

Outlier Detection for Graph Data

— Proposal for a Tutorial at ASONAM'13 Conference —

Manish Gupta¹, Jing Gao², Charu Aggarwal³, Jiawei Han⁴

¹Microsoft, manishg.iitb@gmail.com

²State Univ of New York, Buffalo, jing@buffalo.edu

³IBM T. J. Watson Research Center, charu@us.ibm.com

⁴Univ. of Illinois at Urbana-Champaign, hanj@illinois.edu

1 Abstract

Outlier detection has been studied in the context of many research areas like statistics, data mining, sensor networks, environmental science, distributed systems, spatio-temporal mining, etc. Outlier detection has been studied on a large variety of data types including high-dimensional data, uncertain data, stream data, graph data, time series data, spatial data, and spatio-temporal data. We present an organized picture of recent research in outlier detection for graph data for both static as well as dynamic graphs. We begin by motivating the importance of graph outlier detection and briefing the challenges beyond usual outlier detection. Static graph outlier detection techniques include Minimum Description Length techniques, techniques based on egonet metrics and random field models. For dynamic graphs, we discuss graph similarity based algorithms, evolutionary community based algorithms and online graph outlier detection algorithms. We also present applications where such techniques have been applied to discover interesting outliers.

2 Rationale of Presenting the Tutorial at ASONAM 2013

With the rapid increase of stored data, the interest in the discovery of hidden information has exploded in the last decade. One important problem that arises during the discovery process is treating data along with links together. Given such huge amounts of graph data, an important task is to find surprising instances (nodes/edges/subgraphs) efficiently. Recently, many effective and efficient graph anomaly detection techniques have been proposed in a variety of research disciplines including data mining, sensor networks, environmental science, distributed systems, spatio-temporal mining, etc. Though there have been multiple surveys and tutorials on general outlier detection, there are not many tutorials or surveys dedicated to a thorough study of the diverse techniques and extensive studies in graph outlier detection. We believe that the organized and extensive coverage of work in this tutorial will greatly benefit researchers in multiple disciplines and motivate cross fertilization of ideas.

ASONAM is the world's premier research conference in social network analysis and mining. Outlier detection is also one of the most important task which has been explored recently for network (or graph) data. So, it seems very natural to present a tutorial on a network-based data mining task in such a network-focused conference.

3 Target Audience and Prerequisites

Intended audience: Researchers and practitioners in data mining, distributed systems and sensor networks. While the audience with a good background on data mining would benefit most from this tutorial, we believe the material to be presented would give general audience and newcomers a complete picture of the current work, introduce important research topics in this field, and inspire them to learn more.

Background: Preliminary knowledge about data mining and algorithms.

4 Related Tutorials by the Authors

“*Outlier Detection for Temporal Data*”, (Manish Gupta, Jing Gao, Charu Aggarwal and Jiawei Han), 2013 SIAM Intl. Conf. on Data Mining (SDM’13), Austin, Texas, May 2013. Attended by around 30 people.

This tutorial was focused on temporal data (time series, data streams, spatio-temporal data, etc.). As against this, the proposed tutorial at ASONAM will be focused on outlier detection for graph data (both from a static as well as a temporal perspective).

5 Related Tutorials by Other Researchers

Many related tutorial dedicated to outlier detection were held by other people in data mining, sensor networks, communication networks, and distributed systems communities.

The following list of tutorials have focused on the general topic of outlier detection. In the proposed tutorial, we aim to specifically focus on graph data only.

1. “*Anomaly Detection: A Tutorial*”, (Sanjay Chawla and Varun Chandola), The 2011 IEEE Intl. Conf. on Data Mining (ICDM’11), Vancouver, Canada, Dec 2011.
2. “*Outlier Detection Techniques*”, (Hans-Peter Kriegel, Peer Kröger, Arthur Zimek), The 16th ACM SIGKDD Conf. on Knowledge Discovery and Data Mining (KDD’10), Washington, D.C., Jul 2010.
3. “*Outlier Detection Techniques*”, (Hans-Peter Kriegel, Peer Kröger, Arthur Zimek), The 2010 SIAM Intl. Conf. on Data Mining (SDM’10), Columbus, Ohio, Apr 2010.
4. **Article:** “*A Tutorial Overview of Anomaly Detection in Hyperspectral Images*”, (Stefania Matteoli, Marco Diani, Giovanni Corsini), Aerospace and Electronic Systems Magazine, IEEE, 25:7 pages 5–28, May 2009.
5. “*Outlier Detection Techniques*”, (Hans-Peter Kriegel, Peer Kröger, Arthur Zimek), The 13th Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD’09), Bangkok, Thailand, Apr 2009.
6. “*Data Mining for Anomaly Detection*”, (Aleksander Lazarevic, Jaideep Srivastava, Vipin Kumar, Arindam Banerjee and Varun Chandola), The 2008 European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECML PKDD’08), Antwerp, Belgium, Sep 2008.
7. “*Anomaly Detection*”, (Arindam Banerjee, Varun Chandola, Vipin Kumar and Jaideep Srivastava), The 2008 SIAM Intl. Conf. on Data Mining (SDM’08), Atlanta, Georgia, Apr 2008.
8. “*Outlier Detection: Principles, Techniques and Applications*”, (Sanjay Chawla), The 2006 Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD’06), Singapore, Apr 2006.

