Neural Networks Discovery

Understanding How Neurons Build Intelligence
Pre-Class Discovery Handout

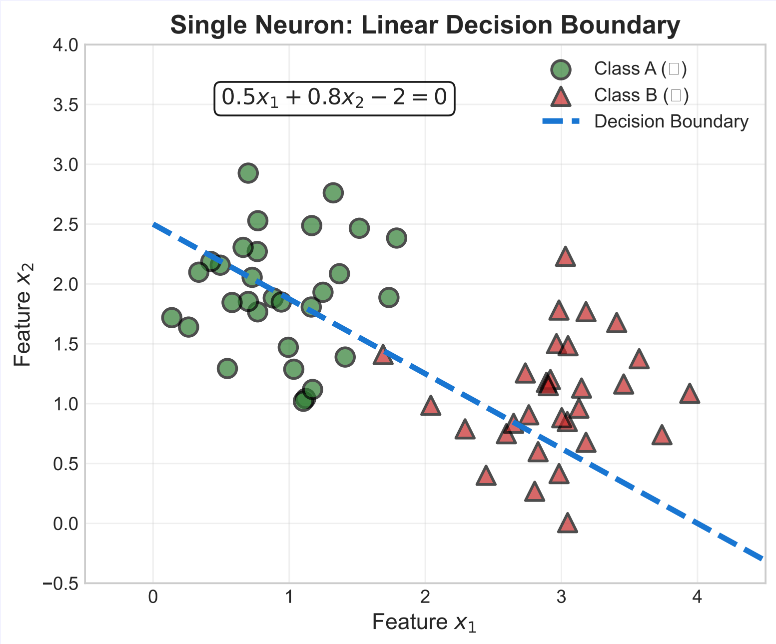
Neural Networks Primer - Student Version

Time: 30-40 minutes
Objective: Discover how simple neurons combine to solve complex problems through hands-on exploration.

Part 1: The Single Neuron - A Line Drawer (10 minutes)

Understanding Linear Boundaries

Look at the figure below showing a single neuron with weights $w_1 = 0.5$, $w_2 = 0.8$, and bias $b = -2$.



Questions:

1. The neuron's decision boundary follows the equation: $0.5x_1 + 0.8x_2 - 2 = 0$.

   This is a ______________ (line/curve/circle).

2. Can this neuron separate data arranged in a circular pattern (inner circle vs outer circle)?

   ☐ Yes

   ☐ No

3. What's the fundamental limitation of a neuron without activation?

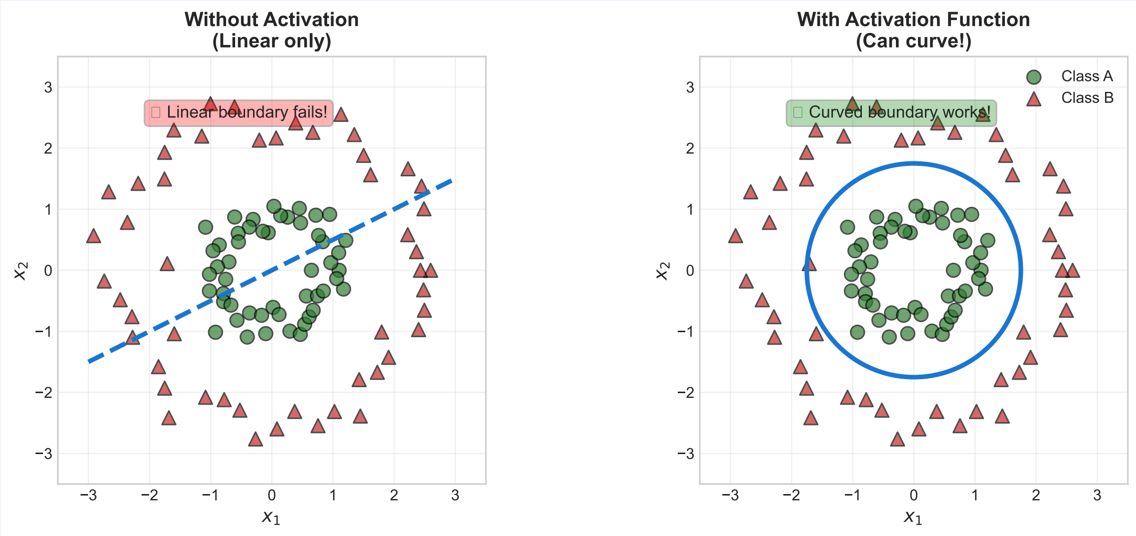
Key Takeaway

Without activation functions: A single neuron can only draw __________ lines. It cannot create curved boundaries!

