Article

Network criminology: the criminology based on network science

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Abstract
In present study, I proposed the science discipline, network criminology. Network criminology roots in criminology and network science, which focuses on network analysis of criminal networks. It uses the theory and methodology of network science to analyze, predict and control criminal patterns and behavior. The criminal network refers to a criminal group, a terrorism network, etc. Network criminology aims to understand topological structure, organization, function, identification, and control, etc., of criminal networks. Meanwhile, I defined the aims, scope, theory and methodology of network criminology.

Keywords network criminology; criminal networks; scientific discipline.

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1 Introduction

In present study, I proposed the science, network criminology. Network criminology is the science on network analysis of criminal networks. The criminal network refers to a criminal group, a terrorism network, etc. In a criminal network, nodes represent individuals (e.g., offenders, victims, potential victims, or areas, etc), and links (i.e., ties) represent relationships between the individuals (Wikipedia, 2016a). Network criminology aims to understand topological structure, organization, function, identification, and control, etc., of criminal networks. Meanwhile, I defined the aims, scope, theory and methodology of network criminology in this study.

2 Definition, Aims and Scope

Network criminology is an interdisciplinary science rooted in criminology, network science, sociology, and other related scientific disciplines. It is a network analysis based (Zhang, 2016c, 2016g, 2016p-q) criminology, and is thus a branch of criminology. It uses the theory and methodology of network science to analyze, predict and control criminal patterns and behavior. Network criminology aims to investigate and understand the structure, properties, organization, function, identification, and control, etc., of criminal networks (e.g.,

offender networks, offender-victim networks, offender-victim-area networks, etc). The scope of network criminology covers, but not limits to: (1) theories, models, algorithms and software of network criminalogy; (2) network analysis of criminal networks; (3) identification of criminal groups, terrorism networks, offenders, victims, and areas; (4) causes and consequences of criminal behaviors; (5) dynamics and control of criminal networks; (6) methods to prevent the development of criminal groups, terrorism networks, etc.

3 Scientific Foundations

3.1 Criminology

Criminology is the scientific area on the nature, extent, management, causes, control, consequences, and prevention of criminal patterns and behavior, both on the individual and social levels (Wikipedia, 2016a). Criminology is an interdisciplinary field in both the behavioral and social sciences.

Criminology has some branches, e.g., Marxist criminology, conflict criminology, biosocial criminology, and critical criminology, etc. Marxist criminology stated that "defiance is normal - the sense that men are now consciously involved…in assuring their human diversity." (Sparks, 1980). Marxist criminology, conflict criminology and critical criminology argue that most of the relationships between state and citizen are non-consensual and criminal law is not necessarily representative of public beliefs and wishes. Criminal law is exercised in the interests of the ruling or dominant class (Wikipedia, 2016a). Some theories in criminology include (Wikipedia, 2016a)

(1) Sociological positivism. Sociological positivism suggests that societal factors, e.g., poverty, membership of subcultures, or low levels of education, etc., are causes of crimes (Beirne, 1987; Lochner, 2004).

(2) Differential association: It holds that crime is learned through association (Anderson, 1992).

(3) Social structure theories (Hester and Eglin, 1992). There are various viewpoints on social structure theories. Social disorganization theory suggests that neighborhoods with poverty and economic problems tend to have high population turnover (Bursik Jr and Robert, 1988). Further, social ecology argues that crime rates are associated with poverty, disorder, richfull abandoned buildings, and other signs of community deterioration (Bursik Jr and Robert, 1988; Morenoff et al., 2001). Subcultural theory focuses on small cultural groups fragmenting away from the mainstream to generate their own values and meanings about life. Social control theories explain why people do not become criminal (Hirschi, 1969). Finally, social network analysis stresses using network analysis to explain criminal patterns and behavior.

(4) Symbolic interactionism. Symbolic interactionism focuses on the relationship between the powerful state, media, and conservative ruling elite and other less powerful groups.

