Neural networks -An overview and application in optical communication

Master's thesis

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Introduction

What is Machine learning and where dose a Neural network fit in ?

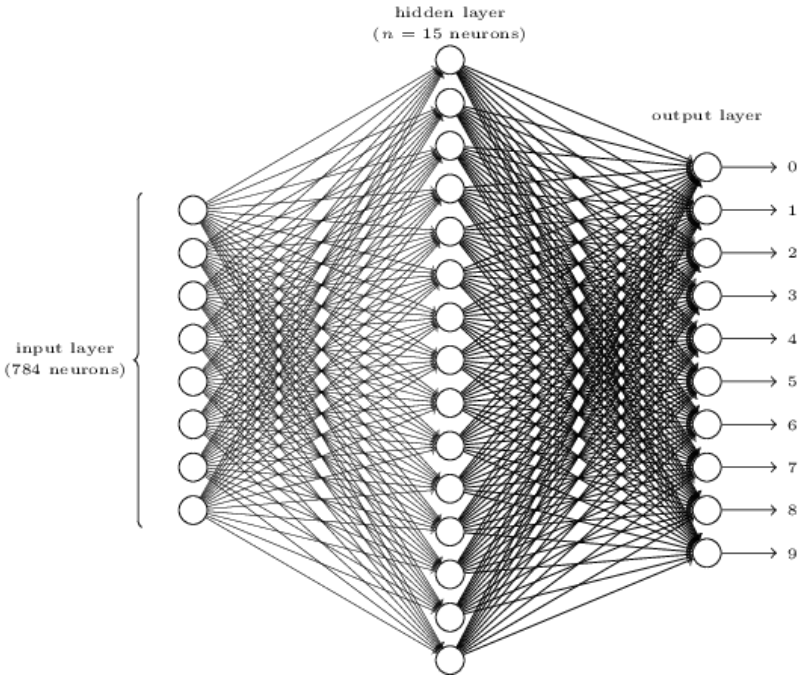


FIGURE – Text classification neural network

- Machine learning is the study of algorithms and statistical models that computer systems use in order to perform a specific task effectively without using explicit instructions, relying on patterns and inference instead.
- Warren McCulloch and Walter Pitts (1943) created a computational model for neural networks, inspired by their work Perceptrons were developed in the 1950s and 1960s by the scientist Frank Rosenblatt.

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com
[2] Machine learning. (2019). Retrieved from https ://en.wikipedia.org/wiki/Machine_ learning

Perceptrons

A perceptron is a device that makes decisions by weighing up evidence.

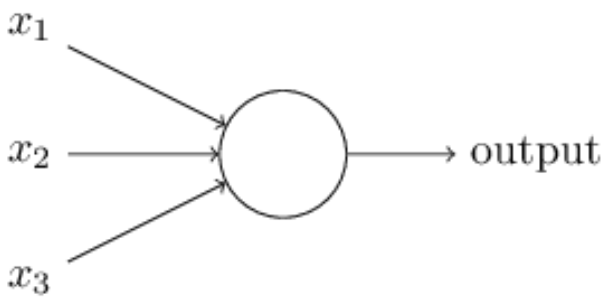


FIGURE – Perception with multiple inputs

$$Output = \begin{cases} 0 & \text{if } \sum_j w_j x_j \leq threshold \\ 1 & \text{if } \sum_j w_j x_j > threshold \end{cases}$$

$$Output = \begin{cases} 0 & \text{if } w \cdot x + b \leq 0 \\ 1 & \text{if } w \cdot x + b > 0 \end{cases}$$

What is so special about this ?

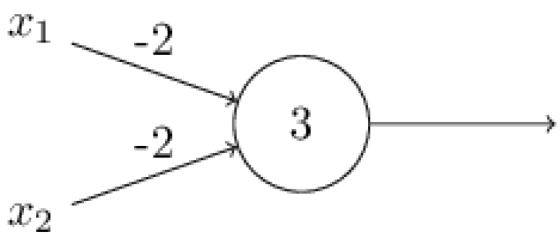


FIGURE – Perceptron NAND gate

$$Output = \begin{cases} 0 & \text{if } x_1 = x_2 = 1 \\ 1 & \text{if } otherwise \end{cases}$$

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Perceptrons Example Implementation

We can use networks of perceptrons to compute any logical function at all since a NAND gate is universal for computation. For example a circuit which adds two bits, x_1 and x_2.

