TA7

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Application fields

Mathematics, science and technology

Biochemistry (genomics)

Electrical engineering (communication networks and coding theory)

Computer science (algorithm and computation)

Operations research (scheduling)

Social science

Marketing

Economics

Finance

Linguistics

- In **linguistics**, graphs are mostly used for **parsing of a language tree** and **grammar of a language tree**.
- Semantics networks are used within **lexical semantics**, especially as applied to computers, modeling word meaning is easier when a given word is understood in terms of related words.
- Methods in **phonology** (e.g. theory of optimality, which uses lattice graphs) and **morphology** (e.g. morphology of finite - state, using finite-state transducers) are common in the analysis of language as a graph.

https://direct.mit.edu/coli/article/42/4/819/1543/Towards-a-Catalogue-of-Linguistic-Graph-Banks

http://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.ojs-issn-2449-7525-year-2014-volume-1-issue-1-article-21609

(a new measure of linguistic complexity)

More chemistry

Balasubramanian, K. "Applications of combinatorics and graph theory to spectroscopy and quantum chemistry." *Chemical Reviews* 85.6 (1985): 599-618.

(Combinatorics and graph theory in quantum chemistry)

Balaban, Alexandru T. "Applications of graph theory in chemistry." *Journal of chemical information and computer sciences* 25.3 (1985): 334-343.

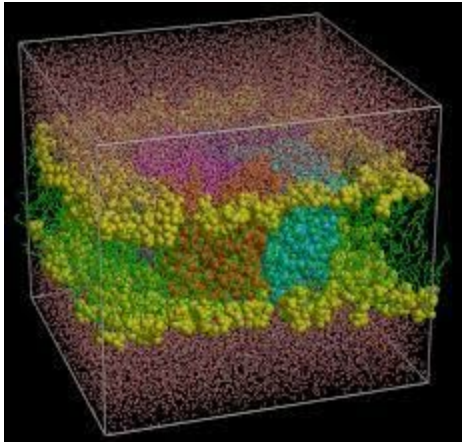
(applications review)

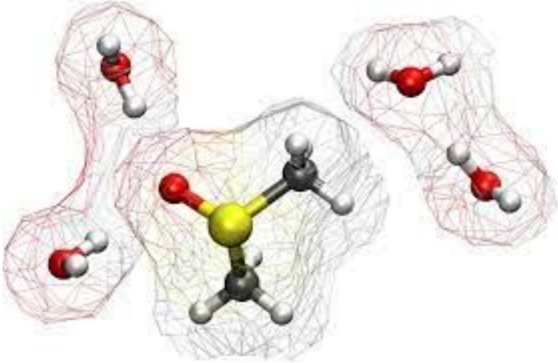
Rouvray, D. H. "Graph theory in chemistry." *Royal Institute of Chemistry, Reviews* 4.2 (1971): 173-195.

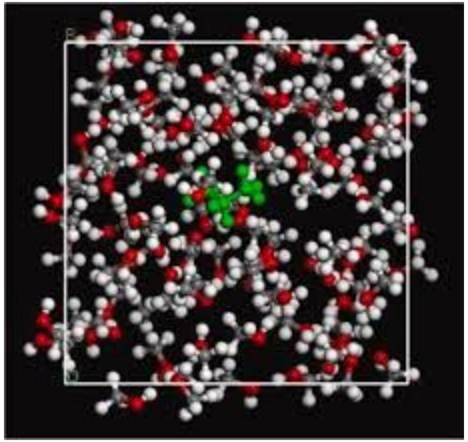
(applications review)

Vergniory, M. G., et al. "Graph theory data for topological quantum chemistry." *Physical Review E* 96.2 (2017): 023310.

(chemistry topology)







Recommendation systems

TYPES

Collaborative/Social-filtering system – aggregation of consumers' preferences and recommendations to other users based on similarity in behavioral patterns

Content-based system – supervised machine learning used to induce a classifier to discriminate between interesting and uninteresting items for the user

Knowledge-based system – knowledge about users and products used to reason what meets the user's requirements, using discrimination tree, decision support tools, case-based reasoning (CBR)

In E-store
Product Dicovery
Search
Recomm. Engines
Loyalty Programs
Bills and mailers
Email Campaigns
Recommendations for new products, up-sell, cross-sell suggestions and product discovery
Matches varying individual customers taste with a huge inventory
Order of search results on the store can be varied for each customer to aid product discovery
Recommendations pertaining to specific program, suggestions for redemption and program upgrades
Whitespace can be used for cross-sell and up-sell. Usage can be analyzed for recommending plans.
Effectively targeting abandoned shopping carts with personalized recommendation

Engine types

- **Collaborative filtering |** This filtering method is usually based on collecting and analyzing information on user's behaviors, their activities or preferences and predicting what they will like based on the similarity with other users.

