A Succinct Tutorial of Neural Networks in Deep Learning

Department of RadiologyTulane University School of Medicine

Jeremy Binh Nguyen, MD

Southwestern Chapter Society of Nuclear Medicine and Molecular Imaging 65th Annual Virtual Meeting

April 16th - April 18th, 2021

Objectives

- To describe the concept of artificial intelligence, machine learning and deep learning
- To discuss the operation of an artificial neuron
- To discuss the architecture of a neural networks and its elements.
- To explain the operation of a neural network
- To describe the concept of steepest descent utilized in neural networks.
- To explain the training and learning of a neural network

What is Artificial Intelligence?

Very simple! Artificial Intelligence (AI) is a branch of computer science that is concerned with building computer systems capable of performing tasks the typically require human intelligence. Basically we try to build computer systems that can simulate human intelligence. Artificial Intelligence relies on algorithms to achieve the result.

What is an algorithm?

An algorithm is a set of instructions that a computer can execute. A complex algorithm can be built on top of other simpler algorithms. Many AI algorithms are capable of learning from data – they can improve themselves.

What is machine learning?

- Machine learning is a SUBSET of artificial intelligence
- MACHINE LEARNING is an application of AI that can automatically learn and improve from experience
- MACHINE LEARNING is built upon an ALGORITHM that uses computational methods to "learn" information directly from data without relying on a predetermined equation as a model
- MACHINE LEARNING algorithms adaptively improve their performance as the data available for learning increases

How can one utilize the data to train and enable the algorithms to learn?

There are four major learning styles of an algorithm

1. **Supervised learning** – Input data is labelled and specific expected outputs are know. The algorithm generates reasonable predictions for the response to new data
2. **Unsupervised learning** – Input data is not labeled and outputs are not known. The algorithm generates results based on the analysis structure of the data
3. **Semi-supervised learning** – Input data is a mixture of labelled and unlabeled dataset. The algorithm generates results based on structure of the data
4. **Reinforcement learning** – Input data is unlabeled. The machine (algorithm) is trained to make specific decisions. The machine is exposed to an environment where it trains itself continually using trial and error through a feedback loop

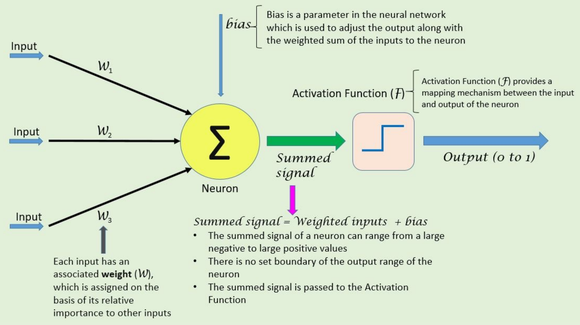
Some practical applications of machine learning

- Image processing and computer vision for face recognition, motion detection, and object detection
- Computational biology for tumor detection, drug discovery, and DNA sequencing

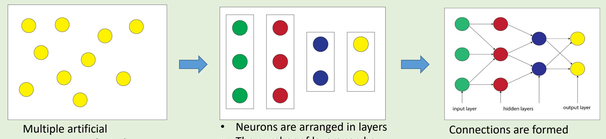
What is Deep Learning?

- Deep learning is an artificial intelligence function that mimics the workings of the human thought process
- Deep learning is a subset of machine learning
- Deep learning utilizes a hierarchical level of artificial neural networks built with artificial neuron nodes connected together to form a topological network
- The hierarchical neural network reflects the ALGORITHM of the network in processing/transforming the data
- The word "deep" in "deep learning" refers to the number of layers through which the data is processed
- Deep learning algorithms propagates data through multiple layers of neurons, each of which passes a simplified representation of the data to the next layer
- Deep learning algorithm is capable of learning from the input data to improve its performance

Structure of an artificial neuron



- The summed signal of a neuron can range from a large negative to large positive values
- There is no set boundary of the output range of the neuron
- The summed signal is passed to the Activation Function

