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Research on Graph Neural Network in Stock Market

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Abstract

The stock market is a very important part of the financial field, and the prediction of the stock market has a great relationship with the returns and risk safety of the entire financial field. With the continuous mature application of machine learning and deep learning in other fields, such as image processing and text analysis, people begin to focus on the use of different models so as to predict stock volatility. However, in view of the unique multi-source and heterogeneous characteristics of stock information, the artificial neural network relying on deep learning cannot make a good prediction on it. At this time, the graph neural network that can well analyze the graph structure data is gradually favored by scholars at home and abroad, and the research thinking is also expanding. This dissertation examines the purpose of deeply analyzing the methods of different graph neural network models on stock prediction through an inductive study of amount of relevant literature. In this paper, we not only classify the literature by various graph neural network models, but also describe objectively the models and ideas presented in each paper. By referring to literature, this paper summarizes the previous research results, analyzes the applicability and results of different methods, and lays a foundation for better stock prediction in the future.

Keywords: Graph neural networks, stocks, forecasts

1. Introduction

Stock market is always a significant part of the financial field. Recently, research on prediction of stock market has attracted more and more experts and scholars. However, the noisy of financial time series, the nonlinear of financial market and the different sources and structures of stock market information [1][2][3] lead to challenging stock forecasting. Fama proposed the theory of random walks that indicates that stock market price changes independently without no memory in the “efficient market”, so stock market prediction is impossible [4]. In spite of the existence of this hypothesis, some articles present different ways to predict stock market. There are two methods to forecast stock market: technical analysis and fundamental analysis [5]. Technical analysis utilizes price,

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trading volume and rule of past stock market for prediction, which includes chart analysis, cycle analysis and computerized technical trading systems [6]. This kind of method has a long history of development, however, some studies about technical analysis present unreasonable result. Fundamental analysis confirms the true intrinsic value of stock, which investor can purchase stock at a lower price [7]. Economic factors, namely fundamental, consists of three parts: financial report with overall performance of this company, analysis of the industry and macro economic indicator [8].

Previous researches of stock prediction have devoted to mining the past stock data and using traditional time series. With the development of artificial intelligence, machine learning that processes complex stock market information and data efficiently becomes the better method to predict stock [9][10][11]. Classic machine learning techniques contain artificial neural networks (ANN) [12], support vector machines (SVM)[13], fuzzy theory [14], random forests [15], decision trees [16] and so on. However, in order to solve the limit of every technique, researches proposed ideas, integration of several technologies [17] and feature selection [18], for improving the accuracy of stock forecast.

Deep learning which is a special portion of machine learning has great ability to deal with data and study non-linear connection between different targets, these characters perform so better in stock prediction that deep learning gets widely attention [19]. At present, deep learning models include Deep Multilayer Perceptron (DMLP), Convolutional Neural Networks (CNN) [20], Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM) [21][22], Restricted Boltzmann Machines (RBMs), Deep Belief Networks (DBNs), Autoencoders (AEs) and so on [23]. In recent literatures, Nelson et al. used LSTM network to forecast complex and noisy stock market [24]. Attention technique was added to the models of RNN/LSTM/GRU then Zhang proposed prediction models called AT-RNN /AT-LSTM /AT-GRU [25]. However, in fact, when process non-euclidean structure data that are different sizes and dimensions, researches have to consider a kind of neural networks based on graph structure data.

Due to graph neural networks show good performance on graph structured data, Graph Neural Network (GNN) was studied maturely in the fields of chemical molecule [26], image processing [27] and community information [28][29]. A lot of scholars begin to study the application of GNN in stock market prediction.

This paper presents latest systematic review of graph neural network in the stock market forecast. Section 2 shows related work and search methodology, which collects a large amount of volume of data and literatures proves that the research is reliable and reasonable. In section 3, this paper introduces graph neural network briefly including concept and a variety of models of graph neural network. Then, in section 4, this paper interprets how various graph neural network models apply to stock market prediction, and the strengths and weaknesses of every model. Finally, we conclude the knowledge of this paper and look forward to future development and trend about graph neural network in stock prediction in section 5.

