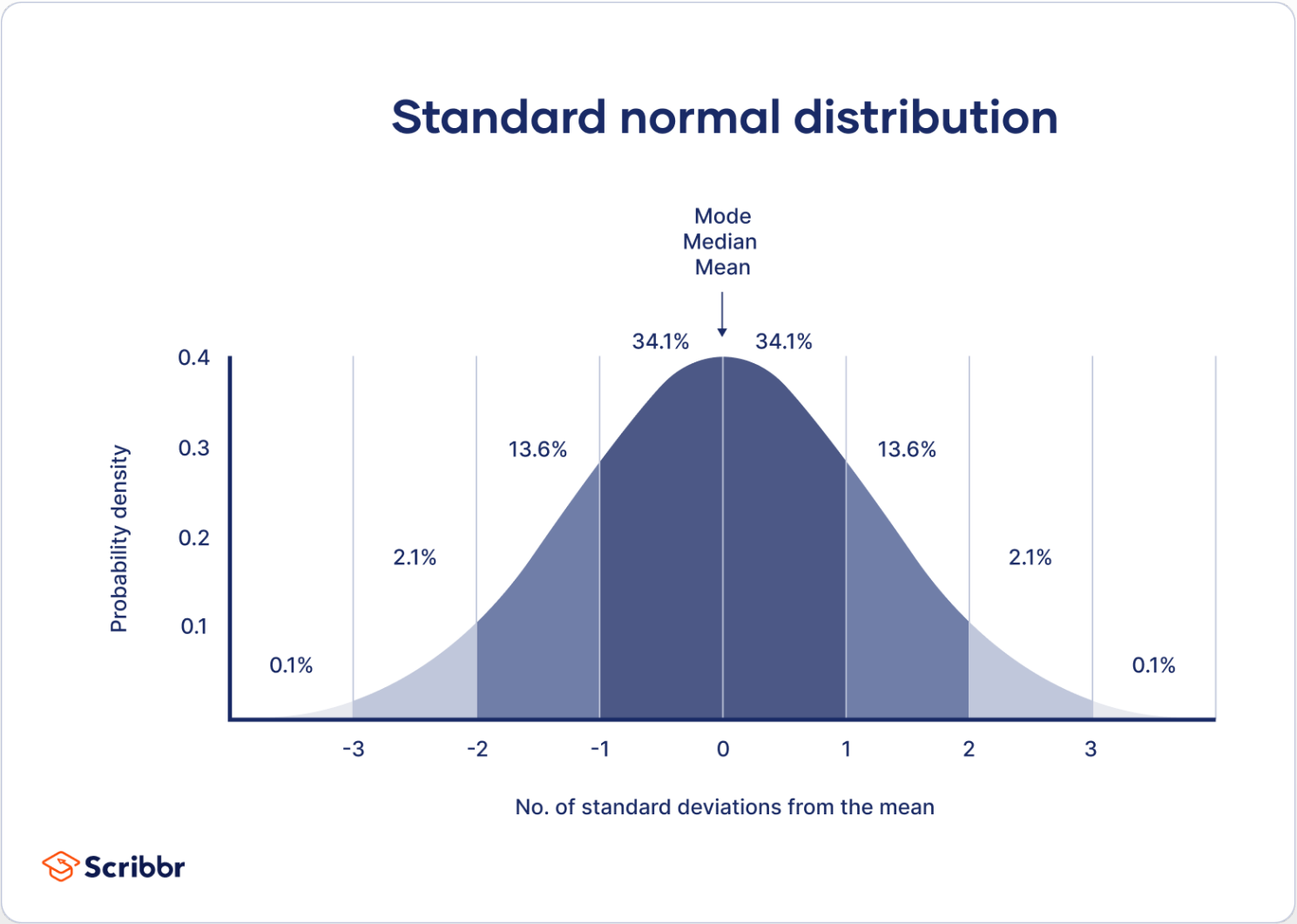
Gradient Descent in Neural Networks



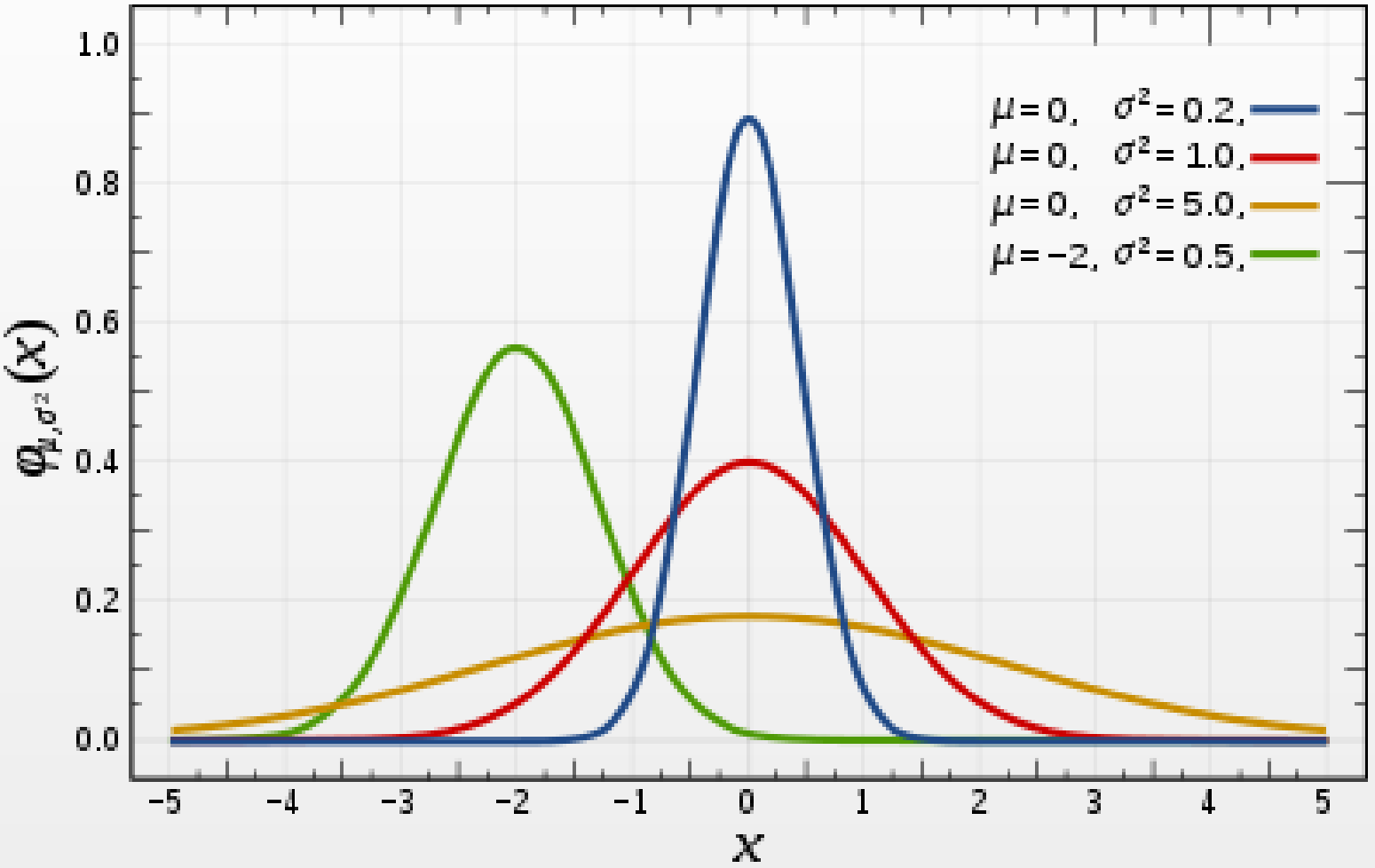
Gradient Formula for Updating Weights



Normal Distribution



Examples of Normal Distributions

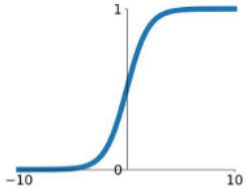


Activation Functions