Part 2: Adding the Magic - Activation Functions (10 minutes)

From Lines to Curves

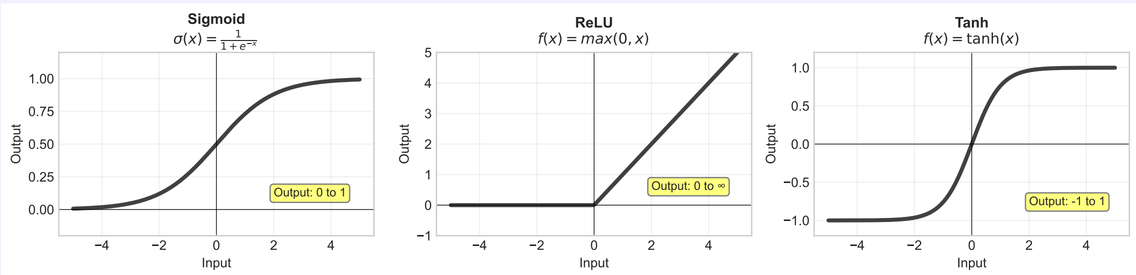
Activation functions transform the neuron's output, enabling curved decision boundaries.



Fill in the comparison table:

Property	Without Activation	With Activation
Boundary shape	________________	________________
Can make curves?	Yes / No	Yes / No
Can separate circles?	Yes / No	Yes / No

Common Activation Functions:



Question: Which activation function outputs values between 0 and 1? ________________

Part 3: Two Neurons, More Power - The XOR Challenge (15 minutes)

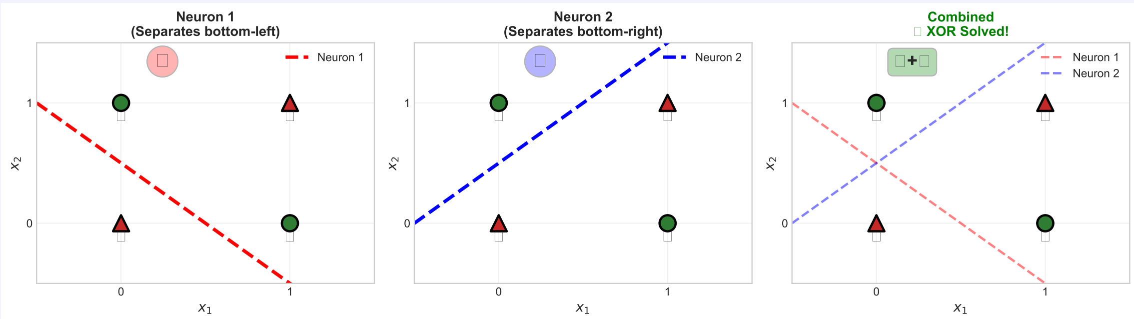
Why One Neuron Isn't Enough

The XOR (exclusive OR) problem is a classic challenge that reveals why we need multiple neurons.

XOR Truth Table:

x_1	x_2	Output
0	0	0 (X)
0	1	1 (checkmark)
1	0	1 (checkmark)
1	1	0 (X)

Task: Below is a 2D plot of the XOR problem. Try drawing ONE straight line that separates the checkmarks from the X's.

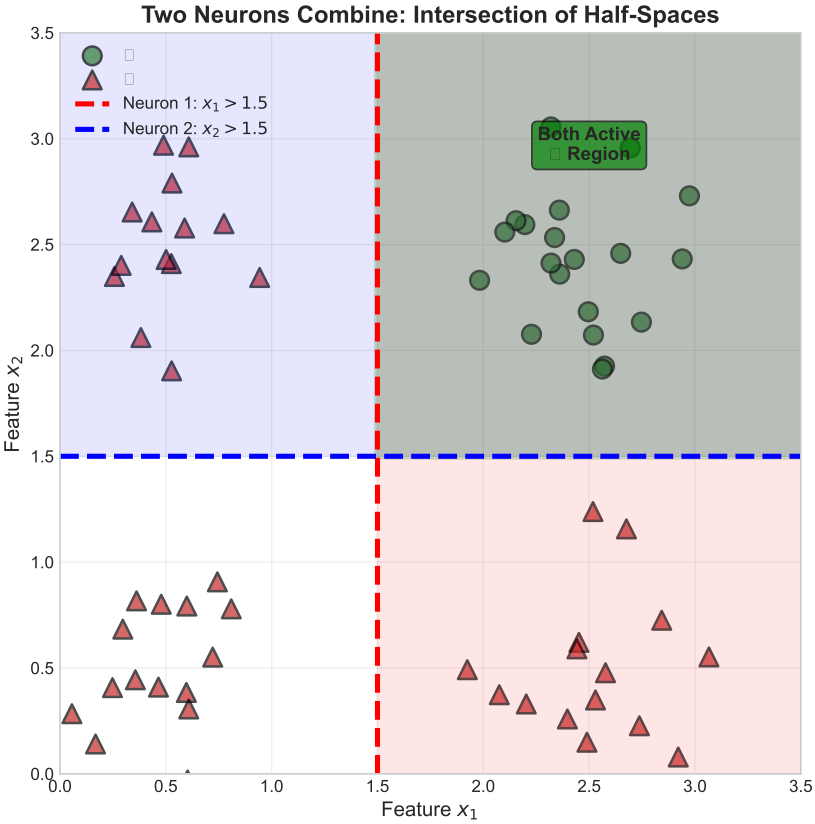


Questions:

1. Can you draw a single straight line to solve XOR? ___________
2. Look at panels 1 and 2. Neuron 1 creates a ___________ boundary, and Neuron 2 creates another ___________ boundary.
3. In panel 3, both neurons work together. The solution region is where both neurons are ___________ (active/inactive).
4. This demonstrates that _____ neurons can solve problems that _____ neuron cannot!

Hint

Geometric Intuition: Two neurons create two half-spaces. Their *intersection* creates a region that can solve XOR!



Trace Through a Calculation: Given the XOR input $x_1 = 1, x_2 = 0$, let's calculate step-by-step:

(Assume: Hidden Neuron 1 has weights [1.0, 1.0], bias=-0.5; Hidden Neuron 2 has weights [1.0, 1.0], bias=-1.5)

a) Hidden Neuron 1: $z_1 = 1.0 \times 1 + 1.0 \times 0 - 0.5 =$ __________

b) After sigmoid: $h_1 = \sigma(z_1) \approx$ __________ (use 0.62 if $z_1 = 0.5$)

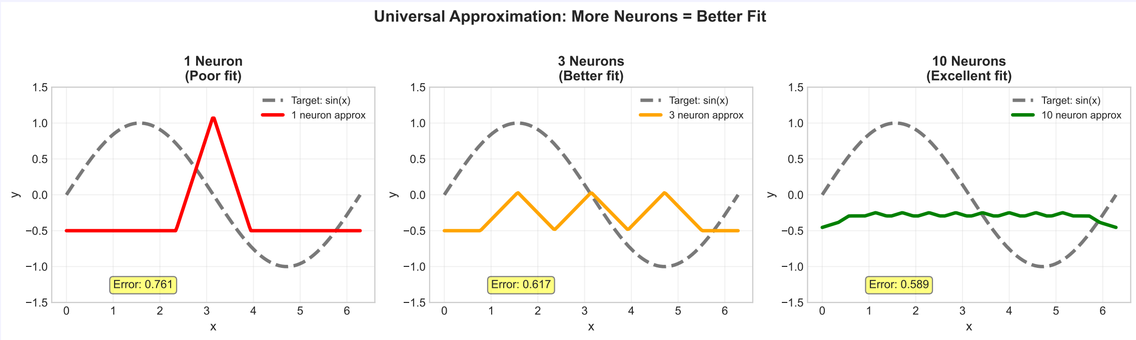
c) Hidden Neuron 2: $z_2 = 1.0 \times 1 + 1.0 \times 0 - 1.5 =$ __________

d) After sigmoid: $h_2 = \sigma(z_2) \approx$ __________ (use 0.27 if $z_2 = -0.5$)

Part 4: Many Neurons = Any Function! (5 minutes)

The Universal Approximation Theorem

As we add more neurons, we can approximate *any* smooth function!



Observations:

1. With 1 neuron, the approximation is ________________ (poor/excellent).
2. With 3 neurons, the fit is ________________ (worse/better).
3. With 10 neurons, the approximation is ________________ (poor/nearly perfect).
4. **Pattern:** More neurons = ________________ approximation.

True or False:

- ☐ Neural networks with enough neurons can approximate any continuous function. (T/F)
- ☐ One neuron is always enough to solve any problem. (T/F)
- ☐ Activation functions are optional. (T/F)
- ☐ Deep networks build features hierarchically (simple to complex). (T/F)

Key Takeaway

Universal Approximation Theorem (Cybenko, 1989): A neural network with enough hidden neurons can approximate *any* continuous function to *any* desired accuracy. This is why neural networks are so powerful!

Summary: What You Discovered Today

Fill in the blanks to consolidate your learning:

1. **Without activation:** Neurons can only make ________________ boundaries.
2. **With activation:** Neurons can make ________________ shapes (lines/curves/any shape).
3. **Multiple neurons:** Can solve problems like ________________ that single neurons cannot.
4. **Many neurons:** Can approximate ________________ function(s) (one specific/any smooth).
5. **Key insight:** Neural networks build complex functions by ______________________.

Before Class: Think about these questions:

- How do we actually *learn* the right weights for neurons?
- What happens if we stack many layers of neurons?
- Can neural networks learn *any* pattern, or are there limitations?

Answers will be revealed in class! Bring your questions.