The Role of Gradients in Convolutional Neural Networks

LeNet and the Use of Gradient Descent in Machine Learning

Maxwell Banks

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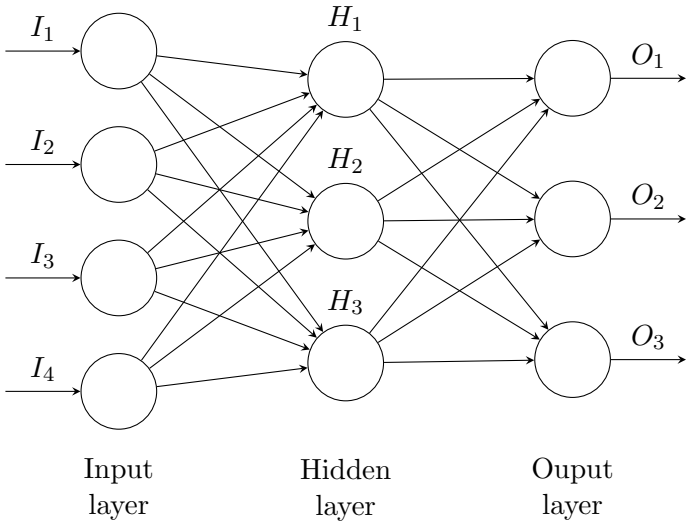
1 Background: Neural Networks

Neural networks are a machine learning architecture commonly used for pattern recognition. Named for their similarity to human brains, traditional neural networks break inputs are composed of groups of nodes (called *layers* of *neurons*). Each node in a layer is connected to nodes in the preceding and following layers, and contains some innate value (called a *weight*). To process data with a neural network, data is broken into discrete chunks that are fed into the first (input) layer of neurons. These neurons mutate the input according to their weight, then pass the result to the next (hidden) layer to continue the process. This process continues until the final (output) layer, wherein each node outputs a single number. These numbers can be used to classify inputs–for example, a neural net classifying images into "dog" or "cat" might have two output nodes O_1 and O_2 corresponding to "dog" and "cat" respectively. The classification of an image into "dog" or "cat" would be decided by $max(O_1, O_2)$.

A Simple Diagram of a Neural Network



2 Historical Event

This historical event analyzed by this paper is the publication of *Gradient-Based Learning Applied to Document Recognition* (LeCun et al., 1998). This paper revolutionized the training of neural networks and is the antecedent to much of the modern field of machine learning.

3 Summary

The breakout research paper *Gradient-Based Learning Applied to Document Recognition* (LeCun et al., 1998) outlined LeNet-5, one of the first published instances of a Convolutional Neural Network (CNN). CNNs are a subtype of neural network that generally specialize in image recognition (this is not univerally true, but for brevity this paper will assume inputs are pixels of an image). LeCun et al. (1998) discusses using gradient-based learning techniques to train neural networks in recognizing letters, highlighting a variety of network architectures and explaining the effectiveness of gradient-based learning in the context of those architectures.

LeCun et al. (1998) had wide-ranging impacts on the field of machine learning as a whole, but perhaps the most notable impact was the popularization of CNNs trained using gradient-based learning. As the paper itself notes, "Gradient-Based Learning procedures have been used since the late 1950's, but they were mostly limited to linear systems." (LeCun et al. 1998) The key innovation of LeCun et at. (1998) was to apply gradient-based learning (specifically, gradient descent) as a training mechanism for CNNs by using gradient descent to determine the adjustment of node weights by minimizing the "loss function", a function representing how incorrect a neural network's guess was.

Gradient descent is a technique that dates back to Augustin-Louis Cauchy who outlined the technique in his pamphlet *Méthode générale pour la résolution des systèmes d'équations simultanées* (Cauchy, 1847/2010). Cauchy described this technique as "...a general method which may be able to serve to resolve directly a system of simultaneous equations", and was mostly concerned with using it to determine the movement of a star with precision. This technique minimizes a system of equations by repeatedly calculating the gradient (interestingly, the paper itself does not appear to use the term gradient–it exclusively uses partial derivatives) at a point, then "stepping" in the opposite direction of the gradient to a "lower" point. This process is repeated until a minimum is reached.

4 Explanation of Enhancement

Explain in detail how the concepts utilized have directly led to innovations in our world that have made lives better for certain individuals, communities, nations, or the entire world

5 Calculus Steps

Explain the calculations utilized showing either a portion or all of the steps within the calculations.

6 What If...

7 Bibliography

http://vision.stanford.edu/cs598$_spring07/papers/Lecun98.pdf https://cs.uwaterloo.ca/\ y328yu/cl$
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