The following tutorials have been presented for networks. However, in these networks, often times, the inherent data representation is not in the form of a graph, though the application is a network. For example, for computer networks, the outlier detection mechanisms mostly look at time series of various metrics at different nodes in the network and so do not use the linkage behavior. Also these tutorials were not in the data mining community and so were focused on specific applications.

1. “*Anomaly Detection in Military Communication Networks*”, (Ritu Chadha and Akshay Vashist), The 2012 Military Communications Conf. (MILCOM’12), Orlando, Florida, Oct 2012.
2. “*Network Anomaly Detection: From Basics to Advanced Methods*”, (Christian Callegari), The 8th Intl. Wireless Communications and Mobile Computing Conf. (IWCMC’12), Limassol, Cyprus, Aug 2012.
3. “*Wavelets and Network Anomaly Detection*”, (Michele Pagano and Christian Callegari), The 3rd Intl. Conf. on Security of Information and Networks (SIN’10), Taganrog, Russia, Sep 2010.

4. “*Advanced Statistical Approaches for Network Anomaly Detection*”, (Christian Callegari), The 2010 Intl. Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS’10), Ottawa, Canada, Jul 2010.
5. “*Statistical Approaches for Network Anomaly Detection*”, (Christian Callegari), The 2nd Intl. Conf. on Security of Information and Networks (SIN’09), Gazimagusa, North Cyprus, Oct 2009.

The following tutorials have focused partially on outlier detection for graph data. But they miss on certain aspects. For example, they do not refer to the temporal graph outlier detection techniques at all. On the other hand, they have focused on topics that are not directly related to our theme and so we do not focus on them: Outlier detection in clouds of multi-dimensional points, Relational Learning with networks, Discovering roles in graphs.

1. “*Discovering Roles and Anomalies in Graphs: Theory and Applications*”, (Tina Eliassi-Rad and Christos Faloutsos), 2012 SIAM Intl. Conf. on Data Mining (SDM’12), Anaheim, CA, Apr 2012.
2. “*What is Strange in Large Networks? Graph-based Irregularity and Fraud Detection*”, (Leman Akoglu and Christos Faloutsos), 2012 Intl. Conf. on Data Mining (ICDM’12), Brussels, Belgium, Dec 2012.
3. “*Anomaly, Event, and Fraud Detection in Large Graph Datasets*”, (Leman Akoglu and Christos Faloutsos), The 5th Intl. Conf. on Web Search and Data Mining (WSDM’12), Seattle, WA, Feb 2012.

6 All Tutorials by Authors

The instructors have rich experience at teaching various kinds of courses on data mining. The following heavily-attended tutorials were delivered in the international conferences in the last several years.

