CSE4261: Neural Network and Deep Learning

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Targeted Topics

1. Computer Vision
    a. Image Classification
    b. Image Segmentation
    c. Object Detection
    d. Vision Model Interpretability
    e. Video Classification
2. Natural Language Processing
    a. Text Classification
    b. Machine Translation
    c. Text Similarity Search
    d. Language Modeling
3. Audio Data Processing
    a. Speech recognition
    b. Vocal Track Separation
4. Graph Data Processing
5. Generative Deep Learning
    a. Image Generation
    b. Text Generation
    c. Audio Generation
    d. Graph Generation

Artificial Neuron

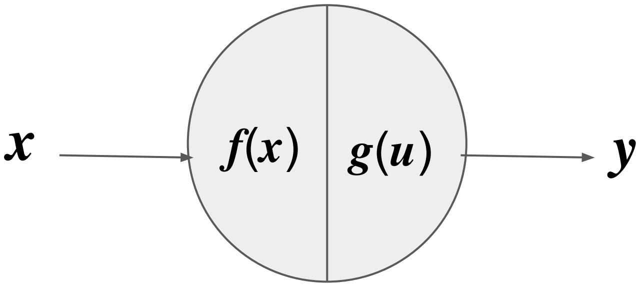
Artificial neuron is nothing but a composite function, $(g \circ f)(x)$

$$u = f(x)$$

$$y = g(u)$$

where

- x is input and y is output
- $f(x)$ is a linear function
- $g(u)$ is generally a nonlinear function



Artificial Neuron

Artificial Neuron

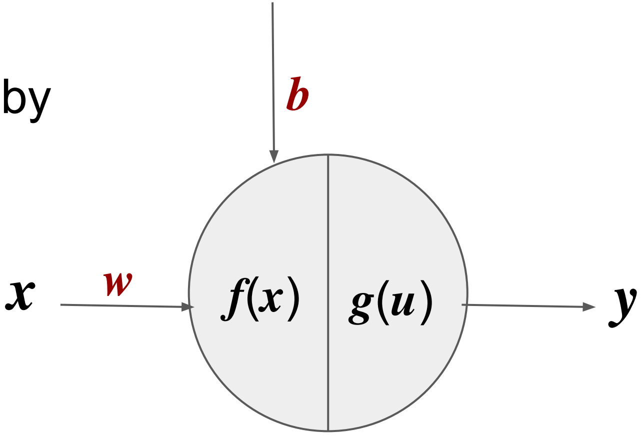
In an artificial neuron, at first input is multiplied by a weight and summed with bias.

$$y = g(f(x))$$

$$u = f(x) = wx + b$$

where

- w is weight which decides how much influence x will have on u.
- b is bias which ensures that u is not too big or too small on average



Artificial Neuron

Artificial Neuron

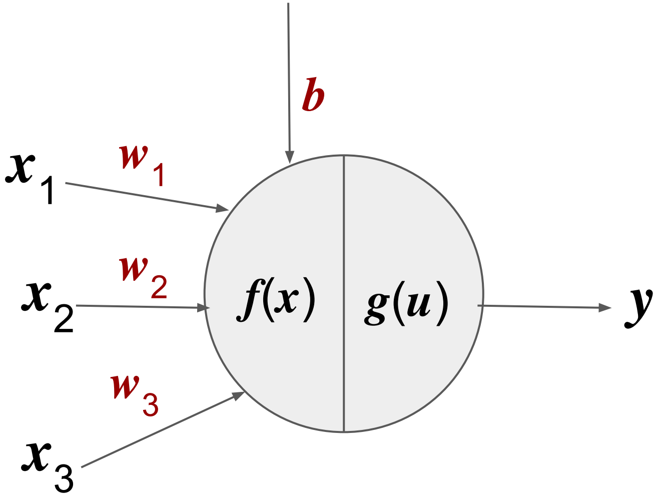
For a vector x, weight w is a vector and bias b is a scalar.

$$u = f(x)$$

$$= w_1 x_1 + w_2 x_2 + w_3 x_3 + b$$

$$= w^T x + b$$

$g(u)$ is known as **activation function**. Generally nonlinear functions are used as activation functions.