2. Search methodology

The literature and theories mentioned in this paper are derived from the following authoritative databases: web of science, scopus, google scholar and arXiv.org. For purpose of ensuring the quality of the article, most of the literature that were published in the last three years also contain the term “GNN” and “stock”. The rough steps of selecting proper articles contains: enter the keywords “graph neural network” and “stock prediction” in the search box, then choose articles from the last three years, finally make decision through reading article.

3. Brief introduction of graph neural network

Graph is a data structure that simulates target object as point and connection of different target objects as edge. As shown in Fig. 1, graph neural network [30] concentrates on the research of non-Euclidean structure data that are different sizes and dimensions in structure data and is a technique that operates on a graph based on deep learning knowledge. The mainstream models of graph neural network are Graph Convolutional Network (GCN), Graph Auto-encoder (GAE), Graph Generative Network (GGN), Graph Recurrent Network (GRN), Graph Attention Network (GAT).

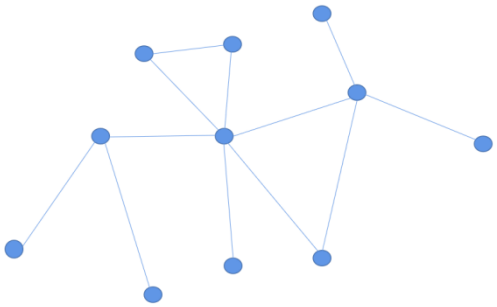

Fig.1. graph in non-Euclidean space.

3.1. Graph convolutional network

The development of spectral method of graph convolutional neural network is closely connected with graph signal processing [31]. Convolution Theorem converts original signal from time domain to spectral domain in order to do the multiplication, then through making the inverse Fourier transform to transform signal to the original space. The formulas used are Fourier transform, inverse Fourier transform, Chebyshev polynomials and so on [32]. Then the nonlinear activation function is applied to the aggregation result, and the neural network is constructed by stacking multiple layers [33]. Previously, in order to better realize the locality of neural networks, scholar constantly proposed to replace Fourier transform with Wavelet transform to complete the convolution theorem [34].

Starting from node domain, spatial approach of graph convolutional neural network [33] aggregates each central node and its neighboring nodes by defining aggregation function, which mainly covers three key points: the selection of central node, the size of receptive field and the construction of appropriate aggregation function. However, due to this technique has intense dependency on the central node and choice of receptive field that is an uncertain process, it is difficult to determine the parameters of aggregate function [25]. In order to solve these issues, different models are proposed, like PATCHY-SAN [36] and DCNN [37].

3.2. Graph recurrent network

Recurrent graph neural network is a first model of graph neural networks. Compared with recurrent neural network (RNN), graph recurrent network transforms graph data to sequence, then nodes exchange information with neighbor nodes constantly until reaching a steady state [38][39][40]. Also, recurrent graph neural network frequently uses Bidirectional RNN (Bi-RNN) and Long Short-Term Memory Network (LSTM)[30]. With the development of the theory, new variants are constantly being proposed based on previous studies: GGS-NN [41], GGT-NN [42], Graphrnn [43], GCRN [44] and STAR [45].

3.3. Graph attention network

Graph attention network that is suitable for sequential task handles varisized inputs and pays close attention to the most important unit of input, and it includes Self-Attention, Multi-head Attention Mechanism and Hierarchical Attention [30]. Veli proposed introducing self-attention into spatial approach of graph convolutional neural network and using attention coefficients to express the importance of the adjacent node to the central node [46]. In order to make better use of the information of neighbor nodes, multi attention network and gated attention network are also proposed [47].

4. Applications to stock forecasting

Graph neural networks are applied to some financial applications [48], for example, stock market prediction [49], loan default risk prediction [50][51], recommender system of e-commerce [52], fraud detection [53][54] and event

prediction [55]. This section focuses on the research of graph neural network on stock prediction. Meanwhile, in many models of graph neural networks, Graph Convolutional Network (GCN) and Graph Attention Network (GAT) are popular models for stock forecasting. By using the research methodology of section 2, we carefully select many articles. This part will analyze these articles in detail, and the result of objective analysis can be seen in the following subsection.

