Deep Learning for Event-Driven Stock Prediction

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Abstract

We propose a deep learning method for event-driven stock market prediction. First, events are extracted from news text, and represented as dense vectors, trained using a novel neural tensor network. Second, a deep convolutional neural network is used to model both short-term and long-term influences of events on stock price movements. Experimental results show that our model can achieve nearly 6% improvements on S&P 500 index prediction and individual stock prediction, respectively, compared to state-of-the-art baseline methods. In addition, market simulation results show that our system is more capable of making profits than previously reported systems trained on S&P 500 stock historical data.

1 Introduction

It has been shown that the financial market is "informationally efficient" [Fama, 1965] — stock prices reflect all known information, and the price movement is in response to news or events. As web information grows, recent work has applied Natural Language Processing (NLP) techniques to explore financial news for predicting market volatility.

Pioneering work mainly uses simple features from news documents, such as bags-of-words, noun phrases, and named entities [Kogan *et al.*, 2009; Schumaker and Chen, 2009]. Although useful, these features do not capture structured relations, which limits their potentials. For example, representing the event "Microsoft sues Barnes & Noble." using term-level features {"Microsoft", "sues", "Barnes", "Noble"} alone, it can be difficult to accurately predict the price movements of *Microsoft Inc.* and *Barnes & Noble Inc.*, respectively, as the unstructured terms cannot differentiate the accuser ("Microsoft") and defendant ("Barnes & Noble").

Recent advances in computing power and NLP technology enables more accurate models of events with structures. Using open information extraction (Open IE) to obtain structured events representations, we find that the actor and object of events can be better captured [Ding *et al.*, 2014]. For example, a structured representation of the event above can be (Actor = *Microsoft*, Action = *sues*, Object = *Barnes & Noble*). They report improvements on stock market prediction using their structured representation instead of words as features.

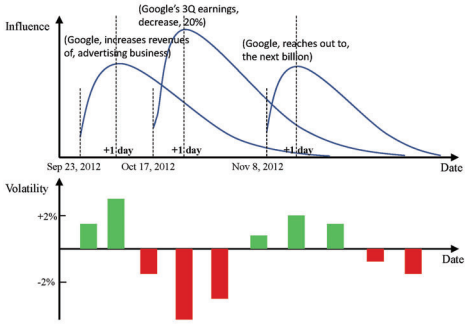

Figure 1: Example news influence of *Google Inc.*

One disadvantage of structured representations of events is that they lead to increased sparsity, which potentially limits the predictive power. We propose to address this issue by representing structured events using *event embeddings*, which are dense vectors. Embeddings are trained such that similar events, such as (Actor = *Nvidia fourth quarter results*, Action = *miss*, Object = *views*) and (Actor = *Delta profit*, Action = *didn't reach*, Object = *estimates*), have similar vectors, even if they do not share common words. In theory, embeddings are appropriate for achieving good results with a density estimator (e.g. convolutional neural network), which can misbehave in high dimensions [Bengio *et al.*, 2005]. We train event embeddings using a novel neural tensor network (NTN), which can learn the semantic compositionality over event arguments by combining them multiplicatively instead of only implicitly, as with standard neural networks.

For the predictive model, we propose to use deep learning [Bengio, 2009] to capture the influence of news events over a history that is longer than a day. Research shows diminishing effects of reported events on stock market volatility. For example, Xie et al. [2013], Tetlock et al. [2008] and Ding et al. [2014] show that the performance of daily prediction is better than weekly and monthly prediction. As shown in Figure 1, the influences of three actual events for Google

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