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Mining Signed Networks: Theory and Applications

Tutorial proposal for the Web Conference 2020

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ABSTRACT

Signed networks transform the information encoded by conventional graphs by attaching either a positive or a negative sign to every edge. This subtle modification vastly enhances the modelling capabilities of graphs. For instance, in a social network, where edges might represent interactions between users, the sign may determine whether an exchange was friendly or hostile. However, the introduction of edge signs invalidates many established methods and results from the graph-mining toolbox, and thus, problem formulations and algorithmic techniques must be studied anew. In this tutorial we aim to provide an overview of the literature in mining signed networks. We will present the most important theoretical results since their inception to the present day, we will discuss some of the most common applications, and we will reflect on emerging applications and directions for future work.

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1 TOPIC AND RELEVANCE

Just like graphs, signed networks are comprised of a set of vertices and a set of edges, each of which connects a pair of vertices. The difference is that in signed networks, every edge is either positive or negative. The study of signed networks was initially motivated by social balance theory [9], which essentially formalizes the old adage *"the enemy of my enemy if my friend"*. The introduction of signs entails significant changes in fundamental graph notions. For instance, density measures in an unsigned graph are usually formulated such that a missing edge induces a penalty. However, in signed networks, what should incur a larger penalty? The absence of an edge or the presence of a negative one? Conventional formulations of density and the associated algorithms are thus insufficient to meaningfully analyze signed networks, and we must therefore consider novel approaches. Similar differences apply to a host of other graph mining tasks, such as community detection, graph partitioning and graph drawing.

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Relevance. Over the last few years, social-media platforms have gained a foothold as one of the main stages where public discourse takes place. In addition, increasing polarization in politics and abusive behaviour online are eroding the health of democratic societies worldwide. Thus, whereas past applications of graph mining in social media have focused, for instance, on finding dense communities and clusters, today there is a growing interest in finding pockets of antagonistic activity, or in predicting abusive interactions. Thus, the study of signed networks is particularly well motivated in the current political and societal climate.

1.1 Outline

The tutorial will be divided in four sections: introduction, theory, problems & applications, and future directions. Here we present and outline of the topics to be covered.

Introduction.

- Definition of signed network.
- Motivation.

Theory.

- Balance and status theory. Signs can be interpreted in different ways. They can for instance indicate friendship/enmity or admiration/disdain. These interpretations lead to balance [9] and status theory [16], respectively. We will discuss basic concepts and present fundamental results.
- Spectral theory. The spectral theory of signed graphs is fundamentally different to that of their unsigned counterparts. We will define the signed Laplacian [10] and discuss its properties. We will introduce the concept of switching equivalence [18] and its implications.

Problems and applications.

- Node ranking [6, 12, 20].
- Graph partitioning and clustering [4, 11].
- Community detection and polarization in social media [1, 5, 8].
- Link and sign prediction [3, 14, 15].
- Dense subgraph discovery in signed networks [2].
- Graph embedding and representation learning [7, 13, 19].
- Recommendations in signed networks [17].

Future directions. Research interest in signed networks has increased significantly over the last few years. We will discuss opportunities for further inquiry in the near future, covering some of the most compelling open problems and emerging applications.

2 TUTORIAL DETAILS

Duration. The tutorial is planned as half-day tutorial.

Interaction style. This is a lecture-style tutorial. There is no need for the audience members to use any software during the tutorial.

Audience. This tutorial is aimed at

- algorithm designers and practitioners interested in graph analysis;
- researchers in the domain of social-network analysis.

Only elementary graph theory and basic linear algebra are required. Attendees are expected to gain a high-level understanding of the most important concepts in signed graph mining, such as balance and spectral theory.

Previous editions. This is the first edition of this tutorial. To the best of our knowledge, a similar tutorial covering a broad range of topics in signed networks has not been presented before.

Tutorial materials. The employed slides will be made freely available online.

There are no copyright issues.

Equipment. Only the standard equipment is needed.

3 TUTORS

Aristides Gionis is a professor in the department of Computer Science in Aalto University. He is currently a fellow in the ISI foundation, Turin, while he has been a visiting professor in the University of Rome. His previous appointment was with Yahoo! Research, Barcelona, where he has been a senior research scientist and group leader. He obtained his PhD in 2003 from Stanford University, USA. He is currently serving as an action editor in the Data Management and Knowledge Discovery journal (DMKD), an associate editor in the ACM Transactions on Knowledge Discovery from Data (TKDD), and an associate editor in the ACM Transactions on the Web (TWEB). He has contributed in several areas of data science, such as algorithmic data analysis, web mining, social-media analysis, data clustering, and privacy-preserving data mining. His current research is funded by the Academy of Finland (projects Nestor, Agra, AIDA, and MLDB) and by the European Commission with an ERC Advanced grant (REBOUND) and projects SoBigData and SoBigData++. Aristides Gionis has presented several tutorials on graph mining and web mining in conferences such as the Web Conference (2008 and 2018), KDD (2013, 2015, 2018, and 2019), ECML PKDD (2008, 2013, and 2015), IJCAI (2011), as well as in many summer schools, including the Data Science Summer School 2019 and the EDBT Summer School 2019.

Antonis Matakos is a PhD student in the Data Mining Group of the Computer Science Department at Aalto University. He obtained his MSc degree from the University of Ioannina, Greece. His research interests belong broadly to the area of algorithmic data mining, with specific focus on social network analysis, graph theory and web mining. His PhD thesis project focuses on proposing social media models and algorithms for social good.