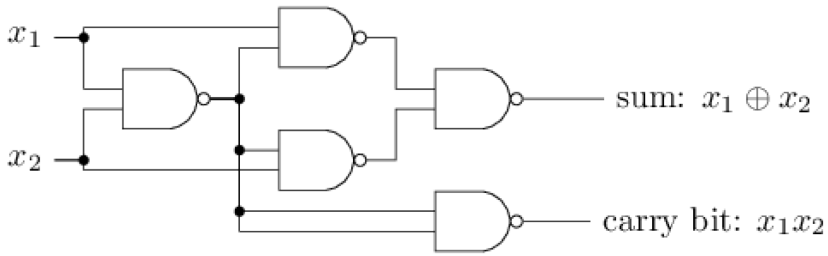


FIGURE – Bitwise sum using NAND gates

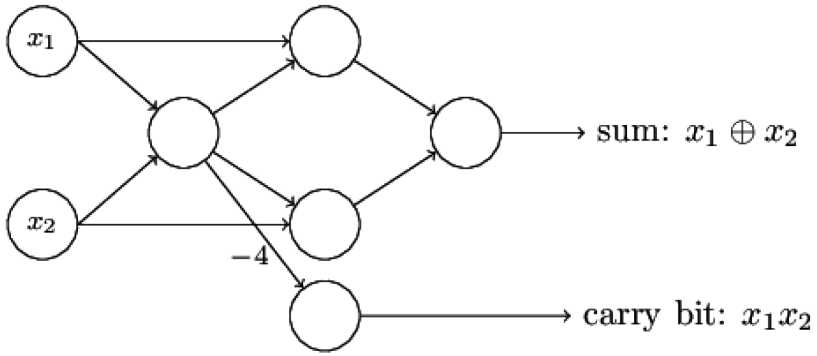


FIGURE – Bitwise sum using Perceptrons

Its that all there is ?

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Sigmoid Neurons

Sigmoid neurons are similar to perceptrons, but modified so that small changes in their weights and bias cause only a small change in their output. That's the crucial fact which will allow a network of sigmoid neurons to learn.

$$Output = \sigma(w \cdot x + b)$$

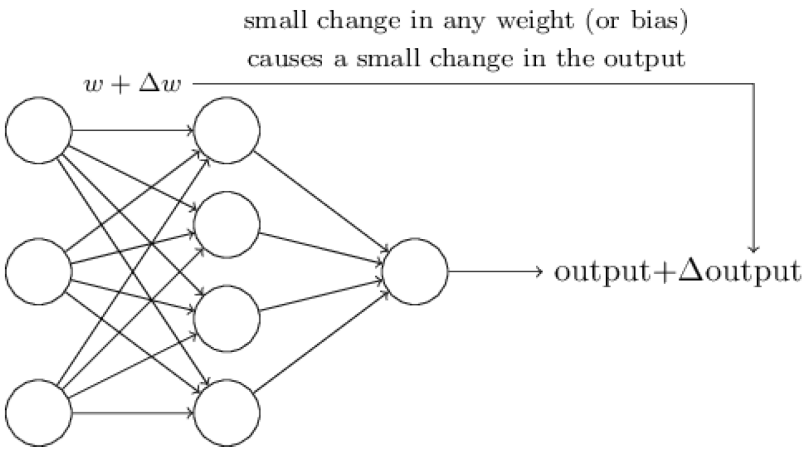


FIGURE – Motivation for a Sigmoid neuron

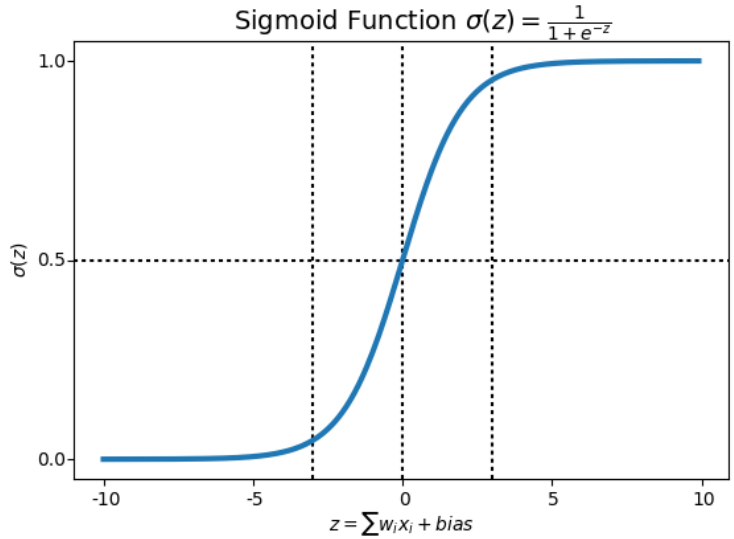


FIGURE – Sigmoid function used to pass from a discrete out put to continues between 0 and 1

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Architecture for hand written text recognition

One place where neural networks are implemented is to detect hand written text. How can we understand what the network might be doing in this case ?