1. **Conference tutorial:** “*Information Network Analysis and Extraction on the World Wide Web*”, (Tim Weninger and Jiawei Han), 2013 Intl. Conf. on the World Wide Web (WWW’13), Rio de Janeiro, Brazil, May 2013.
2. **Conference tutorial:** “*Outlier Detection for Temporal Data*”, (Manish Gupta, Jing Gao, Charu Aggarwal and Jiawei Han), 2013 SIAM Intl. Conf. on Data Mining (SDM’13), Austin, Texas, May 2013.
3. **Conference tutorial:** “*Exploring Structure and Content on the Web: Extraction and Integration of the Semi-Structured Web*”, (Tim Weninger and Jiawei Han), 2013 Intl. Conf. on Web Search and Data Mining (WSDM’13), Rome, Italy, Feb. 2013.
4. **Conference tutorial:** “*On the Power of Heterogeneous Information Networks*”, (Yizhou Sun, Jiawei Han, Xifeng Yan, and Philip S. Yu), 2012 Intl. Conf. on Advances in Social Network Analysis and Mining (ASONAM’12), Istanbul, Turkey, Aug 2012.
5. **Conference tutorial:** “*Mining Knowledge from Interconnected Data: A Heterogeneous Information Network Analysis Approach*”, (Yizhou Sun, Jiawei Han, Xifeng Yan, and Philip S. Yu), 2012 Intl. Conf. on Very Large Data Bases (VLDB’12/PVLDB), Istanbul, Turkey, Aug 2012.
6. **Invited tutorial:** “*Data Mining with Social and Trajectory Data: Urban Computing in the Big Data Age*”, (Jiawei Han), China Computer Federation - Advanced Disciplines Lectures (CCF-ADL), Beijing, China, Aug 2012.
7. **Conference tutorial:** “*Mining Knowledge from Data: An Information Network Analysis Approach*”, (Jiawei Han, Yizhou Sun, Xifeng Yan, Philip S. Yu), 2012 IEEE Intl. Conf. on Data Engineering (ICDE’12), Arlington, VA, Apr 2012.
8. **Conference tutorial:** “*Data Stream Mining: Challenges and Techniques*”, (Latifur Khan, Wei Fan, Jiawei Han, Jing Gao, Mohammad Mehedy Masud), The 15th Pacific-Asia Conference on Knowledge Discovery and Data Mining (PAKDD’11), Shenzhen, China, May 2011.

9. **Conference tutorial:** “*Mining Heterogeneous Information Networks*”, (Jiawei Han, Yizhou Sun, Xifeng Yan, and Philip S. Yu), 2010 ACM SIGKDD Conf. on Knowledge Discovery and Data Mining (KDD’10), Washington, D.C., Jul 2010.
10. **Conference tutorial:** “*Mining Knowledge from Databases: An Information Network Analysis Approach*”, (Jiawei Han, Yizhou Sun, Xifeng Yan, and Philip S. Yu), 2010 ACM SIGMOD Intl. Conf. on Management of Data (SIGMOD’10), Indianapolis, Indiana, Jun 2010.
11. **Conference tutorial:** “*On the Power of Ensemble: Supervised and Unsupervised Methods Reconciled*”, (Jing Gao, Wei Fan, and Jiawei Han), 2010 SIAM Data Mining Conf. (SDM’10), Columbus, Ohio, May 2010.
12. **Conference tutorial:** “*Mining Moving Object and Traffic Data*”, (Jiawei Han, Zhenhui Li, and Lu An Tang), 2010 Intl. Conf. on Database Systems for Advanced Applications (DASFAA’10), Tsukuba, Japan, Apr 2010.
13. **Conference tutorial:** “*A Geometric Perspective on Dimensionality Reduction*”, (Deng Cai, Jiawei Han, and Xiaofei He), 2009 SIAM Data Mining Conf. (SDM’09), Sparks, NV, Apr 2009.
14. **Conference tutorial:** “*Scalable OLAP and Mining of Information Networks*”, (Jiawei Han, Xifeng Yan, and Philip S. Yu), 2009 Intl. Conf. on Extending Database Technology (EDBT’09), Saint-Petersburg, Russia, Mar 2009.
15. **Conference tutorial:** “*Integration of Classification and Pattern Mining: A Discriminative and Frequent Pattern-based Approach*”, (Hong Cheng, Jiawei Han, Xifeng Yan, and Philip S. Yu), 2008 Intl. Conf. on Data Mining (ICDM’08), Pisa, Italy, Dec 2008.
16. **Conference tutorial:** “*Mining Massive RFID, Trajectory, and Traffic Data Sets*”, (Jiawei Han, Jae-Gil Lee, Hector Gonzalez, Xiaolei Li), 2008 ACM SIGKDD Intl. Conf. on Knowledge Discovery and Data Mining (KDD’08), Las Vegas, NE, Aug 2008.
17. **Conference tutorial:** “*Exploring the Power of Links in Scalable Data Analysis*”, (Jiawei Han, Xiaoxin Yin, and Philip S. Yu), 2008 Intl. Conf. on Data Engineering (ICDE’08), Cancun, Mexico, Apr 2008.
18. **Conference tutorial:** “*Mining for Software Reliability*”, (Chao Liu, Tao Xie, and Jiawei Han), 2007 Intl. Conf. on Data Mining (ICDM’07), Omaha, NE, Oct 2007.
19. **Conference tutorial:** “*Exploring the Power of Links in Data Mining*”, (Jiawei Han, Xiaoxin Yin, and Philip S. Yu), 2007 Intl. Conf. on Principles and Practice of Knowledge Discovery in Databases (PKDD’07), Warsaw, Poland, Sep 2007.
20. **Conference tutorial:** “*Mining and Searching Graphs and Structures*”, (Jiawei Han, Xifeng Yan, and Philip S. Yu), 2006 ACM SIGKDD Intl. Conf. on Knowledge Discovery and Data Mining (KDD’06), Philadelphia, PA, Aug 2006.
21. **Conference tutorial:** “*Mining, Indexing, and Similarity Search in Graphs and Complex Structures*”, (Jiawei Han, Xifeng Yan, and Philip S. Yu), 2006 Intl. Conf. on Data Engineering (ICDE’06), Atlanta, GA, Apr 2006.
22. **Conference invited tutorials:** “*Mining and Searching of Graph-Structured Databases*”, (Jiawei Han, Xifeng Yan and Philip S. Yu), 2005 Intl. Conf. on Data Mining (ICDM’05), Houston, TX, Nov 2005.
23. **Conference industry portal tutorials:** “*Traditional Data Mining*,” and “*Data Mining Today*,” (Jiawei Han), 2004 Asian-Pacific Conf. on Knowledge Discovery and Data Mining (PAKDD’04), Sydney, Australia, May 2004.
24. **Conference tutorial:** “*Data Mining for Machine Learners*,” (Johannes Gehrke and Jiawei Han), 2003 Intl. Conf. on Knowledge Discovery and Data Mining (KDD’03), Washington, D.C., Aug 2003.

