Big Data and AI Strategies

Neural Network Explained Part III: Towards a Trading Model

In the previous note, we discussed some common neural network architectures that could be relevant for finance applications. In this note, we will apply what we have learned so far to formulate a prototypical equity long/short model.

Beyond Classical Treatment of Nonlinearity

But first, let's take a step back. Why choose neural nets over linear models, and take on the additional computational complexity? The most important reason is that neural nets are capable of capturing the nonlinearity in the data. Nonlinear models are not new. Take momentum as an example, we can think of at least a couple of ways where nonlinearity may arise: 1) potential interactions between momentum and volatility, and 2) performance of momentum strategy seems to depend on seasonality or market regimes.

We can account for the above by 1) adjusting a stock's momentum by its volatility, and 2) condition the strategy on some timing model (e.g., end of day, end of month, etc.). These treatments are rule-based and do not scale well. That is, a lot of efforts go into dealing with a single factor, and if we apply such efforts to all factors, the combined computational complexity may in fact exceed that of a neural net. Judicious use of neural nets allows us to capture nonlinear relationships between factors and future stock returns in a scalable and systematic manner.

Time Series vs. Cross-Sectional Modeling

Although it may seem a bit counterintuitive, cross-sectional models are better at estimating long-term relationships, and time series models estimate short-term relationships. Given the cross section of the Russell 3000 index members, we would observe the relationship between fundamental stock variables and returns for companies with market caps from as small as $70M to as large as Apple's. If we only had a time series of Apple data over, say, the last 10 years, the observed relationship would still be confined to the US mega-cap segment. This is why most of the equity long/short models are cross-sectional in nature.

Does neural network change the cost/benefit consideration between time series vs. cross-sectional analysis? After all, Recurrent Neural Network (RNN) is much more powerful than traditional time series models. One would think that momentum strategies, which essentially captures the memory properties in returns, is a natural candidate for RNN. The flexibility of RNN allows it to learn the optimal combinations of historical returns, so we can let the data decide the best momentum model.

Although it may sound appealing in theory, in practice the implementation is far from straight forward. The main issue is that equity return data are so noisy that, when combined with a parameter-intensive RNN, they become extremely challenging to produce a reasonable model based simply on historical data. An example is shown here where a 2-layer LSTM network is used to forecast S&P 500 returns. The performance of the model turned out to be disappointing. The training data contain 14 years of S&P daily returns, or approximately 3,500 data points. This amount of data is simply not enough to train the 70,000 parameters in the model[1]. As we can see, a large amount of data is required by time series models to estimate long-term relationships, and the use of neural network exacerbates the issue.

That is not to say memory cannot be incorporated into neural nets. The data can be pre-processed appropriately to account for the memory properties, and fed into the neural net as inputs. For momentum specifically, we will pre-set the look-back windows (e.g., weekly, monthly, quarterly, etc.) and the decay rate (e.g., equally weighted, exponential decay, etc.), in the same way we currently do for an equity multifactor model.

Learning to Combine Linear and Nonlinearity

The limitation of data availability argues for a cross-sectional approach. Feedforward neural net is a natural generalization of the cross-sectional regression, and therefore will serve as our starting point.

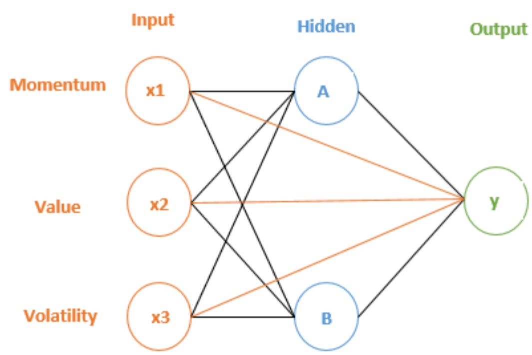
[1] As an aside, it is acceptable for our neural net to have more parameters than data points, thanks to various measures such as dropouts that reduces the risk of overfitting. This is a topic we will look to cover in a future installment.

Let's consider the potential functional form we want to model. As we emphasized previously, the main advantage of neural nets is the flexibility to capture the nonlinear relationships. Continuing with the momentum example, the model should be able to capture its interactions with other factors such as volatility. On the other hand, we should not overlook any linear relationship, because stock factors and returns are likely to be related by a mixture of linear and nonlinear functions, and over a wide domain, the linear function dominates. For instance, stock returns may be modeled linearly with respect to dividend yield within a reasonable range of values, but exceptions occur at extremes, e.g., 0% dividend yield (high-growth companies) or 20% (distressed companies).

Although handling linearity may appear trivial for neural nets, the issue is actually more complicated than it seems. 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 non-convergence of the model.

Residual network (ResNet) represents a middle ground: the inputs go through a layer of nonlinear transformation, but also get passed directly (without transformation) onto the next layer. A prototypical ResNet model can be seen in Figure 1. The inputs are three commonly used factors, and the outputs could be the subsequent stock returns. The difference from a vanilla feedforward network is the existence of the orange lines (known as skip connections) directly connecting the input nodes and the output layer.

Figure 1: Prototypical ResNet Model



Source: J.P. Morgan Quantitative and Derivatives Strategy

$$y = a + b_1 A + b_2 B + \boldsymbol{b_3 x1 + b_4 x2 + b_5 x3}$$

$$A = \sigma(\alpha_A + \beta_{A1} x1 + \beta_{A2} x2 + \beta_{A3} x3)$$

$$B = \sigma(\alpha_B + \beta_{B1} x1 + \beta_{B2} x2 + \beta_{B3} x3)$$

Put another way, the ResNet in Figure 1 can be expressed as the equations above. In the vanilla feedforward architecture, the highlighted parts of the first equation would be absent. The skip connections enable ResNet to explicitly fit a linear relationship, which may otherwise be obscured by the nonlinear transformation of the activation functions. At the same time, note that this benefit does not come for free. There are now three more parameters (b3, b4, and b5) to estimate than the vanilla network.

Global Quantitative and Derivatives Strategy
Peng Cheng, CFA AC
(1-212) 622-5036
peng.cheng@jpmorgan.com
J.P. Morgan Securities LLC

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