(5) Individual theories. Traitor theory exploits how a process of brutalization by parents or peers that usually occurs in childhood results in violent crimes in adulthood (Rhodes, 2000). Rational choice theory argues that punishment, if certain, swift, and proportionate to the crime, was a deterrent for crime, with risks outweighing possible benefits to the offender. Routine activity theory draws upon control theories and explains crime in terms of crime opportunities that occur in everyday life (Felson, 1994).

(6) Biosocial criminology is an interdisciplinary field that aims to explain crime and antisocial behavior by exploring both biological and environmental factors (Kevin and Anthony, 2011).

3.2 Network science

The United States National Research Council defined network science as "the study of network representations of physical, biological, and social phenomena leading to predictive models of these phenomena." (Committee on Network Science for Future Army Applications, 2006). More specifically, it is the science dealt with complex networks such as telecommunication networks, computer networks, biological networks, and social

networks, considering distinct elements or actors represented by nodes and the connections between the elements or actors as links (Wikipedia, 2016b). Network science draws on theories and methods including graph theory from mathematics, statistical mechanics from physics, data mining and information visualization from computer science, inferential modeling from statistics, and social structure from sociology (Zhang, 2012a; Wikipedia, 2016b).

Some new scientific disciplines, e.g., network biology, network pharmacology, network informatics, network toxicology, etc., are rooted in network science (Barabasi and Otlvai, 2004; Hopkins, 2007, 2008; Zhang, 2011a-b, 2012a-d, 2015a-d, 2016a-r).

4 Methodology

4.1 Data sources

There are two sources of data for research in network criminology, public databases and field investigation/survey. Public databases include unpublished public data and published data. They can be used to construct criminal networks and models. In addition, criminal data can be achieved by investigating the interactions between individuals.

4.2 Big data analytics

Big data is the data sets so large or complex that conventional data processing tecgniques are inadequate. Big data analytics is the process of examining big data to uncover hidden patterns, unknown correlations and other useful information. With big data analytics, e.g., high-performance data mining, predictive analytics, text mining, forecasting and optimization, one can analyze huge volumes of data that conventional analytics can not handle with (Zhang, 2007, 2016g, 2016p-q). Contents of big data analysis include analysis, capture, storage, search, querying, sharing, transfer, visualization, etc (Wikipedia, 2016c; Zhang, 2016g, 2016p-q). Many problems in network criminology may be addressed by using big data analytics.

4.3 Network construction and link prediction

Network construction is the basic procedure for producing a criminal network. There are various methods for constructing a network. Zhang (2011a, 2012a, 2012b) proposed a series of correlation methods to construct networks. Zhang and Li (2015) found that the utilization of Pearson correlation measure may produce false results. For this reason, Zhang (2015c) suggested partial linear correlation and proposed some other partial correlation measures, and used them to jointly predict network links (interactions) (Zhang, 2015b). In addition, there are some other studies and methods about construction and prediction of networks (Goh et al., 2000; Pazos and Valencia, 2001; Guimera and Sales-Pardo, 2009).

In many cases, the criminal networks we achieved are probably incomplete, i.e., some links are missing in the netwok. We may be interesting in finding missing links in the network. Link information in the incomplete network can be used to predict missing links (Clauset et al., 2008; Guimera and Sales-Pardo, 2009; Barzel and Barabási, 2013; Lü et al., 2015; Zhang, 2015d, 2016a, 2016d; Zhang and Li, 2015). Further, network evolution based (Zhang, 2012a, 2015a, 2016b), node similarity based (Zhang, 2015d), and correlation based (Zhang, 2007, 2011a, 2012a, 2012b, 2015b-c, 2016d; Zhang and Li, 2015) methods can be used in link prediction. For example, Zhang (2015d) proposed a node similarity based algorithm to predic missing links in the network. In this algorithm, whether a node v_k can connect to v_i or not, depending on the similarity between v_k and v_i, the similarities between v_i and its adjacent nodes, the similarities between v_k and the adjacent nodes of v_i, and the degree of node v_i, and vice versa. Pearson correlation measure, cosine measure, and (negative) Euclidean distance measure, contingency correlation measure, and Jaccard coefficient measure were used as the between-node similarity.