25. **Conference tutorial:** “*Frequent Pattern Mining Methods and Applications: An Overview*,” (Jiawei Han, Laks V.S. Lakshmanan, and Jian Pei), 2001 Intl. Conf. on Knowledge Discovery and Data Mining (KDD’01), San Jose, California, Aug 2001.
26. **Conference tutorial:** “*Sequential Pattern Mining: From Shopping History Analysis to Weblog Mining and DNA Mining*,” (Jiawei Han), 2001 Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD’01), Hong Kong, April 2001.

7 Tutors’ Short Bio

- **Manish Gupta**, <http://dais.cs.uiuc.edu/manish/> is an applied researcher at Microsoft Bing, India. He received his Masters in Computer Science from IIT Bombay in 2007 and his PhD in Computer Science from Univ of Illinois at Urbana Champaign in 2013. He worked for Yahoo! Bangalore from 2007 to 2009. His research interests are in the areas of data mining and information retrieval.
- **Jing Gao**, <http://www.cse.buffalo.edu/~jing/>, received the Ph.D. degree from University of Illinois at Urbana Champaign in 2011. She is an assistant professor in the Computer Science and Engineering Department of the State University of New York at Buffalo. She was a recipient of an IBM PhD fellowship. She is broadly interested in data and information analysis with a focus on information integration, ensemble methods, transfer learning, anomaly detection, and mining data streams. She is a member of the IEEE.
- **Charu Aggarwal**, <http://charuaggarwal.net/>, is a Research Scientist at the IBM T. J. Watson Research Center in Yorktown Heights, New York. He completed his Ph.D. from Massachusetts Institute of Technology in 1996. He has since worked in the field of performance analysis, databases, and data mining. He has published over 200 papers in refereed conferences and journals, and has applied for or been granted over 80 patents. He has received IBM Corporate Award (2003), IBM Outstanding Innovation Award (2008), IBM Research Division Award (2008) and Master Inventor at IBM thrice. He is a fellow of the IEEE and a life-member of the ACM.
- **Jiawei Han**, <http://www.cs.uiuc.edu/~hanj/> (Ph.D., Univ. of Wisconsin at Madison), is Abel Bliss Professor in the Department of Computer Science at the University of Illinois. He has been researching into data mining, information network analysis, and database systems, with more than 500 publications. He received the ACM SIGKDD Innovation Award (2004), the IEEE Computer Society Technical Achievement Award (2005), and the IEEE W. Wallace McDowell Award (2009). His book *Data Mining: Concepts and Techniques* (Morgan Kaufmann) has been used worldwide as a textbook. He is a fellow of the ACM and the IEEE.