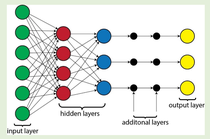


Multiple artificial neurons are selected

- Neurons are arranged in layers
- The number of layers can be multiple, depending on the complexity of the network

Connections are formed between the neurons according to the algorithm

This is how a neural network is constructed

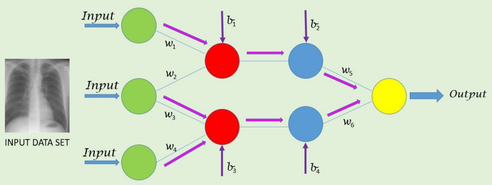


- Design of the network can be modified to handle more complex task.
- This is achieved by adding neurons and layers to the network.
- New connections can also be formed according to the requirement of new algorithm

How can we be assured that the network would perform and achieve the desired results?

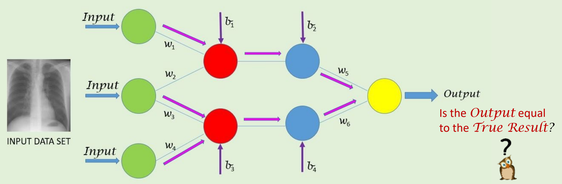
- We need to train the network
- Untrained neural network model (newly designed and never been put to use) is like an inexperience performer – It is essentially ignorant as it must learn to achieve satisfactory performance and yield desired results
- The algorithms of the networks must have actual experience of the intended task through the exposure to a large amount of data
- So by training a neural network on relevant datasets, we seek to improve its performance.
- The way we measure progress is by monitoring the error produced by the network each time it makes a prediction
- Therefore, a very important goal of the network is to reduce the error of the output – This is equivalent to LEARNING to improve itself

Training of a deep learning neural network



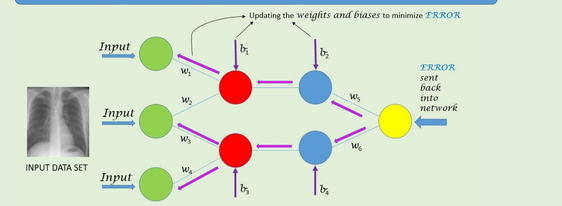
- The dataset is first sent to the Input neurons
- The data will propagate through the network
- Each neuron is activated by through the effects of the $input + weight + bias$
- The interactions of neurons will yield an $Output$

Training of a deep learning neural network



- No, we do not expect the output to yield the $True\ Result$ – there would be some expected error
- The $error$ can be calculated → $ERROR = True\ Result - Output$
- We need adjust the network to minimize the $ERROR$ – this is effectively improving the performance of the network

Training of a deep learning neural network



- We will use a common technique in deep learning network to minimize the $ERROR$
- We send the $ERROR$ back into the network
- The $ERROR$ propagates backward through the network
- Updating the ***weights (w)*** and ***biases (b)*** to new values to minimize the $ERROR$
- This is the technique called ***Back Propagation***

What is ***Backpropagation***?

- ***Backpropagation*** is the central mechanism by which neural networks learn
- ***Backpropagation*** is a smart algorithm that looks for the minimum value of the $ERROR$ in changing the weights and biases
- The algorithm gets its name because the weights and biases are updated backwards, from output towards input
- ***Backpropagation*** employs a mathematical operation called ***Gradient Descent***
- ***Gradient Descent*** calculates the new weights and biases that minimize the $ERROR$

Concept of Gradient Descent

- ***Gradient Descent***
  - A mathematical operation that computes the gradient (rate change) of the $ERROR$
  - It then attempts to find the "direction" to change the weights and biases to reduce the $ERROR$ function most quickly and efficiently

- In plain language, the Gradient Descent optimally relates change in the $ERROR$ and the weights/biases of the network as follows

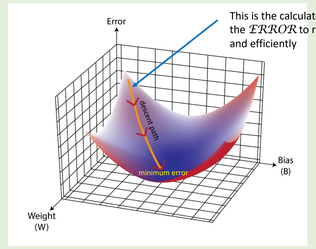
$$\text{Change in } ERROR = \left[\left(\frac{\text{Rate of } ERROR \text{ change}}{\text{Rate of weight change}}\right)\right] \text{X Change in weight} + \left[\left(\frac{\text{Rate of } ERROR \text{ change}}{\text{Rate of bias change}}\right)\right] \text{X Change in bias}$$