4.4 Network analysis

Network analysis covers a variety of areas and methods (Fath et al., 2007; Zhang, 2012a). The following methods and theory of network analysis can be used in network criminology.

4.4.1 Attribute analysis

Attribute analysis aims to screen node attributes (e.g., characteristics of offenders or victims) based on their contribution to topological structure of the network (Zhang, 2016e). Zhang (2016e) proposed a method to screen node attributes that significantly influence node centrality in the network. In this method, four node centralities, degree centrality, closeness centrality, betweenness centrality, and circuit centrality, can be used as the dependent variable and attribute-by-node data are used as the data of independent variables. Stepwise linear regression method was applied to screen statistically significant node attributes from candidate attributes.

Brantingham and Brantingham (1994, 1998) argues that four factors – accessibility through high-volume transportation conduits, placement, juxtaposition, and the operation of facilities can account for the criminogenic capacity of specific places (Wikipedia, 2016c).

4.4.2 Topological analysis

Topological analysis of networks mainly includes the following, which are useful in network criminology

Find trees in the network: DFS algorithm, Minty's algorithm, etc (Minty, 1965; Zhang, 2012a, 2016o).

Find the shortest tree: Kruskal algorithm (Zhang, 2012a).

Find the shortest path: Dijkstra algorithm, Floyd algorithm (Dijkstra, 1959; Zhang, 2012a, 2016r).

Find the maximal flow: Ford-Fulkerson algorithm (Ford and Fulkerson , 1956; Zhang, 2012a).

Find circuits (Paton, 1969; Zhang, 2012a).

Calculate network connectedness (connectivity), blocks, cut vertices, and bridges (Zhang, 2012a, 2016i, 2016m), for examples of application, closeness or connectedness of a criminal network, or crucial offenders, victims, potential victims, or areas, etc.

Calculate node centrality and find critical nodes (Zhang, 2012a, 2012c; Zhang and Zhan, 2011; Shams and Khansari, 2014; Khansari et al., 2016). These methods can be used to find critical offenders or victims in criminal networks, etc. Bichler et al. (2010) defined magnetic facilities as the attractiveness of a location for deviant behavior. They looked at the self-nominated hangouts of 5082 delinquent youth living in Southern California. The structure of these networks remained relatively constant over the time during the study period. The centrality statistics used were in-degree and betweenness to identify facilities operating as stable regional convergence locations. Of the locations included in the network, the top twenty with the highest in-degree centrality scores in both the valued and dichotomous networks were investigated for the three characteristics: facility type, place type and school accessibility (Wikipedia, 2016c).

Analyze degree distribution and find critical nodes (Huang and Zhang, 2012; Li and Zhang, 2013; Zhang, 2011a, 2012a, 2012c; Zhang and Zhan, 2011; Rahman et al., 2013; Nuwagaba and Hui, 2015). Critical offenders or victims can be screended by using these methods.

In network criminology, we are interesting in finding criminal groups. The methods for finding modules, mosaics, and sub-networks can be used in this aspect (Kondoh, 2008; Bascompte, 2009; Begum et al., 2014; Nuwagaba and Hui, 2015; Zhang, 2016f, 2016n; Zhang and Li, 2016). Zhang (2016f, 2016n), and Zhang and Li (2016) proposed some methods for identifying hierarchical sub-networks / modules and weighting network links based on their similarity in sub-network / module affiliation. These methods were based on the cluster analysis in which between-node similarity in sets of adjacency nodes is used. Two matrices, linkWeightMat and linkClusterIDs, were achieved by using the algorithm. Two links with both the same weight in linkWeightMat and the same cluster ID in linkClusterIDs belong to the same sub-network / module. Two links

with the same weight in linkWeightMat but different cluster IDs in linkClusterIDs belong to two sub-networks / modules at the same hirarchical level. A sub-network / module with the greater weight is the more connected sub-network / modules.