8 Outline of the Tutorial

1. Introduction to Graph Outlier Detection
 - (a) Main challenges
 - (b) Taxonomy of techniques for graph outlier detection
 - (c) Comparisons with general outlier detection
 - (d) Motivations
2. Static Graph Outlier Detection Algorithms
 - (a) Minimum Description Length Methods [Cha04, EH07, LYY+05, NC03]
 - (b) Methods based on Egonet Metrics [AMF10, GOP04, HERF+10]
 - (c) Methods based on Random Walks [MT06, SQCF05]
 - (d) Random Field Models [GLF+10, QAH12]
3. Dynamic Graph Outlier Detection Algorithms

- (a) Graph Similarity based Methods [DBDK02, DK03, KDD07, PDGM10, Pin05, SKR99]
 - (b) Evolutionary Community Outlier Detection Algorithms [GGSH12a, GGSH12b]
 - (c) Online Graph Outlier Detection Algorithms [AZY11, AF10, IK04]
 - (d) Other Methods [GAH11, GAHS11, PCMP05]
4. Applications in Real Datasets
 5. Summary

9 Length of the Tutorial

Based on the outline above, we propose to give a short tutorial (1.5–2 hours).

10 25 Most Important References

The following is a list of references which will be used in the preparation of the tutorial material. Many other papers will be referenced as well.

References

- [AF10] L. Akoglu and C. Faloutsos. Event Detection in Time Series of Mobile Communication Graphs. In *Proc. of the Army Science Conf.*, 2010.
- [AMF10] Leman Akoglu, Mary McGlohon, and Christos Faloutsos. Oddball: Spotting anomalies in weighted graphs. In *Proc. of the 14th Pacific-Asia Conf. on Advances in Knowledge Discovery and Data Mining (PAKDD)*, pages 410–421. Springer, 2010.
- [AZY11] Charu C. Aggarwal, Yuchen Zhao, and Philip S. Yu. Outlier Detection in Graph Streams. In *Proc. of the 27th Intl. Conf. on Data Engineering (ICDE)*, pages 399–409. IEEE Computer Society, 2011.
- [Cha04] Deepayan Chakrabarti. AutoPart: Parameter-free Graph Partitioning and Outlier Detection. In *Proc. of the 8th European Conf. on Principles and Practice of Knowledge Discovery in Databases (PKDD)*, pages 112–124, 2004.
- [DBDK02] P. Dickinson, H. Bunke, A. Dadej, and M. Kraetzl. Median Graphs and Anomalous Change Detection in Communication Networks. In *Proc. of the Intl. Conf. on Information, Decision and Control*, pages 59–64, Feb 2002.
- [DK03] P. Dickinson and M. Kraetzl. Novel Approaches in Modelling Dynamics of Networked Surveillance Environment. In *Proc. of the 6th Intl. Conf. of Information Fusion*, volume 1, pages 302–309, 2003.
- [EH07] William Eberle and Lawrence Holder. Discovering structural anomalies in graph-based data. In *Proc. of the 7th IEEE Intl. Conf. on Data Mining Workshops (ICDMW)*, pages 393–398, 2007.
- [GAH11] Manish Gupta, Charu C. Aggarwal, and Jiawei Han. Finding Top-K Shortest Path Distance Changes in an Evolutionary Network. In *Proc. of the 12th Intl. Conf. on Advances in Spatial and Temporal Databases (SSTD)*, pages 130–148, 2011.
- [GAHS11] Manish Gupta, Charu C. Aggarwal, Jiawei Han, and Yizhou Sun. Evolutionary Clustering and Analysis of Bibliographic Networks. In *Proc. of the 2011 Intl. Conf. on Advances in Social Networks Analysis and Mining (ASONAM)*, pages 63–70, 2011.
- [GGSH12a] Manish Gupta, Jing Gao, Yizhou Sun, and Jiawei Han. Community Trend Outlier Detection using Soft Temporal Pattern Mining. In *Proc. of the 2012 European Conf. on Machine Learning and Knowledge Discovery in Databases (ECML PKDD)*, pages 692–708, 2012.
- [GGSH12b] Manish Gupta, Jing Gao, Yizhou Sun, and Jiawei Han. Integrating Community Matching and Outlier Detection for Mining Evolutionary Community Outliers. In *Proc. of the 18th ACM Intl. Conf. on Knowledge Discovery and Data Mining (KDD)*, pages 859–867, 2012.
- [GLF⁺10] Jing Gao, Feng Liang, Wei Fan, Chi Wang, Yizhou Sun, and Jiawei Han. On Community Outliers and their Efficient Detection in Information Networks. In *Proc. of the 16th ACM Intl. Conf. on Knowledge Discovery and Data Mining (KDD)*, pages 813–822, 2010.