- User-User Collaborative Filtering:
- Item-Item Collaborative Filtering
- Others

- **Content-Based Filtering** | These filtering methods are based on the description of an item and a profile of the user's preferred choices.
- **Hybrid Recommendation Systems** | Hybrid approaches can be implemented by making content-based and collaborative-based predictions separately and then combining them.

Yang, Kaige, and Laura Toni. "Graph-based recommendation system." *2018 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*. IEEE, 2018.

Silva, Nitai B., et al. "A graph-based friend recommendation system using genetic algorithm." *IEEE congress on evolutionary computation*. IEEE, 2010.

Feng, Chenyuan, et al. "Attention-based graph convolutional network for recommendation system." *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2019.

Bae, Donghwan, et al. "AppTrends: A graph-based mobile app recommendation system using usage history." *2015 International Conference on Big Data and Smart Computing (BIGCOMP)*. IEEE, 2015.

Peng, Tao, et al. "A graph indexing approach for content-based recommendation system." *2010 Second International Conference on Multimedia and Information Technology*. Vol. 1. IEEE, 2010.

Genetic algorithms

They are commonly used to generate high-quality solutions for optimization problems and search problems. Genetic algorithms simulate the process of natural selection which means those species who can adapt to changes in their environment are able to survive and reproduce and go to next generation.

1. Individual in population compete for resources and mate
2. Those individuals who are successful (fittest) then mate to create more offspring than others
3. Genes from “open parent propagate throughout the generation, that is sometimes parents create offspring which is better than either parent.
4. Thus each successive generation is more suited for their environment.

Fitness Score

A Fitness Score is given to each individual which **shows the ability of an individual to “compete”**. The individual having optimal fitness score (or near optimal) are sought.

Operators of Genetic Algorithms

1) Selection Operator: The idea is to give preference to the individuals with good fitness scores and allow them to pass their genes to successive generations.

2) Crossover Operator: This represents mating between individuals. Two individuals are selected using selection operator and crossover sites are chosen randomly. Then the genes at these crossover sites are exchanged thus creating a completely new individual (offspring).

3) Mutation Operator: The key idea is to insert random genes in offspring to maintain the diversity in the population to avoid premature convergence.

Genetic algos and Network science

Sha, Zhendong, Yuanzhu Chen, and Ting Hu. "Genetic heterogeneity analysis using genetic algorithm and network science." *Proceedings of the Genetic and Evolutionary Computation Conference Companion*. 2022.

Cevallos, Fabian, and Fang Zhao. "Minimizing transfer times in public transit network with genetic algorithm." *Transportation Research Record* 1971.1 (2006): 74-79.

Li, Wei. "Using genetic algorithm for network intrusion detection." *Proceedings of the United States department of energy cyber security group* 1 (2004): 1-8.

Roeva, Olympia, ed. *Real-world applications of genetic algorithms*. BoD–Books on Demand, 2012.

Particle swarms optimization

Particle Swarm Optimization was proposed by Kennedy and Eberhart in 1995. As mentioned in the original paper, sociobiologists believe a school of fish or a flock of birds that moves in a group “can profit from the experience of all other members”. In other words, while a bird flying and searching randomly for food, for instance, all birds in the flock can share their discovery and help the entire flock get the best hunt.

Utilized for minimum cost functions |

Similar to the flock of birds looking for food, we start with a number of random points on the plane (call them **particles**) and let them look for the minimum point in random directions. At each step, every particle should search around the minimum point it ever found as well as around the minimum point found by the entire swarm of particles. After certain iterations, we consider the minimum point of the function as the minimum point ever explored by this swarm of particles.

Yıldız, Ali Rıza. "A novel particle swarm optimization approach for product design and manufacturing." *The International Journal of Advanced Manufacturing Technology* 40.5 (2009): 617-628.