4.4.3 Network stability and robusteness

Network stability and robustness are expected to find some utilization in the network criminology, e.g., analyzing stability and robustness of a criminal network that experienced external destruction or attack. Recently, Zhang (2016h, 2016l) exploited methods and theory on network robustness and network sensitivity. Network stability has been extensively studied in the past (Din, 2014). Studies on ecosystems show that there is a relationship between network connectance and different types of ecosystem stability. Some models suggest that lower connectance involve higher local (May, 1973; Pimm, 1991; Chen and Cohen, 2001) and global (Cohen et al., 1990; Chen and Cohen, 2001) stability, i.e., the system recovers faster after a disturbance. However, another theory suggests that a food web with higher connectance has more numerous reassembly pathways and can thus recover faster from perturbation (Law and Blackford, 1992).

4.4.4 Flow balance analysis

Flow balance analysis analyzes network flows at steady state. Differential equations and other equations are usually used to describe network dynamics (Chen et al., 2010; Schellenberger et al., 2011). As an example, Jain et al. (2011) used mathematical models to decipher balance between cell survival and cell death using insulin. Some standardized indices and matrices can be used in flow balance analysis (Latham, 2006; Fath et al., 2007; Zhang, 2012a), including Average Mutual Information (AMI) (Rutledge et al., 1976) and Ascendency (A) index (Ulanowicz, 1983, 1997). Zorach and Fath and Patten (1999) developed a measure (measures the evenness of flow in a network) for network homogenization. Ulanowicz (2003) presented effective measures (effective connectivity, effective flows, effective nodes, effective rules) for weighted networks. Compartmentalization index is used to measure the degree of well-connected subsystems within a network (Pimm and Lawton, 1980). Constraint efficiency is a measure of a total of constraints that govern flow out of individual compartments (Latham and Scully, 2002). Models and measures above are suggested using in network analysis of criminal networks.

4.5 Network dynamics, evolution and control

Network dynamics can be best described with various mathematical models. Zhang (2015a) proposed a generalized network evolution model and self-organization theory on community assembly, in which the model is a series of differential (difference) equations with different number as the time. In addition, Zhang (2016b) developed a random network based, node attraction facilitated network evolution method. The two dynamic models are useful to study the network evolution, dynamics, and to predict links. Ferrarini (2011, 2011b, 2013a-c, 2014, 2016) have proposed a series of thoughts and methods on the dynamics, controllability and dynamic control of biological networks. A network can be optimized to search for an optimal search plan, and achieve a topological structure so that the network possesses relative stability (Zhang, 2012a, 2016g, 2016p-q).

The dynamic control of network means to change topological structure and key parameters of the network stage by stage so that the goal function of entire network achieves the optimum or suboptimum (Zhang, 2012a, 2016g, 2016p-q).

The control and management of criminal networks are expected to be achieved by using mathematical network models (e.g., differential equations, difference equations) or computer simulation (e.g., addition/deletion of nodes/links following some given rules) of network structure.

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References

Anderson F. 1992. Criminological Theory Summaries. Cullen & Agnew. Retrieved November 3, 2011

Barabasi AL, Otlvai ZN. 2004. Network biology: understanding the cell's functional organization. Nature Reviews Genetics, 5(2): 101-113

Barzel B, Barabási AL. 2013. Network link prediction by global silencing of indirect correlations. Nature Biotechnology, 31: 720-725

Begum M, Bagga J, Blakey A, Saha S. 2014. Network motif identification and structure detection with exponential random graph models . Network Biology, 4(4): 155-169

Beirne P. 1987. Adolphe quetelet and the origins of positivist criminology. American Journal of Sociology. 92(5): 1140-1169