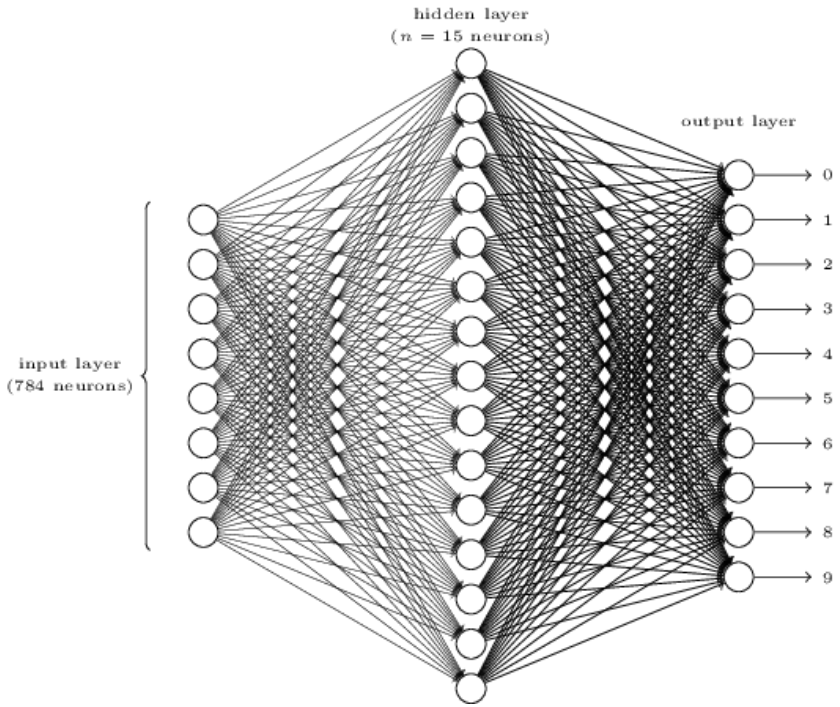


FIGURE – Neural network for hand written number detection.

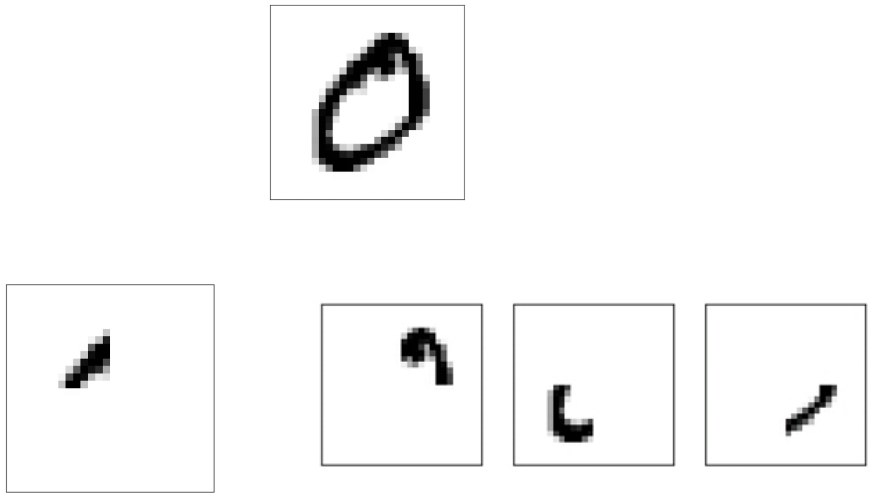


FIGURE – Image for each neuron weight distribution.