Park, Jong-Bae, et al. "An improved particle swarm optimization for nonconvex economic dispatch problems." *IEEE Transactions on power systems* 25.1 (2009): 156-166.

Thakkar, Ankit, and Kinjal Chaudhari. "A comprehensive survey on portfolio optimization, stock price and trend prediction using particle swarm optimization." *Archives of Computational Methods in Engineering* 28.4 (2021): 2133-2164.

Nenortaite, Jovita, and Rimvydas Simutis. "Stocks' trading system based on the particle swarm optimization algorithm." *International Conference on Computational Science*. Springer, Berlin, Heidelberg, 2004.

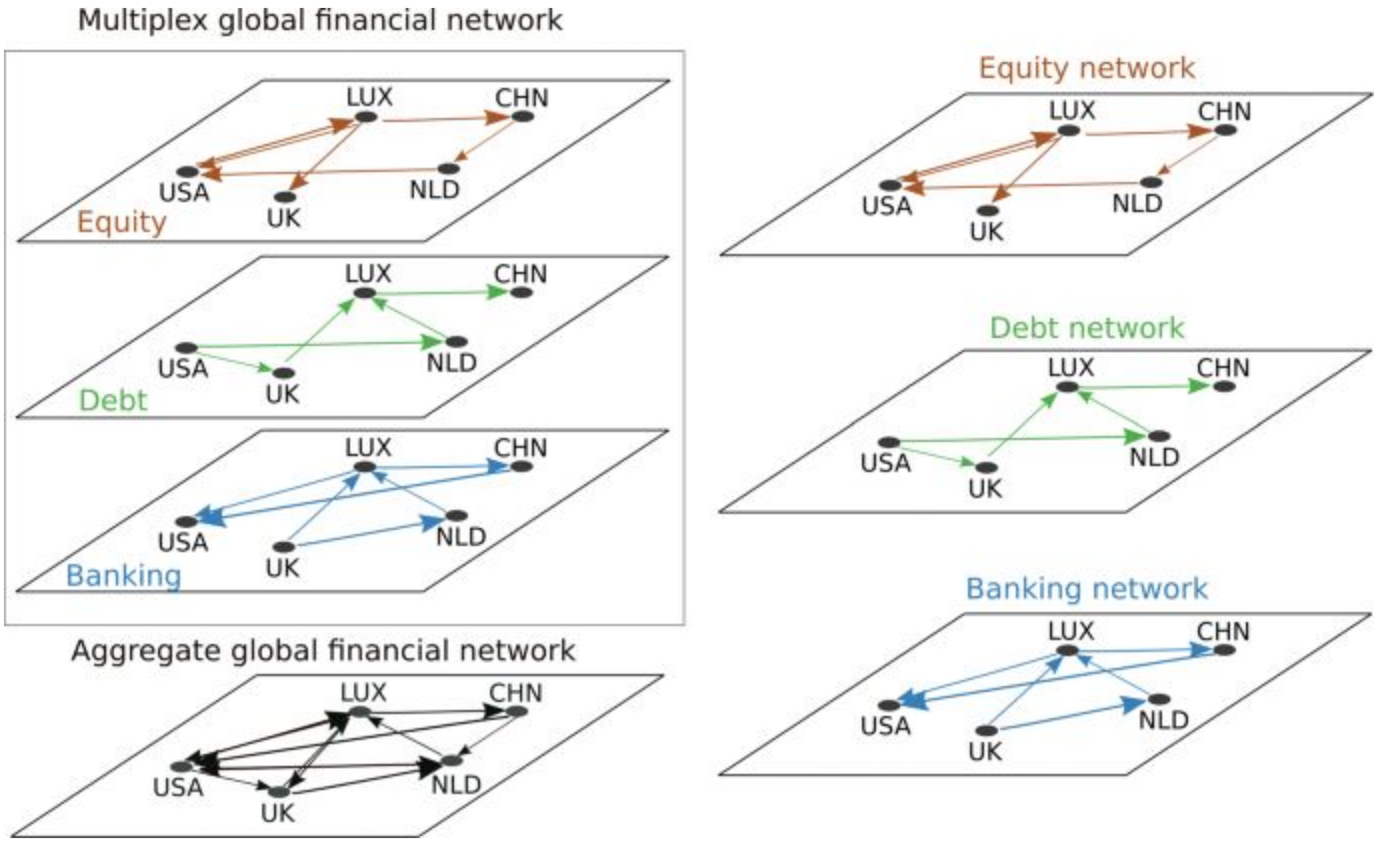
Nenortaite, Jovita, and Rimvydas Simutis. "Adapting particle swarm optimization to stock markets." *5th International Conference on Intelligent Systems Design and Applications (ISDA'05)*. IEEE, 2005.