Bichler GM, Malm A, Enriquez J. 2010. Magnetic Facilities: Identifying the Convergence Settings of Juvenile Delinquents. Crime and Delinquency, 1-28

Brantingham PJ, Brantingham PL. 1994. The Influence of Street Networks on the Patterning of Property Offenses. In: Crime Prevention Studies (Clarke, ed). Criminal Justice Press, NY, USA

Brantingham PJ, Brantingham PL. 1998. Environmental criminology: From theory to urban planning practice. Studies on Crime and Crime Prevention, 7: 31-60

Bursik Jr, Robert J. 1988. Social disorganization and theories of crime and delinquency: problems and prospects. Criminology, 26(4): 519-539

Chen Q, Wang Z, Wei DQ. 2010. Progress in the applications of flux analysis of metabolic networks. Chinese Science Bulletin, 2010, 55(22): 2315-2322

Chen X, Cohen JE. 2001. Global stability, local stability and permanence in model food webs. Journal of Theoretical Biology, 212: 223-235

Clauset A, Moore C, Newman MEJ. 2008. Hierarchical structure and the prediction of missing links in networks. Nature, 453: 98-101

Committee on Network Science for Future Army Applications. 2006. Network Science. National Research Council

Dijkstra EW. 1959. A note on two problems in connexion with graphs. Numerischemathematik, 1(1): 269-271

Din Q. 2014. Stability analysis of a biological network. Network Biology, 4(3): 123-129

Fath BD, Patten BC. 1999. Quantifying resource homogenization using network flow analysis. Ecological Modelling, 123: 193-205

Fath BD, Scharler UM, Ulanowiczd RE, Hannone B. 2007. Ecological network analysis: network construction. Ecological Modeling, 208: 49-55

Felson M. 1994. Crime and Everyday Life. Pine Forge, Pennsylvania, USA

Ferrarini A. 2011. Some thoughts on the controllability of network systems. Network Biology, 1(3-4): 186-188

Ferrarini A. 2013a. Exogenous control of biological and ecological systems through evolutionary modelling. Proceedings of the International Academy of Ecology and Environmental Sciences, 3(3): 257-265

Ferrarini A. 2013b. Controlling ecological and biological networks via evolutionary modelling. Network Biology, 3(3): 97-105

Ferrarini A. 2013c. Networks control: introducing the degree of success and feasibility. Network Biology, 3(4): 115-120

Ferrarini A. 2014. Local and global control of ecological and biological networks. Network Biology, 4(1): 21-30

Ferrarini A. 2016. Decentralized control of ecological and biological networks through Evolutionary Network Control. Network Biology, 6(3): 65-74

Ford LR Jr, Fulkerson DR. l956. Maxima1 flow through a network. Canadian Journal of Mathematics, 8: 399-404

Goh CS, Bogan AA, Joachimiak M, et al. 2000. Co-evolution of proteins with their interactions partners. Journal of Molecular Biology, 299: 283-293

Guimera R, Sales-Pardo M. 2009. Missing and spurious interactions and the reconstruction of complex networks. Proceedings of the National Academy of Sciences of USA, 106: 22073-22078

Hester S, Eglin P. 1992. A Sociology of Crime. Routledge, London, UK

Hirschi T. 1969. Causes of Delinquency. Transaction Publishers, USA

Hopkins AL. 2007. Network pharmacology. Nature Biotechnology, 25(10): 1110-1111

Hopkins AL. 2008. Network pharmacology: the next paradigm in durg discovery. Nature Chemical Biology, 4(11): 682-690

Huang JQ, Zhang WJ. 2012. Analysis on degree distribution of tumor signaling networks. Network Biology, 2(3): 95-109

Jain S, Bhooshan SV, Naik PK. 2011. Mathematical modeling deciphering balance between cell survival and cell death using insulin. Network Biology, 1(1): 46-58

Kevin MB, Anthony W. 2011. Biosocial Criminology. In: The Ashgate Research Companion to Biosocial Theories of Crime (Beaver KM, ed). Routledge, USA