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Cost function and gradient descent

Cost function gives a way to quantify a small change in the network over all data points x.

$$C(w,b) = \frac{1}{2n}\sum_x ||y(x) - a^L(x)||^2$$

One wants to minimize the error.

$$\Delta C \approx \frac{\partial C}{\partial \nu_1}\Delta\nu_1 + \frac{\partial C}{\partial \nu_2}\Delta\nu_2 \approx \nabla C \Delta\nu$$

$$\Delta\nu = -\eta\nabla C \rightarrow \Delta C \approx -\eta||\nabla C||^2$$

$$\nu \rightarrow \nu' = \nu - \eta\nabla C$$

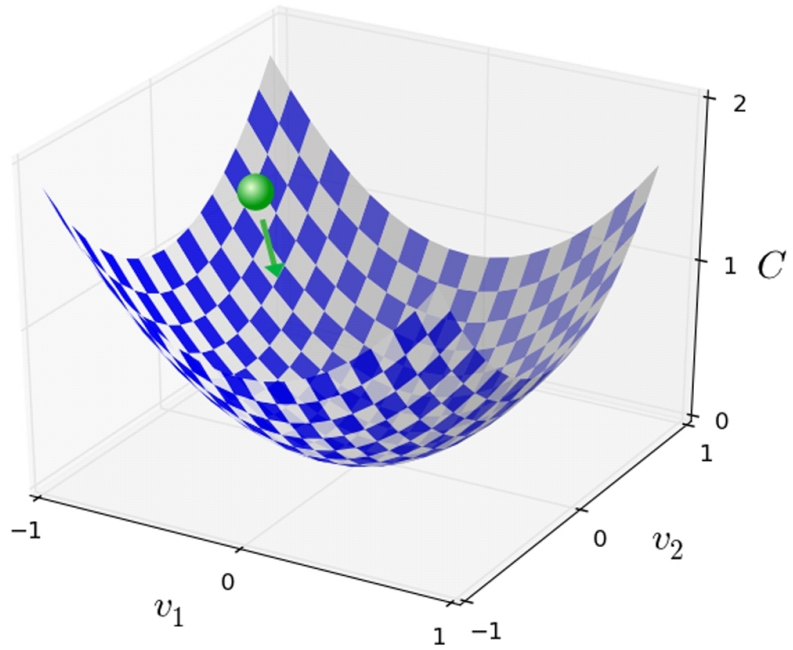


FIGURE – Gradient descent to minimize the loss function.

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Backpropagation notation

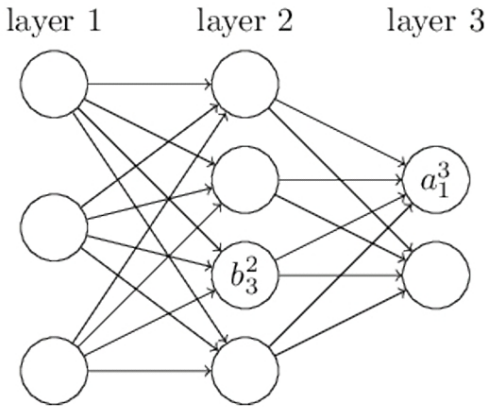
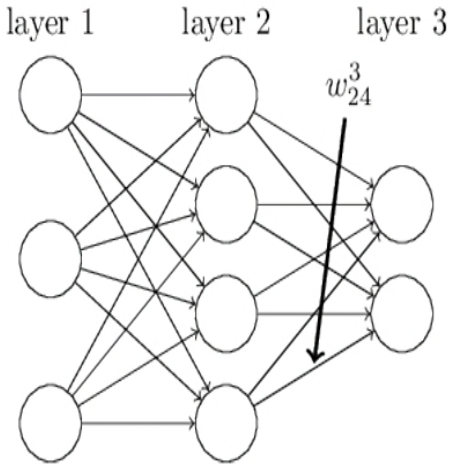


FIGURE – b_j^l a_j^l are the bias and activation of the j-th neuron in the l-th layer.



w_{jk}^l is the weight from the k^{th} neuron in the $(l-1)^{\text{th}}$ layer to the j^{th} neuron in the l^{th} layer

FIGURE – Notation for the weights of each neural link between layer l-1 and l

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Backpropagation algorithm

1. Input a set of training examples
2. For each training example x: Set the corresponding input activation $a^{x,1}$, and perform the following steps:
   - Feedforward: For each l$= 2, 3, \ldots, L$ compute $z^{x,l} = w^l a^{x,l-1} + b^l$ and $a^{x,l} = \sigma(z^{x,l})$.
   - Output error $\delta^{x,L}$: Compute the vector $\delta^{x,L} = \nabla_a C_x \odot \sigma'(z^{x,L})$.
   - Backpropagate the error: For each $l = L-1, L-2, \ldots, 2$ compute $\delta^{x,l} = ((w^{l+1})^T \delta^{x,l+1}) \odot \sigma'(z^{x,l})$.
3. Gradient descent: For each $l = L, L-1, \ldots, 2$ update the weights according to the rule $w^l \to w^l - \frac{\eta}{m} \sum_x \delta^{x,l} (a^{x,l-1})^T$, and the biases according to the rule $b^l \to b^l - \frac{\eta}{m} \sum_x \delta^{x,l}$.