Multilayer networks

Multilayer networks also consist of *nodes and edges*, but the nodes exist in separate *layers*, representing different forms of interactions, which connect to form an *aspect*. Aspects, or stacks of layers, can be used to represent different types of contacts, spatial locations, subsystems, or points in time. The edges between nodes in the same layer of an aspect are called *intralayer connections*, whereas edges between nodes in different layers are *interlayer connections*.

There are two main types of multilayer networks, *multiplex networks* and *interconnected networks*

In *multiplex networks*, interlayer edges can only connect nodes that represent the same actor in different layers. Therefore, multiplex networks typically represent sets of interactions between the same (or a similar set) of entities (e.g., individuals, farms). In *interconnected networks*, interlayer edges can connect between different actors, and therefore different layers typically represent different entities (e.g., individuals of different species, or farms in different production systems)


Multiplex global financial network
Equity
Debt
Banking
LUX
CHN
USA
UK
NLD
Aggregate global financial network
Equity network
Debt network
Banking network

Network science in finance and economics

The global financial system can be represented as a large complex network in which banks, hedge funds and other financial institutions are interconnected to each other through visible and invisible financial linkages.

- Breakdown of this link, diversification, propagation of risk. Findings on default cascades to bilateral exposures to overlapping portfolios

Banking:

The dynamic structure of the model is represented as a set of differential equations. This dynamic structure allows us to analyse systemic risk and also to incorporate an analysis of control mechanisms.

Uncertainty is introduced in the system by applying stochastic shocks to the bank deposits, which are assigned as an exogenous signal. The behaviour of the system can be analysed for different initial conditions and parameter sets.

Using core- periphery

Core-periphery structure, the arrangement of a network into a dense core and sparse periphery, is a versatile descriptor of various social, biological, and technological networks.

Gallagher, Ryan J., Jean-Gabriel Young, and Brooke Foucault Welles. "A clarified typology of core-periphery structure in networks." *Science advances* 7.12 (2021): eabc9800.

Caccioli, Fabio, Paolo Barucca, and Teruyoshi Kobayashi. "Network models of financial systemic risk: a review." *Journal of Computational Social Science* 1.1 (2018): 81-114.

Bazzi, M. Community Structure in Temporal Multilayer Networks, and Its Application to Financial Correlation Networks. University of Oxford, 2016.

Allen, Franklin, and Ana Babus. "Networks in finance." *The network challenge: strategy, profit, and risk in an interlinked world* 367 (2009).

Nagurney, Anna. "Networks in finance." *Handbook on Information Technology in Finance*. Springer, Berlin, Heidelberg, 2008. 383-419.

Money laundering

Savage, David, et al. "Detection of money laundering groups using supervised learning in networks." *arXiv preprint arXiv:1608.00708* (2016).

Shen, Yeming, et al. "Interdicting interdependent contraband smuggling, money and money laundering networks." *Socio-Economic Planning Sciences* 78 (2021): 101068.

Journal

Network theory in Finance

https://www.risk.net/journal-of-network-theory-in-finance

An algorithm of propagation in weighted directed graphs with applications to economics and finance

This paper puts forward an algorithm that computes the diffusion of events and actions across networks of economic agents, an algorithm that is applicable when such networks can be represented as weighted directed graphs. The functioning of the algorithm is shown in three applications. First, the algorithm is applied to a model of diffusion of innovation driven by the agents' imitation of their neighbors' behavior. Second, a graph-theoretic model of financial networks is introduced, and the corresponding algorithm is used to compute the so called *domino effect*, i.e., the diffusion of losses and insolvencies caused by the initial default of one or more agents. Finally, the algorithm is applied to the transfer of deposits operated by interbank liquidity networks.