Bruno Ordozgoiti is a postdoctoral researcher for the Data Mining Group at the department of Computer Science in Aalto University. He earned a PhD in Computer Science from Universidad Politécnica de Madrid, Spain, in 2018. His research interests cover graph theory, graph mining and approximate matrix decompositions. His recent work covers polarized community detection in signed networks and algorithmic methods to tackle polarization in social media.

Han Xiao is currently a 4th year PhD student in the Data Mining group of Computer Science Department at Aalto University. He received his MSc degree from University of Helsinki, Finland. His research interests include data mining, combinatorial optimization, spectral graph theory and algorithmic fairness. Previously, he worked as Research Assistant at ISI foundation, Helsinki University, and Tongji University, as well as a Data Science Intern at Facebook, London.

REFERENCES

[1] Francesco Bonchi, Edoardo Galimberti, Aristides Gionis, Bruno Ordozgoiti, and Giancarlo Ruffo. 2019. Discovering Polarized Communities in Signed Networks. *arXiv preprint arXiv:1910.02438* (2019).

[2] Jose Cadena, Anil Kumar Vullikanti, and Charu C Aggarwal. 2016. On dense subgraphs in signed network streams. In *2016 IEEE 16th International Conference on Data Mining (ICDM)*. IEEE, 51–60.

[3] Kai-Yang Chiang, Nagarajan Natarajan, Ambuj Tewari, and Inderjit S Dhillon. 2011. Exploiting longer cycles for link prediction in signed networks. In *Proceedings of the 20th ACM international conference on Information and knowledge management*. ACM, 1157–1162.

[4] Kai-Yang Chiang, Joyce Jiyoung Whang, and Inderjit S Dhillon. 2012. Scalable clustering of signed networks using balance normalized cut. In *Proceedings of the 21st ACM international conference on Information and knowledge management*. ACM, 615–624.

[5] Lingyang Chu, Zhefeng Wang, Jian Pei, Jiannan Wang, Zijin Zhao, and Enhong Chen. 2016. Finding gangs in war from signed networks. In *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*. ACM, 1505–1514.

[6] Fan Chung, Alexander Tsiatas, and Wensong Xu. 2013. Dirichlet pagerank and ranking algorithms based on trust and distrust. *Internet Mathematics* 9, 1 (2013), 113–134.

[7] Tyler Derr, Yao Ma, and Jiliang Tang. 2018. Signed graph convolutional networks. In *2018 IEEE International Conference on Data Mining (ICDM)*. IEEE, 929–934.

[8] Ming Gao, Ee-Peng Lim, David Lo, and Philips Kokoh Prasetyo. 2016. On detecting maximal quasi antagonistic communities in signed graphs. *Data mining and knowledge discovery* 30, 1 (2016), 99–146.

[9] Frank Harary. 1953. On the notion of balance of a signed graph. *Michigan Math. J.* 2, 2 (1953), 143–146. https://doi.org/10.1307/mmj/1028989917

[10] Yao Ping Hou. 2005. Bounds for the Least Laplacian Eigenvalue of a Signed Graph. *Acta Mathematica Sinica* 21, 4 (01 Aug 2005), 955–960.

[11] Cho-Jui Hsieh, Kai-Yang Chiang, and Inderjit S Dhillon. 2012. Low rank modeling of signed networks. In *Proceedings of the 18th ACM SIGKDD international conference on Knowledge discovery and data mining*. ACM, 507–515.

[12] Jinhong Jung, Woojeong Jin, Lee Sael, and U Kang. 2016. Personalized ranking in signed networks using signed random walk with restart. In *2016 IEEE 16th International Conference on Data Mining (ICDM)*. IEEE, 973–978.

[13] Junghwan Kim, Haekyu Park, Ji-Eun Lee, and U Kang. 2018. Side: representation learning in signed directed networks. In *Proceedings of the 2018 World Wide Web Conference*. 509–518.

[14] Srijan Kumar, Francesca Spezzano, VS Subrahmanian, and Christos Faloutsos. 2016. Edge weight prediction in weighted signed networks. In *2016 IEEE 16th International Conference on Data Mining (ICDM)*. IEEE, 221–230.

[15] Jure Leskovec, Daniel Huttenlocher, and Jon Kleinberg. 2010. Predicting positive and negative links in online social networks. In *Proceedings of the 19th international conference on World wide web*. ACM, 641–650.

[16] Jure Leskovec, Daniel Huttenlocher, and Jon Kleinberg. 2010. Signed Networks in Social Media. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. ACM, New York, NY, USA, 1361–1370. https://doi.org/10.1145/1753326.1753532

[17] Jiliang Tang, Charu Aggarwal, and Huan Liu. 2016. Recommendations in signed social networks. In *Proceedings of the 25th International Conference on World Wide Web*. 31–40.

[18] J.H. van Lint and J.J. Seidel. 1966. Equilateral point sets in elliptic geometry. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen: Series A: Mathematical Sciences* 69, 3 (1966), 335–348.

[19] Suhang Wang, Jiliang Tang, Charu Aggarwal, Yi Chang, and Huan Liu. 2017. Signed network embedding in social media. In *Proceedings of the 2017 SIAM international conference on data mining*. SIAM, 327–335.

[20] Zhaoming Wu, Charu C Aggarwal, and Jimeng Sun. 2016. The troll-trust model for ranking in signed networks. In *Proceedings of the Ninth ACM international conference on Web Search and Data Mining*. ACM, 447–456.