- [GOP04] Amol Ghoting, Matthew Eric Otey, and Srinivasan Parthasarathy. LOADED: Link-Based Outlier and Anomaly Detection in Evolving Data Sets. In *Proc. of the 4th IEEE Intl. Conf. on Data Mining (ICDM)*, pages 387–390, 2004.
- [HERF⁺10] Keith Henderson, Tina Eliassi-Rad, Christos Faloutsos, Leman Akoglu, Lei Li, Koji Maruhashi, B. Aditya Prakash, and Hanghang Tong. Metric Forensics: A Multi-level Approach for Mining Volatile Graphs. In *Proc. of the 16th ACM SIGKDD Intl. Conf. on Knowledge Discovery and Data Mining (KDD)*, pages 163–172, 2010.
- [IK04] Tsuyoshi IDÉ and Hisashi KASHIMA. Eigenspace-based Anomaly Detection in Computer Systems. In *Proc. of the 10th ACM Intl. Conf. on Knowledge Discovery and Data Mining (KDD)*, pages 440–449, 2004.
- [KDD07] K. M. Kapsabelis, P. J. Dickinson, and K. Dogancay. Investigation of Graph Edit Distance Cost Functions for Detection of Network Anomalies. In *Proc. of the 13th Biennial Computational Techniques and Applications Conf. (CTAC)*, volume 48, pages C436–C449, Oct 2007.
- [LYY⁺05] Chao Liu, Xifeng Yan, Hwanjo Yu, Jiawei Han, and Philip S. Yu. Mining Behavior Graphs for “Back-trace” of Noncrashing Bugs. In *Proc. of the 5th SIAM Intl. Conf. on Data Mining (SDM)*, pages 286–297, 2005.
- [MT06] H. D. K. Moonesignhe and Pang-Ning Tan. Outlier Detection Using Random Walks. In *Proc. of the 18th IEEE Intl. Conf. on Tools with Artificial Intelligence (ICTAI)*, pages 532–539, 2006.
- [NC03] Caleb C. Noble and Diane J. Cook. Graph-Based Anomaly Detection. In *Proc. of the 9th ACM SIGKDD Intl. Conf. on Knowledge Discovery and Data Mining (SIGKDD)*, pages 631–636. ACM, 2003.
- [PCMP05] Carey E. Priebe, John M. Conroy, David J. Marchette, and Youngser Park. Scan Statistics on Enron Graphs. *Computational & Mathematical Organization Theory*, 11(3):229–247, Oct 2005.
- [PDGM10] Panagiotis Papadimitriou, Ali Dasdan, and Hector Garcia-Molina. Web Graph Similarity for Anomaly Detection. *Journal of Internet Services and Applications*, 1(1):19–30, 2010.
- [Pin05] Brandon Pincombe. Anomaly Detection in Time Series of Graphs using ARMA Processes. *ASOR Bulletin*, 24(4):2–10, 2005.
- [QAH12] Guo-Jun Qi, Charu C. Aggarwal, and Thomas S. Huang. On Clustering Heterogeneous Social Media Objects with Outlier Links. In *Proc. of the 5th ACM Intl. Conf. on Web Search and Data Mining (WSDM)*, pages 553–562, 2012.
- [SKR99] P. Shoubridge, M. Kraetzl, and D. Ray. Detection of Abnormal Change in Dynamic Networks. In *Proc. of the Intl. Conf. on Information, Decision and Control*, pages 557–562, 1999.
- [SQCF05] Jimeng Sun, Huiming Qu, Deepayan Chakrabarti, and Christos Faloutsos. Neighborhood Formation and Anomaly Detection in Bipartite Graphs. In *Proc. of the 5th IEEE Intl. Conf. on Data Mining (ICDM)*, pages 418–425, 2005.

11 Specific Audio/Video/Computer Requirements

No special requirements. A standard projector is needed.

12 URLs of the Slides/Notes of the Previous Tutorials By Authors

Please visit <http://tinyurl.com/jiaweiHanPubs> for slides of most of the tutorials.