This is essentially a complex process of differential calculus

But the bottom line to remember

CHANGE IN WEIGHTS AND BIASES RESULT IN A CHANGE IN ERROR

Concept of Gradient Descent



This is the calculated path of descent in reducing the $ERROR$ to reach a minimum most quickly and efficiently

- Graph of the $ERROR$ as a function of the weight and bias, now represented as a surface function of two variables
- Gradient Descent technique finds the direction to change the $weights$ and $biases$ to reduce the $ERROR$ most quickly and efficiently (blue arrow)
- The new $weights$ and $biases$ associated with this decent are then the most optimal for error reduction

Do we stop now since we have done Backpropagation and found a set of weights biases to reduce the ***ERROR***

No, absolutely not, our work is not done yet

- We will train the network with more data sets
- Each time a new data set is run through the network, the Backpropagation algorithm will improve the performance of the network
- The Gradient Descent force updates of the $weights$ and $biases$ towards a smaller ***ERROR***
- In another word, the network continues to LEARN and improves its predictive output

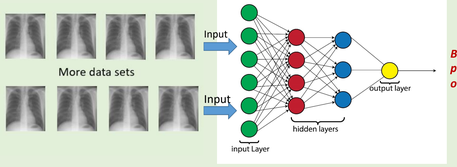
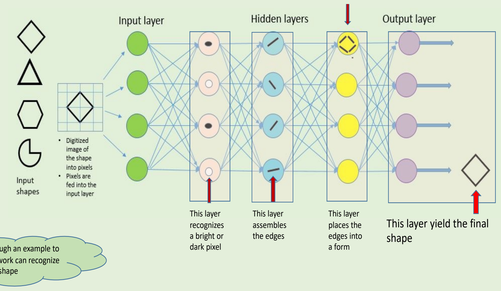


Illustration of hierarchical feature of a neural network in deep learning



FINAL NOTE

- Deep learning utilizes a hierarchical neural network with cascading architecture
- The cascading architecture consists of multiple levels of neural network structure
- The outputs of the hidden neurons in the higher hierarchical level are treated as an equivalent input data to the input neurons at the lower hierarchical level
- Each level of neuron layer learns to transform its input data into a slightly more abstract and composite representation

References

ARTICLES

- Chartrand G, Cheng P, Vorontsov E et al. Deep Learning: A Primer for Radiologists. Radiographics. 2017;37(7):2113-2131.
- Yasaka K, Akai H, Kunimatsu A et al. Deep learning with convolutional neural network in radiology. Jpn J Radiol. 2018 Apr;36(4):257-272.
- Suzuki K. Overview of deep learning in medical imaging. Radiol Phys Technol. 2017 Sep;10(3)257-273.
- Tajbakhsh N, Shin JY, Gurudu SR et al. Convolutional neural networks for medical image analysis: full training or fine tuning? IEEE Trans Med Imaging. 2016 May;35(5):1299-1312.
- Tavanaei A, Ghodrati M, Kheradpisheh SR et al. Deep learning in spiking neural networks. Neural Netw. 2019 Mar;111:47-63.
- Esteva A, Robicquet A, Ramsundar B et al. A guide to deep learning in healthcare. Nat Med. 2019 Jan;25(1):24-29.

BOOKS

- Aggarwal C. Neural Networks and Deep Learning: A Textbook. Springer, 2018. Print.
- Charniak E. Introduction to Deep Learning. The MIT Press, 2019. Print.
- Goodfellow I. Deep Learning. The MIT Press, 2016. Print.

Jeremy Nguyen, MD, MS. Associate Professor of Radiology at Tulane University Medical Center Email: jnguye2@tulane.edu

Special thanks to Donald Olivares, Digital Imaging Specialist, for assistance with graphics arts design.