[1] Nielsen, M. (2019). Neural Networks and Deep Learning. Retrieved from http ://neuralnetworksanddeeplearning.com

Previous project

Machine learning in astrophysics

- Predicting the amount of planets that a star system could have based on its gas and dust cloud.
- Determining the number of planets, their total mass and the mass efficiency.
- Compared the prediction efficiency between three different machine learning algorithms SVM, Random forest and ANN.

ANN Optical communication

- Modulation format identification in heterogeneous fiber-optic networks using artificial neural networks.
- End-to-end Deep learning of Optical Fiber Communications.
- Multimode optical fiber transmission with a deep learning network.

Thank you !

MFI using ANN

Modulation format identification in heterogeneous fiber-optic networks using artificial neural networks

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[2]*School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia (USM), Penang, Malaysia*
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Abstract: We propose a simple and cost-effective technique for modulation format identification (MFI) in next-generation heterogeneous fiber-optic networks using an artificial neural network (ANN) trained with the features extracted from the asynchronous amplitude histograms (AAHs). Results of numerical simulations conducted for six different widely-used modulation formats at various data rates demonstrate that the proposed technique can effectively classify all these modulation formats with an overall estimation accuracy of 99.6% and also in the presence of various link impairments. The proposed technique employs extremely simple hardware and digital signal processing (DSP) to enable MFI and can also be applied for the identification of other modulation formats at different data rates without necessitating hardware changes.

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OCIS codes: (060.1660) Coherent communications; (060.2330) Fiber optics communications; (060.2360) Fiber optics links and subsystems; (060.4510) Optical communications; (060.5060) Phase modulation.

End to end ANN

End-to-end Deep Learning of Optical Fiber Communications

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Félix Thouin, Tobias A. Eriksson, Henning Bülow, Domaniç Lavery, *Member, IEEE,*
Polina Bayvel, *Fellow, IEEE,* and Laurent Schmalen, *Senior Member, IEEE*

***Abstract*—In this paper, we implement an optical fiber communication system as an end-to-end deep neural network, including the complete chain of transmitter, channel model, and receiver. This approach enables the optimization of the transceiver in a single end-to-end process. We illustrate the benefits of this method by applying it to intensity modulation/direct detection (IM/DD) systems and show that we can achieve bit error rates below the 6.7% hard-decision forward error correction (HD-FEC) threshold. We model all componentry of the transmitter and receiver, as well as the fiber channel, and apply deep learning to find transmitter and receiver configurations minimizing the symbol error rate. We propose and verify in simulations a training method that yields robust and flexible transceivers that allow—without reconfiguration—reliable transmission over a large range of link dispersions. The results from end-to-end deep learning are successfully verified for the first time in an experiment. In particular, we achieve information rates of 42 Gb/s below the HD-FEC threshold at distances beyond 40 km. We find that our results outperform conventional IM/DD solutions based on 2 and 4 level pulse amplitude modulation (PAM2/PAM4) with feedforward equalization (FFE) at the receiver. Our study is the first step towards end-to-end deep learning-based optimization of optical fiber communication systems.**

Neural networks in depth explanation

Neural Networks and Deep Learning

Neural Networks and Deep Learning is a free online book. The book will teach you about:

- Neural networks, a beautiful biologically-inspired programming paradigm which enables a computer to learn from observational data
- Deep learning, a powerful set of techniques for learning in neural networks

Neural networks and deep learning currently provide the best solutions to many problems in image recognition, speech recognition, and natural language processing. This book will teach you many of the core concepts behind neural networks and deep learning.

For more details about the approach taken in the book, see here. Or you can jump directly to Chapter 1 and get started.

Neural Networks and Deep Learning
What this book is about
On the exercises and problems
Using neural nets to recognize handwritten digits
How the backpropagation algorithm works
Improving the way neural networks learn
A visual proof that neural nets can compute any function
Why are deep neural networks hard to train?
Deep learning
Appendix: Is there a *simple* algorithm for intelligence?
Acknowledgements
Frequently Asked Questions

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Neural networks in depth explanation

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A quick guide to set up a Neural Network without using a framework.



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