4.1. Graph convolutional network based methods

In stock forecasting, researchers not only consider individual information alone, but also expand the scope to related information even information about the entire stock market. Chen et al. proposed GC-CNN method to drop out the stock market [56]. This method leverages IGCN to capture stock market information and Dual-CNN to capture individual stock information simultaneously. After passing through multiple network layers, the two kinds of data are combined to form GC-CNN. The performance evaluation of Chinese stock market shows that although the computational performance is not as good as others, it's stable and produces the highest financial returns. Ye et al. combined graph convolutional network (GCN) with gates recurrent unit (GRU) to form Multi-GCCRU [57]. This theory considers not only the historical information on individual stocks but also the "cross effect" among other stocks, then GRU devotes to forecasting stock market. Experimental result in the stock market shows that putting cross effect in the model can improve the accuracy of prediction. Similarly, Yin et al. utilized GCN to extract stock and related stock features and GRU to capture temporal dependence [58]. Meanwhile, RNN is used in each task sequence prediction.

For better applying spatial graph convolutional neural network, articles exploit various information and models to construct spatial graph structure. In order to change the limitation of chart similarity that stock market information cannot be fully utilized in traditional technical analysis, Li et al. proposed a novel method, chart spatial graph convolutional network (Chart GCN)[59]. This method converts key nodes that are obtained in stock price series to graph, then uses GNN to compare the similarity of the graphs and uses technical chart creatively. It has stronger robustness and supposes chart is critical to stock prediction. Hou et al. put forward a kind of innovative hybrid model, VAE-GCN-LSTM [60]. In this hybrid model, VAE is applied to reduce the dimension and calculate the Euclidean distance between different nodes, at the same time, GCN-LSTM is designed to combine spatial features with time features to forecast stock fluctuation [61][62].

4.2. Graph attention network based methods

Considering the complexity of stocks relationship, researchers have some unique ideas. Feng et al. came up with a hybrid structure that is known as Relation-aware Dynamic Attributed Graph Attention Network (RA-AGAT)[63]. This architecture on one hand takes advantage of GCN for aggregating related topology information and feature information between different stocks, on the other hand integrates these information using self attention mechanism that belongs to graph attention network. Yin et al. employed time-aware graph relational attention network (TRAN) to meet challenges that how to calculate the strength of the relationship between stocks and the strength of these relationships changes over time [64]. TRAN is divided into two parts: time aware relation attention (TRA) which makes the strength of time-aware stock relation as the weight of edges in stock relation graph, graph convolution (GC) that renews node characteristics and the strength of edges in stock relation graph. Likewise, Huang et al. constructed an innovative model, multilevel graph attention network (ML-GAT)[65][66]. The important unit in the model is capturing nodes representation, which adds attention mechanism to diverse levels and selects valid information from all collected node information. Surprisingly, Cheng et al. presented an original model, attributed-driven graph attention network (AD-GAT), which applies momentum spillover to forecast stock [67]. About this model, attributed-mattered aggregation avoids the pitfalls of GCN that overlooks the disturb of the attributes of linked companies, the relation building selects masked attention mechanism for inferring potential relationship between various firms.

Most of the previous studies are based on Euclidean space. However, Ramit et al. published a very different path, Hyperbolic Stock Graph Attention Network (Hyperstock-GAT), which replaces Euclidean space with Hyperbolic space [68]. The biggest feature of this path is that it can handle the scale-free nature of the real stock market.

5. Conclusion

This paper explains the knowledge of different graph neural networks: GCN, GAT and GNA. After consulting a large number of literatures, we discover that the most commonly used models for stock forecasting are GCN and GAT. However, each researcher's understanding is diversified for the methods of forecasting stock. Hence, from considering individual information alone to related information, from using technical indicators to technical chart, form using only financial information to find it changed over time, many variations of graph neural network models have appeared in predicting stocks. After understanding and summarizing the methods and theories of previous scholars, we can better predict the stock market volatility in the future research.

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References

[1] Abu-Mostafa, Yaser S., and Amir F. Atiya. (1996) "Introduction to financial forecasting." *Applied Intelligence* **6**: 205–13.

[2] LI X, WANG J, JIA H, et al. (2022) "Stock market volatility prediction method based on graph neural network with multi-attention mechanism. " *Journal of Computer Applications* **42(7)**: 2265.

[3] Shah D, Isah H, Zulkernine F. (2019) "Stock market analysis: A review and taxonomy of prediction techniques." *International Journal of Financial Studies* **7(2)**: 26.

[4] Fama, Eugene F. (1995) "Random walks in stock market prices." *Financial Analysts Journal* **51**: 75–80.