Dynamic visualization of large financial networks

Some cool visualization in the paper

https://www.researchgate.net/profile/Clement-Levallois/publication/336485971_Dynamic_visualization_of_large_financial_networks/links/5e145a744585159aa4b8670d/Dynamic-visualization-of-large-financial-networks.pdf

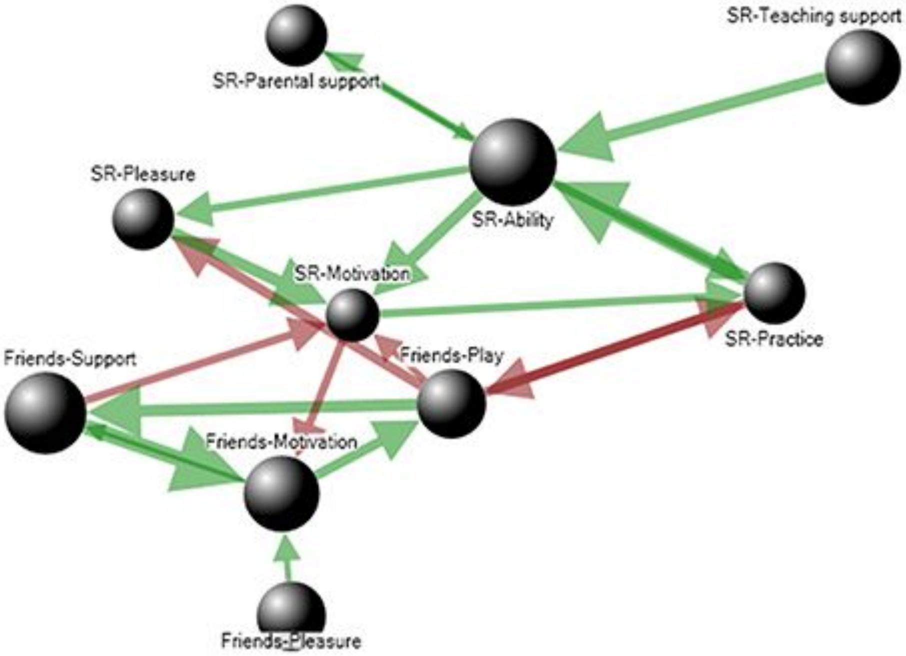
Dynamic network models

The general idea of a dynamic network model is that higher-order properties are emergent phenomena, that is, patterns of order and structure that emerge on the basis of the dynamic interactions between lower-level components (e.g., Watts and Strogatz, 1998; Strogatz, 2001; Newman, 2003; Barabási, 2009).

- The network is dynamic in the sense that the values of the nodes (the levels) change, among others as a consequence of the interactions with other nodes, and nodes may appear or disappear over developmental time (cf. Barabási, 2009).
- Accordingly, the relationships between components in the network can take various forms (cf. Van Geert, 1991, 1994, 2014).
- Furthermore, connections between the variables can be supportive or competitive, symmetric or asymmetric. For example, if domain-specific persistence positively affects the domain-specific ability and the ability positively affects the persistence, the connection is symmetric and supportive.
- Connections may also be either direct or indirect.
- Any variable in the network is directly connected with a relatively small number of other variables and indirectly connected with a considerably greater number of other variables (cf. Watts and Strogatz, 1998).

Example of Dynamic network in SNA

To provide a simple example of an individual's ability network dynamics, imagine that a particular child has a keen interest in elementary science (e.g., studying insects with a magnifying glass, building marble tracks, etc.). The parents recognize the child's science reasoning ability and stimulate this. To the extent that their child's ability improves, the parents will tend to buy more children's books about science, take the child to museums, and so forth. In addition, the child in this example is strongly intrinsically motivated to work on science and physics problems by means of scientific reasoning. Furthermore, the child also experiences considerable pleasure with solving science problems. This pleasure increases as the knowledge and insights in science increase. In turn, the pleasure further increases the child's motivation for working on science problems and exploration. Then, at secondary school the child meets new friends who like to hang out after school. After having joined the friends for the first time, the child obtains more support from the friends, for example in the form of increasing popularity in the group. In this particular network, hanging out with friends competes with scientific ability development, for instance through a competition for available time (after school) or through a competition between motivation for hanging out with friends and motivation for science learning. If we now take a look at this individual's scientific ability network, the interconnected variables can be displayed in the form of a directed graph consisting of nodes and arrows (Figure 4). Each node corresponds with one component in the child's ability network, and the color of the arrow represents a level of support (green) or competition (red) between two components.



Green arrows represent uni- or bidirectional positive influences from one node on another, red arrows represent negative influences.