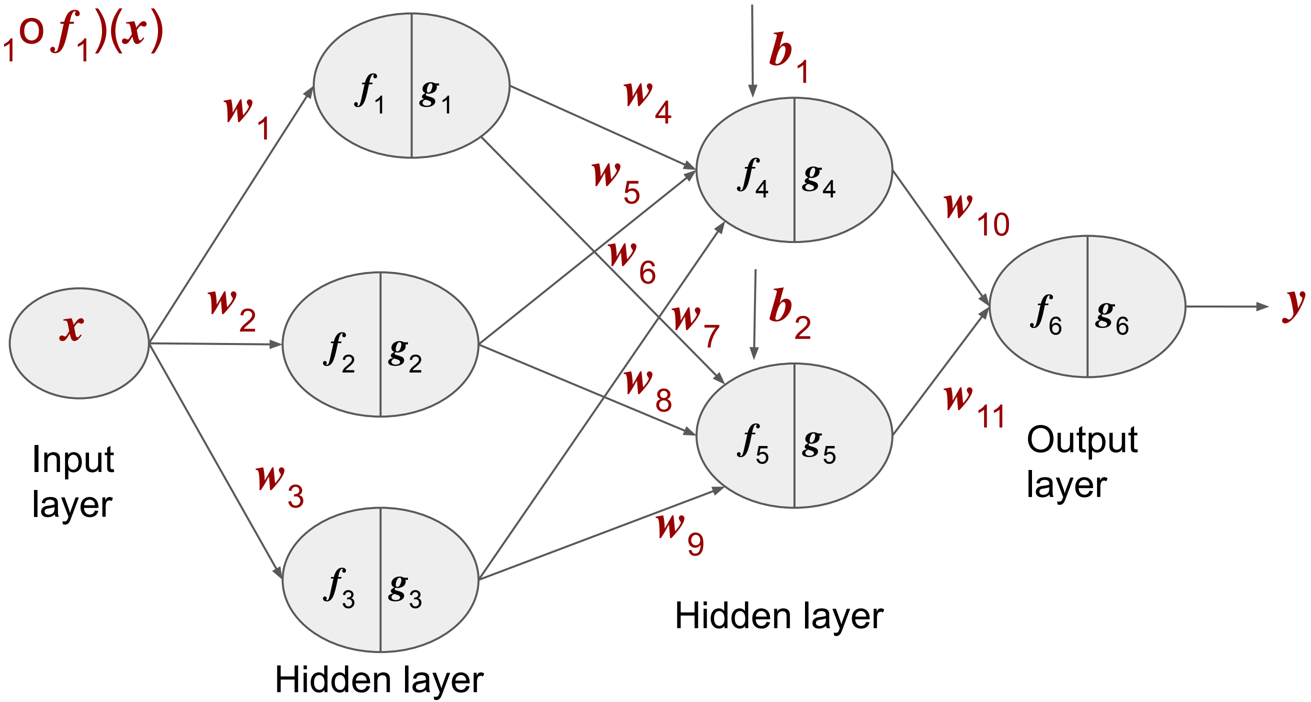
Artificial Neuron

Artificial Neural Network (ANN)

ANN is nothing but a composite of composite functions:

$(g_n \circ f_n \ldots\ldots g_2 \circ f_2 \circ g_1 \circ f_1)(x)$

Number of parameters: weights + bias (optional) + any variables in $g(.)$ (optional)



ANN

- ANN is a machine learning algorithm that uses a network of interconnected artificial neurons to process data to imitate our human brain.
- All ANNs have three kinds of layers:
  - **One** Input Layer: to receive data.
  - **One or Multiple** Hidden Layers: to process data
  - **One** Output layer: to produce the output.
- Shallow NN is a type of ANN with a few hidden layers, usually one or two.
- Deep NN (DNN) is a type of ANN having multiple hidden layers to solve complex problems.
  - GPT-3: 96 hidden layers
  - EfficientNet: 5-400 hidden layers
  - ResNet-152: 152 hidden layers

Universal Function Approximator

The main strong point of DNN is its universal approximation power.

An DNN can approximate any function no matter how complicated the function is if we can ensure that the network has sufficient number of neurons.