[5] Nti I K, Adekoya A F, Weyori B A. (2020) "A systematic review of fundamental and technical analysis of stock market predictions." *Artificial Intelligence Review* **53(4)**: 3007-3057.

[6] Park, Cheol-Ho, and Scott H. Irwin. (2007) "What do we know about the profitability of technical analysis?" *Journal of Economic Surveys* **21**: 786–826.

[7] Petrusheva N, Jordanoski I. (2016) "Comparative analysis between the fundamental and technical analysis of stocks." *Journal of Process Management and New Technologies* **4(2)**: 26-31.

[8] Sharma K, Bhalla R.(2022) "Stock Market Prediction Techniques: A Review Paper."//*Second International Conference on Sustainable Technologies for Computational Intelligence*. Springer, Singapore

[9] Kumbure M M, Lohrmann C, Luukka P, et al. (2022) "Machine learning techniques and data for stock market forecasting: a literature review." *Expert Systems with Applications* 116659.

[10] Schröder T, Schulz M. (2022) "Monitoring machine learning models: a categorization of challenges and methods." *Data Science and Management* **5(3)**: 105-116.

[11] Zhang Peng, Dang Shili, Huang Meiyu. (2022) "A two-step M-SV portfolio optimization based on machine learning prediction of stock returns." *China management science*: 1-14

[12] Nermend, Y., & Alsakaa, K. (2017). "Back-propagation artificial neural networks in stock market forecasting . An application to the warsaw stock exchange WIG20." *The IEB International Journal Of Finance* **15**, 88–99.

[13] Huang, W., Nakamori, Y., & Wang, S. Y. (2005). "Forecasting stock market movement direction with support vector machine." *Computers And Operations Research* **32**, 2513–2522.

[14] Zadeh L A. (1965) "Fuzzy sets." *Information and control* **8(3)**: 338-353.

[15] Lohrmann, C., & Luukka, P. (2019). "Classification of intraday S&P500 returns with a random forest." *International Journal Of Forecasting* **35(1)**, 390–407. http://dx.doi. org/10.1016/j.ij forecast.2018.08.004.

[16] Tsai, C. F., & Hsiao, Y. C. (2010). "Combining multiple feature selection methods for stock prediction: Union, intersection, and multi-intersection approaches." *Decision Support Systems* **50(1)**, 258–269. http://dx.doi.org/10.1016/j.dss.2010.08.028.

[17] Cao, J., & Wang, J. (2019). "Stock price forecasting model based on modified convolution neural network and financial time series analysis." *International Journal Of Communication Systems* **32**, 1–13.

[18] Barak, S., & Modarres, M. (2015). "Developing an approach to evaluate stocks by forecasting effective features with data mining methods." *Expert Systems With Applications* **42(3)**, 1325–1339. http://dx.doi.org/10.1016/j.eswa.2014.09.026.

[19] Jiang W. (2021) "Applications of deep learning in stock market prediction: recent progress." *Expert Systems with Applications*, 184: 115537.

[20] Liang J, Jia G. (2022) "China futures price forecasting based on online search and information transfer." *Data Science and Management*, 2022.

[21] Peng S, Han W, Jia G.(2022) "Pearson correlation and transfer entropy in the Chinese stock market with time delay." *Data Science and Management* **5(3)**: 117-123

[22] Ouyang Hongbing, Huang Kang, Yan Hongju. (2020) "LSTM neural network based financial time series prediction." *Journal of management science in China* **28 (4)** : 27-35, DOI: 10.16381 / j.carol carroll nki issn1003-207 - x. 2020.04.003.