Khansari M, Kaveh A, Heshmati Z, et al. 2016. Centrality measures for immunization of weighted networks. Network Biology, 6(1): 12-27

Latham LG, Scully EP. 2002. Quantifying constraint to assess development in ecological networks. Ecological Modelling, 154: 25-44

Latham LG. 2006. Network flow analysis algorithms. Ecological Modelling, 192: 586-600

Law R, Blackford JC. 1992. Self-assembling food webs. A global view-point of coexistence of species in Lotka-Volterra communities. Ecology, 73: 567–578

Li JR, Zhang WJ. 2013. Identification of crucial metabolites/reactions in tumor signaling networks. Network Biology, 3(4): 121-132

Lochner L. 2004. The effect of Education on crime: Evidence from prison inmates, arrests, and self-reports. The American Economic Review, 94(1): 155-189

Lü LY, Pan LM, Zhou T, et al. 2015. Toward link predictability of complex networks. Proceedings of the National Academy of Sciences of USA, 112: 2325-2330

May RM. 1973. Stability and complexity in model ecosystems. Princeton University Press, USA

Minty GJ. 1965. A simple algorithm for listing all the trees of a graph. IEEE Trans on Circuit Theory, CT-12(1): 120

Morenoff J, Robert S, Stephen R. 2001. Neighborhood inequality, collective efficacy and the spatial dynamics of urban violence. Criminology, 39 (3): 517-560

Nuwagaba S, Hui C. 2015. The architecture of antagonistic networks: Node degree distribution,

compartmentalization and nestedness. Computational Ecology and Software, 5(4): 317-327

Paton K. 1969. An algorithm for finding a fundamental set of cycles of a graph. Communications of the ACM, 12(9): 514-518

Pazos F, Valencia A. 2001. Similarity of phylogenetic trees as indicators of protein-protein interaction. Protein Engineering, 14: 609-614

Pimm SL. 1991. The Balance of Nature. University of Chicago Press, Chicago, USA

Rhodes R. 2000. Why They Kill: The Discoveries of a Maverick Criminologist. Vintage Books, New York, USA

Rutledge RW, Basorre BL, Mulholland RJ. 1976. Ecological stability: an information theory viewpoint. Journal of Theoretical Biology, 57: 355-371

Shams B, Khansari M. 2014. Using network properties to evaluate targeted immunization algorithms. Network Biology, 4(3): 74-94

Sparks RF. 1980. A critique of marxist criminology. Crime and Justice, 2: 170-171

Ulanowicz RE. 1983. Identifying the structure of cycling in ecosystems. Mathematical Biosciences, 65: 219-237

Ulanowicz RE. 1997. Ecology, the ascendent perspective. In: Complexity in Ecological Systems Series (Allen TFH, Roberts DW, eds). Columbia University Press, New York, USA

Wikipedia. 2016a. Criminology. https://en.wikipedia.org/wiki/Criminology. Assesed Nov 30, 2016

Wikipedia. 2016b. Network science. https://en.wikipedia.org/wiki/Network_science. Accessed February 3, 2016

Wikipedia. 2016c. Social network analysis (criminology). https://en.wikipedia.org/wiki/Social_network_analysis_(criminology)?oldid=723893439. Accessed Nov 1, 2016

Zhang WJ. 2007. Computer inference of network of ecological interactions from sampling data. Environmental Monitoring and Assessment, 124: 253-261

Zhang WJ. 2011a. Constructing ecological interaction networks by correlation analysis: hints from community sampling. Network Biology, 1(2): 81-98

Zhang WJ. 2011b. Network Biology: an exciting frontier science. Network Biology, 1(1): 79-80

Zhang WJ. 2012a. Computational Ecology: Graphs, Networks and Agent-based Modeling. World Scientific, Singapore

Zhang WJ. 2012b. How to construct the statistic network? An association network of herbaceous plants constructed from field sampling. Network Biology, 2(2): 57-68