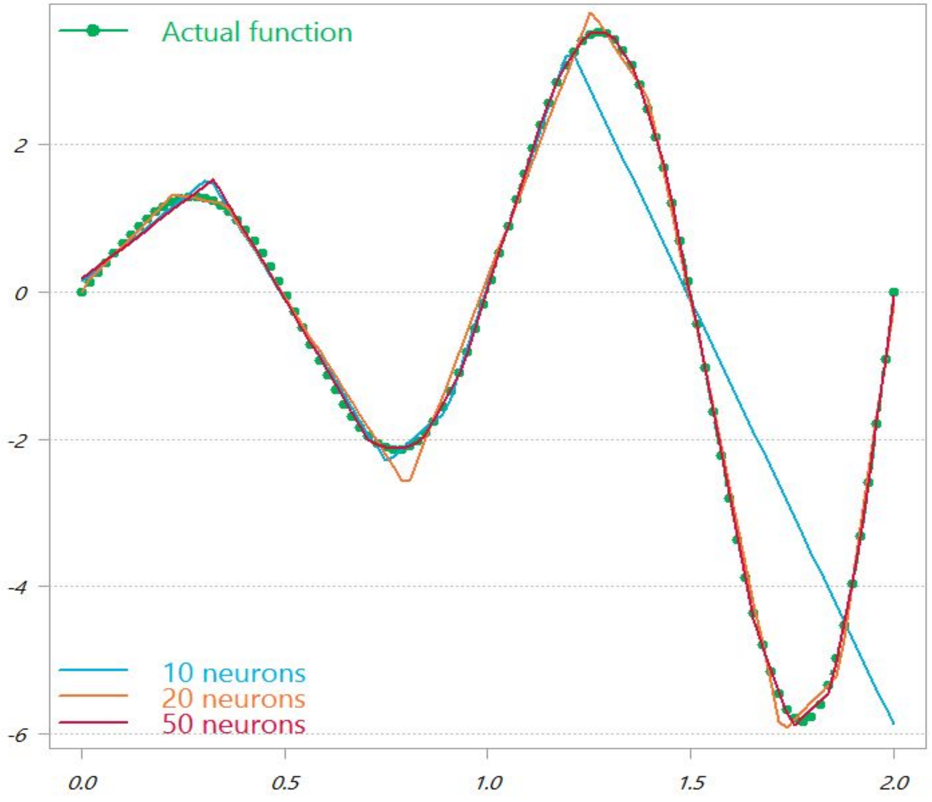


Image Source: Google Search Engine

Hidden Layers

- The number of hidden layers in a DNN depends on the complexity of the data:
  - **Linearly separable data**: No hidden layers are needed
  - **Less complex data**: 1–2 hidden layers are sufficient
  - **Large data**: 3–5 hidden layers are recommended
  - **Complex data**: Additional layers can be helpful
- Depth of an ANN = the number of hidden layers + the output layer
- Sometimes a deeper network has better performance comparing to a shallower network
- A DNN has risks of
  - experiencing vanishing gradient problem
  - high sensitivity to input data
  - having similar performance of a shallow network.

Hidden Layers

- **Increasing the number of hidden layers**
  - Can increase the performance of the network.
- **Adding too many hidden layers**
  - Can lead to overfitting, where the model memorizes the training data but doesn't generalize well to new data.
- **Reducing the number of hidden layers**
  - Can directly impact the accuracy of the network. For complex problems, the network might not be trained properly with fewer hidden layers.
- **Optimal number of layers depends on several factors including:**
  - the data
  - the optimizer, and
  - the network's architecture

Number of Neurons

- Number of neurons in the:
  - input layer depends on the size of the input data
    - for 28x28 input image, 784 neurons in the input layer
  - output layer depends on the size of the output data
    - in a binary classifier, one or two neurons in the output layer
    - in a 10 class classifier, four or ten neurons in the output layer
  - hidden layers depends on us, i.e., who design the architecture of the NN
- More neurons means:
  - more parameters for tuning
  - more time for tuning parameters
  - more data for avoiding overfitting
  - more hardware support, i.e., computational power & memory during parameter tuning, and storage space for saving model.

Parameter Vs Hyperparameter

Parameters: which NN will learn from data

- w, b, any variables in $g(.)$

Hyperparameters: which we need to decide based on our experience, intuition or error-trial such as

- number of layers
- number of neurons in each layer
- activation function
- epoch number
- learning rate

Keep in Mind

- Designing a suitable DNN automatically is not fully explored yet.
  - Recent Works: Neural Architecture Search—Finding the Best Model Design Automatically
- Designing a suitable network architecture is still a error-and-trial process.
- Not an architecture optimum for a data will be optimum for all datasets.
- It is upto us what will be the number of hidden layers and number of neurons in each hidden layer. However, we need to be careful.
- We should not design or work with any network which:
  - cannot be run in our available hardware support.
  - can be easily overfitted on our available training data.

Recommendation

Recommended Video Tutorials:

- **Andrew Ng's Lectures**

  https://www.youtube.com/watch?v=CS4cs9xVecg&list=PLkDaE6sCZn6Ec-XTbcX1uRg2_u4xOEky0

Recommended Reading Materials:

- **Chollet's Book: Deep Learning with Python**

  https://sourestdeeds.github.io/pdf/Deep%20Learning%20with%20Python.pdf

- **Andrew Ng's Materials:**

  https://www.kaggle.com/discussions/getting-started/157360

- **Goodfellow et. al's book: Deep Learning**

  https://www.deeplearningbook.org/

- **Bishop's Book: Deep Learning**

  http://103.203.175.90:81/fdScript/RootOfEBooks/E%20Book%20collection%20-%202024%20-%20D/CSE%20%20IT%20AIDS%20ML/Deep%20Learning.pdf