[23] Ozbayoglu A M, Gudelek M U, Sezer O B. (2020) "Deep learning for financial applications: A survey." *Applied Soft Computing* **93**: 106384.
[24] Nelson D M Q, Pereira A C M, De Oliveira R A. (2017) "Stock market's price movement prediction with LSTM neural networks[C]"//*2017 International joint conference on neural networks* (IJCNN). Ieee, : 1419-1426.
[25] Zhao J, Zeng D, Liang S, et al. (2021) "Prediction model for stock price trend based on recurrent neural network." *Journal of Ambient Intelligence and Humanized Computing* **12(1)**: 745-753.
[26] Coley C W, Jin W, Rogers L, et al. (2019) "A graph-convolutional neural network model for the prediction of chemical reactivity." *Chemical science* **10(2)**: 370-377.
[27] Wang Guoli, Sun Yu, Wei zheng. (2022) "Summary of deep learning segmentation algorithms for medical image graphs." *Computer Engineering and Application* **58 (12)**: 37-50.
[28] Tian Z, Liu Y, Sun J, et al. (2021) "Exploiting group information for personalized recommendation with graph neural networks." *ACM Transactions on Information Systems (TOIS)* **40(2)**: 1-23.
[29] Hu Chun-hua, DENG Ao, TONG Xiao-qin, Miao He, WANG Zong-run. (2021) "Social trust and reputation in the electricity map neural network recommend study." *Journal of management science in China* **29 (10)** : 202-212. The DOI: 10.16381 / j.carol carroll nki issn1003-207 - x. 2021.0708.
[30] Wu Bo, Liang Xun, Zhang Shusen, Xu Rui.(2022) "Figure Progress and Application of Neural Network Frontier." *Journal of Computer Science* **45 (01)**: 35-68.
[31] Tsitsvero M, Barbarossa S. (2015) "On the degrees of freedom of signals on graphs"//*2015 23rd European Signal Processing Conference (EUSIPCO)*. IEEE : 1506-1510.
[32] SandryhailaA, MouraJ M F. (2013) "Discrete signal processing on graphs." *IEEE Transactions on Signal Processing* **61 (7)**:1644-1656
[33] Xu Bingbing, Cen eting, Huang Junjie, Shen Huawei, Cheng Xueqi. (2020) "Figure convolutional neural network review." *Journal of Computer Science* **43 (05)**: 755-780.
[34] Xu B, Shen H, Cao Q, et al. (2019) "Graph wavelet neural network." *arXiv preprint arXiv*:1904.07785
[35] Jordan M I, Mitchell T M. (2015) "Machine learning: Trends, perspectives, and prospects." *Science* **349(6245)**: 255-260
[36] Niepert M, Ahmed M, Kutzkov K. (2016) "Learning convolutional neural networks for graphs."//*International conference on machine learning. PMLR*
[37] Atwood J, Towsley D. (2016) "Diffusion-convolutional neural networks." *Advances in neural information processing systems* **29**.
[38] Zhou J, Cui G, Hu S, et al. (2020) "Graph neural networks: A review of methods and applications." *AI Open* **1**: 57-81.
[39] GoriM M G. SCARSELLIF.(2005) "A new model for learning in graph domains." *Proceeding soft the International Joint Conference on Neural Network*s. Montreal, Canada
[40] ScarselliF, GoriM, TsoiA C, et al. (2009) "The graph neural network model." *IEEE Transactions on Neural Networks* **20(1)**:61-80
[41] Li Y, Tarlow D, Brockschmidt M, et al. (2015) "Gated graph sequence neural networks." *arXiv preprint arXiv*:1511.05493.
[42] JohnsonD D. (2017) "Learning graphical state transitions"//*Proceeding soft the 5th International Conference on Learning Representations*. Toulon, France
[43] YouJ, YingR, RenX, etal. (2018) "GraphRNN:generating realistic graphs with deep auto-regressive models"//*Proceeding soft the 35th International Conference on Machine Learning*. Stockholm,Sweden
[44] Seo Y, Defferrard M, Vandergheynst P, et al. (2018) "Structured sequence modeling with graph convolutional recurrent networks"//*International conference on neural information processing*. Springer, Cham
[45] Xu D, Cheng W, Luo D, et al. (2019) "Spatio-Temporal Attentive RNN for Node Classification in Temporal Attributed Graphs"//*IJCAI*.: 3947-3953.
[46] Veličković P, Cucurull G, Casanova A, et al. (2017) "Graph attention networks." *arXiv preprint arXiv*:1710.10903
[47] ZhangJ, ShiX, XieJ, et al. (2018) "GaAN: gated attention networks for learning on large and spatio temporal graphs"//*Proceeding soft the 34th Conference on Uncertainty in Artificial Intelligence*.Monterey,USA
[48] Wang J, Zhang S, Xiao Y, et al. (2021) "A review on graph neural network methods in financial applications." *arXiv preprint arXiv*:2111.15367,
[49] Feng F, He X, Wang X, Luo C, Liu Y, Chua TS (2019). "Temporal relational ranking for stock prediction." *ACM Transactions on Information Systems (TOIS)* **37(2)**: 1–30.
[50] Xu B, Shen H, Sun B, et al. (2021) "Towards consumer loan fraud detection: Graph neural networks with role-constrained conditional random field."//*Proceedings of the AAAI Conference on Artificial Intelligence* **35(5)**: 4537-4545.
[51] Liang T, Zeng G, Zhong Q, et al. (2021) "Credit risk and limits forecasting in e-commerce consumer lending service via multi-view-aware mixture-of-experts nets."//*Proceedings of the 14th ACM international conference on web search and data mining*. 229-237.
[52] Kudo W, Nishiguchi M, Toriumi F. (2020) "GCNEXT: graph convolutional network with expanded balance theory for fraudulent user detection." *Social Network Analysis and Mining* **10(1)**: 1-12.
[53] Rao S X, Zhang S, Han Z, et al. (2020) "Suspicious massive registration detection via dynamic heterogeneous graph neural networks[J]"*arXiv preprint arXiv*:2012.10831
[54] Zhao T, Deng C, Yu K, et al. (2020) "Gnn-based graph anomaly detection with graph anomaly loss."//*The Second International Workshop on Deep Learning on Graphs: Methods and Applications* 1-7.
[55] Harl M, Weinzierl S, Stierle M, et al. Explainable predictive business process monitoring using gated graph neural networks[J]. *Journal of Decision Systems* **29(sup1)**: 312-327.
[56] Chen W, Jiang M, Zhang W G, et al. (2021) "A novel graph convolutional feature based convolutional neural network for stock trend prediction." *Information Sciences* **556**: 67-94.
[57] Ye J, Zhao J, Ye K, et al.(2021) "Multi-graph convolutional network for relationship-driven stock movement prediction."//2020 *25th International Conference on Pattern Recognition (ICPR)*. IEEE 6702-6709.
[58] Yin X, Yan D, Almudaifer A, et al. (2021) "Forecasting Stock Prices Using Stock Correlation Graph: A Graph Convolutional Network Approach."//*2021 International Joint Conference on Neural Networks (IJCNN)*. IEEE 1-8.
[59] Li S, Wu J, Jiang X, et al. (2022) "Chart GCN: Learning chart information with a graph convolutional network for stock movement prediction." *Knowledge-Based Systems* **248**: 108842.
[60] Hou X, Wang K, Zhong C, et al. (2021) "St-trader: A spatial-temporal deep neural network for modeling stock market movement." IEEE/*CAA*

