

Big Data and AI Strategies

Neural Network Explained Part II: Architectures

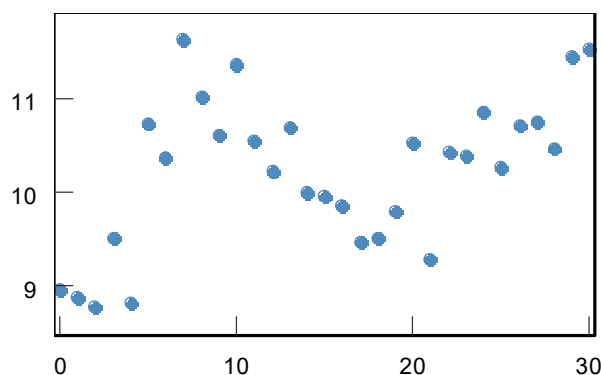
In the [previous note](#), we provided an introduction to neural network. In this note, we will discuss some common architectures that we find to be relevant for finance. Along the way, we will also go over some more important concepts.

Feedforward Network

Feedforward network is one of the first designs of neural network. Since it lends itself well to exposition, we will also introduce concepts such as activation function and backpropagation along the way.

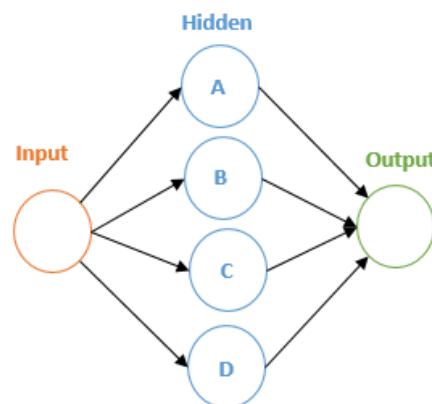
The function seen in Figure 1 serves as a good toy example¹. We use a simple feedforward network (Figure 2), with one input node (since there is only one explanatory variable, x), and four hidden nodes, labelled A to D. The hidden nodes are nonlinear functions, known as **activation functions**, which perform calculations on x . The results from the hidden nodes are then weighted and summed at the output node to produce estimates of the nonlinear function.

Figure 1: Function to be modeled



Source: J.P. Morgan

Figure 2: Neural net used for the nonlinear function



Source: J.P. Morgan

Activation Function: Each node contains an activation function. There are a number of commonly used ones, which can be found online (https://en.wikipedia.org/wiki/Activation_function). For highly nonlinear problems, such as the one seen here, we will use multiple nodes (four in this case) for fitting. The exact choice of activation function are oftentimes arbitrary, and for this exercise sigmoids are used for all four nodes. A sigmoid function (shown below) maps the input data to an S shaped curve ranged between 0 and 1. Parameters (α , β) are used to determine the output the individual nodes (Figure 3). The ‘optimal’ values of the parameters are determined by a process called **backpropagation**.

$$\text{Sigmoid: } \sigma(\alpha + \beta x) = \frac{e^{\alpha + \beta x}}{1 + e^{\alpha + \beta x}}$$

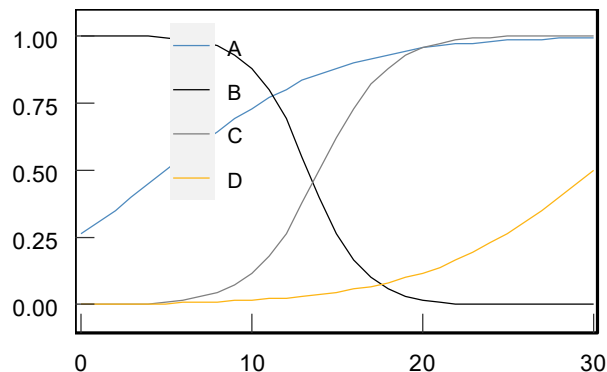
$$y = a + \sum_{i \in \{A, B, C, D\}} b_i \cdot \sigma_i(\alpha_i + \beta_i x)$$

Backpropagation: Our goal is to choose the parameter values (e.g. α , β , a , and b above) so that our estimate is as close as possible to the observed values. This process is known as backpropagation, because at each iteration, the residuals are fed ‘backwards’ to determine the optimal changes in the parameter values for the next iteration. Due to a neural net’s large number of parameters, the algorithm has to be somewhat more sophisticated, and some care has to be taken to minimize the risk of overfitting (we will cover these topics later on in the series). However, the principle is the same as the least squares fitting in linear regression.

¹ The example is borrowed from Kennedy, P., 2003, A Guide to Econometrics, 5th edition, MIT Press

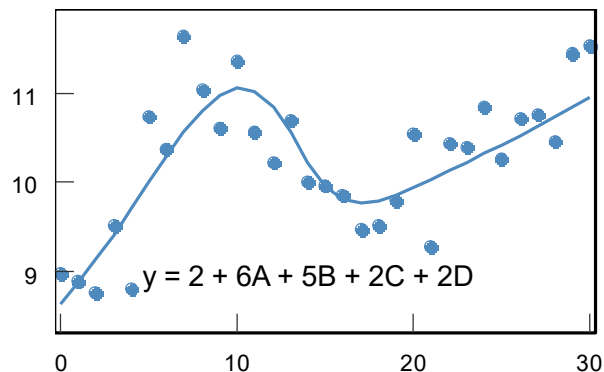
The result of our fitting can be seen in Figure 3. The individual hidden nodes are various simple transformations of the S-shaped curve (sigmoid). When combined, they produce the fitting shown in Figure 4.

Figure 3: Individual node outputs



Source: J.P. Morgan

Figure 4: Final fitted output



Source: J.P. Morgan

$$A = \sigma(-1 + 0.2x)$$

$$B = \sigma(8 - 0.6x)$$

$$C = \sigma(-7 + 0.5x)$$

$$D = \sigma(-6 + 0.2x)$$

Recurrent Neural Network

Some data series have memories, meaning the previous outputs help predict the next output. One can simply use lagged outputs as input nodes in a feedforward network, similar to the autoregressive model in linear regression. However, if the series has a very long memory, doing so results in an unwieldy structure because the lagged inputs become too numerous. A recurrent neural network (RNN) is a preferred solution which can retain infinite memory.

How does RNN manage to accomplish this? Instead of carrying all lagged values, it specifies a ‘forget rate’, and the previous information will decay as a function of the forget rate. We can even have multiple series with different forget rates, to accommodate long term and short term memories. A well-known example in finance is return volatility, i.e. high volatility periods tend to be followed by high volatility ones, and low volatility periods tend to be followed by low volatility ones. In this [report](#), we illustrate how one can model volatility using RNN.

Residual Network

As we have seen above, neural nets are good at modeling nonlinear relationships, which by definition includes linear relationships. In practice, we find the numerical optimization procedure oftentimes has a strong tendency to look for nonlinearity where the underlying relationship is linear. This in turn results in overfitting or nonconvergence of the model. Residual Network (ResNet) is one way to remedy the issue.

Recall that each layer of neural net represents a level of nonlinear transformation of the inputs. ResNet allows the inputs to skip layers, so that both the transformed and untransformed data are passed onto the next layer. The advantage is that we make the model to explicitly evaluate the possibility of a linear relationship, in addition to the nonlinear transformations. In many situations in finance, where the relationship between input variables and future returns are likely to be weakly nonlinear, or a mixture of linear and nonlinear, we find ResNet to offers a simple and effective solution.

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