Zhang WJ. 2012c. Several mathematical methods for identifying crucial nodes in networks. Network Biology, 2(4): 121-126

Zhang WJ. 2012d. A Java software for drawing graphs. Network Biology, 2(1): 38-44

Zhang WJ. 2015a. A generalized network evolution model and self-organization theory on community assembly. Selforganizology, 2(3): 55-64

Zhang WJ. 2015b. A hierarchical method for finding interactions: Jointly using linear correlation and rank correlation analysis. Network Biology, 5(4): 137-145

Zhang WJ. 2015c. Calculation and statistic test of partial correlation of general correlation measures. Selforganizology, 2(4): 65-77

Zhang WJ. 2015d. Prediction of missing connections in the network: A node-similarity based algorithm. Selforganizology, 2(4): 91-101

Zhang WJ. 2016a. A node degree dependent random perturbation method for prediction of missing links in the network. Network Biology, 2016, 6(1): 1-11

Zhang WJ. 2016b. A random network based, node attraction facilitated network evolution method. Selforganizology, 3(1): 1-9

Zhang WJ. 2016c. Network chemistry, network toxicology, network informatics, and network behavioristics: A scientific outline. Network Biology, 6(1): 37-39

Zhang WJ. 2016d. Selforganizology: The Science of Self-Organization. World Scientific, Singapore

Zhang WJ. 2016e. Screening node attributes that significantly influence node centrality in the network. Selforganizology, 3(3): 75-86

Zhang WJ. 2016f. A method for identifying hierarchical sub-networks and weighting network links based on their similarity in sub-network affiliation. Selforganizology, 3(2): 43-53

Zhang WJ. 2016g. Network toxicology: A new science. Network Biology, 6(2): 40-49

Zhang WJ. 2016h. Network robustness: Implication, formulization and exploitation. Network Biology, 6(4): 75-85

Zhang WJ. 2016i. Detecting connectedness of network: A Matlab program and application in tumor pathways and a phylogenic network. Selforganizology, 3(4): 117-120

Zhang WJ. 2016j. A mathematical model for dynamics of occurrence probability of missing links in predicted missing link list. Network Pharmacology, 1(4): 86-94

Zhang WJ. 2016k. A node-similarity based algorithm for tree generation and evolution. Network Biology, 6(3): 55-64

Zhang WJ. 2016l. Some methods for sensitivity analysis of systems / networks. Network Pharmacology, 1(3): 74-81

Zhang WJ. 2016m. How to find cut nodes and bridges in the network? A Matlab program and application in tumor pathways. Network Pharmacology, 1(3): 82-85

Zhang WJ. 2016n. A method for identifying hierarchical sub-networks / modules and weighting network links based on their similarity in sub-network / module affiliation. Network Pharmacology, 1(2): 54-65

Zhang WJ. 2016o. Finding trees in the network: Some Matlab programs and application in tumor pathways. Network Pharmacology, 1(2): 66-73

Zhang WJ. 2016p. Network informatics: A new science. Selforganizology, 3(2): 43-50

Zhang WJ. 2016q. Network pharmacology: A further description. Network Pharmacology, 1(1): 1-14

Zhang WJ. 2016r. A Matlab program for finding shortest paths in the network: Application in the tumor pathway. Network Pharmacology, 1(1): 42-53

Zhang WJ, Li X. 2015. Linear correlation analysis in finding interactions: Half of predicted interactions are undeterministic and one-third of candidate direct interactions are missed. Selforganizology, 2(3): 39-45

Zhang WJ, Li X. 2016. A cluster method for finding node sets / sub-networks based on between- node similarity in sets of adjacency nodes: with application in finding sub-networks in tumor pathways. Proceedings of the International Academy of Ecology and Environmental Sciences, 6(1): 13-23

Zhang WJ, Zhan CY. 2011. An algorithm for calculation of degree distribution and detection of network type: with application in food webs. Network Biology, 1(3-4): 159-170