Journal of Automatica Sinica **8(5)**: 1015-1024.
[61] Li W, Bao R, Harimoto K, et al. (2021) "Modeling the stock relation with graph network for overnight stock movement prediction."//*Proceedings of the Twenty-Ninth International Conference on International Joint Conferences on Artificial Intelligence* 4541-4547.
[62] Wu J M T, Li Z, Herencsar N, et al. (2021) "A graph-based CNN-LSTM stock price prediction algorithm with leading indicators." Multimedia Systems 1-20
[63] Feng S, Xu C, Zuo Y, et al. (2022) " Relation-aware dynamic attributed graph attention network for stocks recommendation." *Pattern Recognition* **121**: 108-119.
[64] Ying X, Xu C, Gao J, et al. (2020) "Time-aware graph relational attention network for stock recommendation."//*Proceedings of the 29th ACM International Conference on Information & Knowledge Management* 2281-2284.
[65] Huang K, Li X, Liu F, et al. (2022) "ML-GAT: A Multilevel Graph Attention Model for Stock Prediction." *IEEE Access* **10**: 86408-86422.
[66] Alshara M A. (2022) "Multilayer Graph-Based Deep Learning Approach for Stock Price Prediction." *Security and Communication Networks.*
[67] Cheng R, Li Q. (2021) "Modeling the Momentum Spillover Effect for Stock Prediction via Attribute-Driven Graph Attention Networks."//*Proceedings of the AAAI Conference on Artificial Intelligence* **35(1)**: 55-62.
[68] Sawhney R, Agarwal S, Wadhwa A, et al. (2021) "Exploring the scale-free nature of stock markets: Hyperbolic graph learning for algorithmic trading" //*Proceedings of the Web Conference* 11-22.