Activation Functions

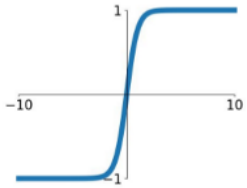
Sigmoid

$\sigma(x) = \frac{1}{1+e^{-x}}$



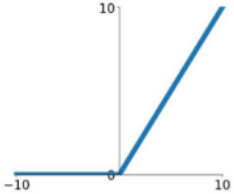
tanh

$\tanh(x)$



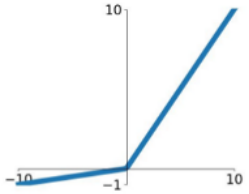
ReLU

$\max(0, x)$



Leaky ReLU

$\max(0.1x, x)$

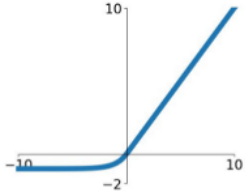


Maxout

$\max(w_1^T x + b_1, w_2^T x + b_2)$

ELU

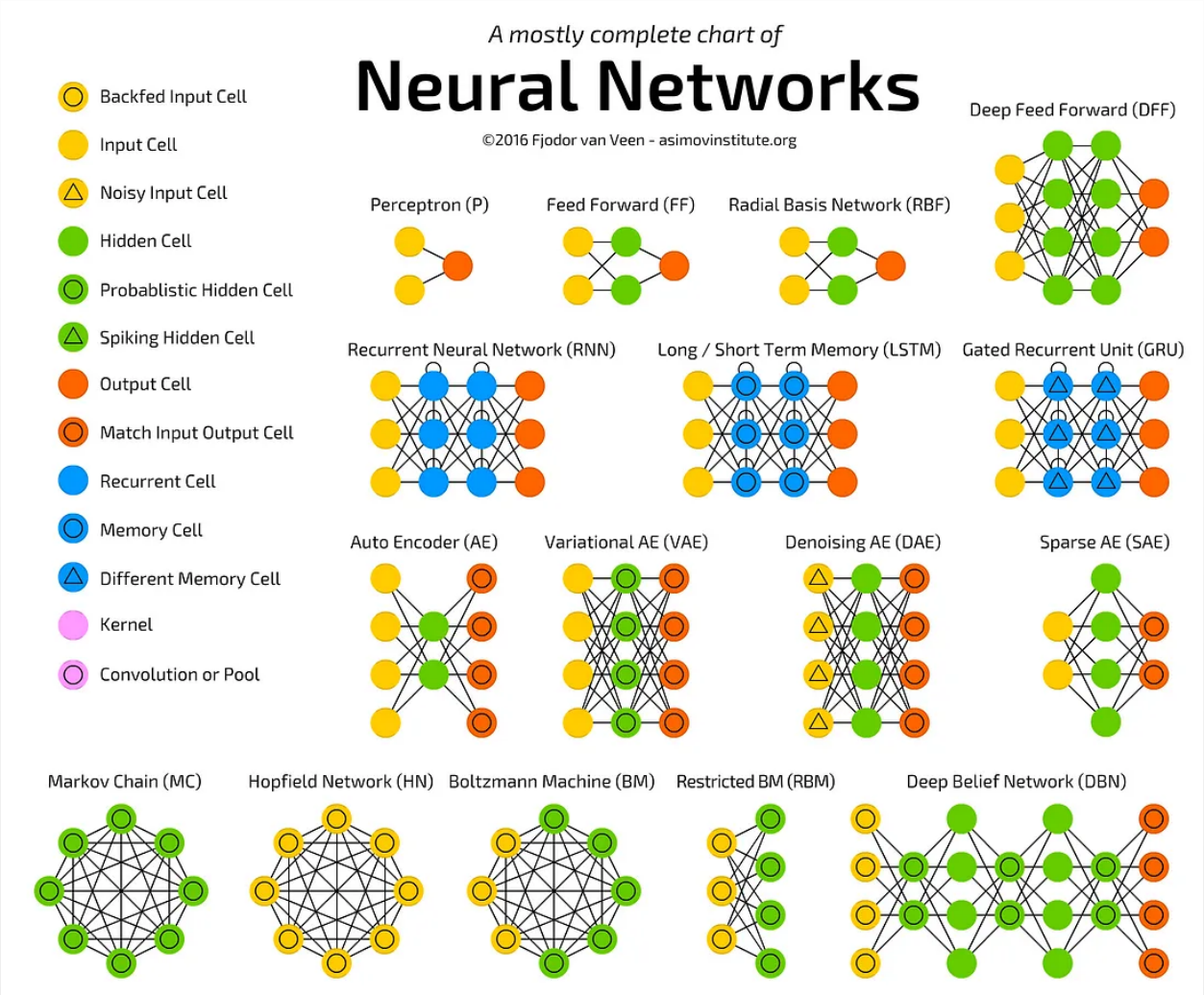
$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$



Optimizers

- SGD
- Adam
- RMSProp
- AdaGrad
- AdamW

Types of Neural Network 1



Types of Neural Network 2