AI Enabled Network Science

17-920

Instructor: Professor Kathleen M. Carley

Meeting Time M/W 4pm-5:30 pm

Virtual only

Short Description:

Network science and AI help us understand, model, and predict human behavior. Where network science focuses on the patterns of relations between entities such as people, ideas, organizations and so forth using graph and statistical methods. AI (including machine learning, computational linguistics, and large language models) is often used to focus on the content of the messages shared during interactions. Both methods have limitations. In this course we explore how they can be used together to overcome these limitations.

This course provides an introduction to network science and how network science is enabled by artificial intelligence (AI). Topics that will be covered include identification of key actors and groups, stance, network comparison, and network dynamics. AI will be used to generate synthetic network data, label groups, and identify missing links in networks. This course will provide an overview of how network science can be used to overcome limitations in AI systems and how AI can be used to overcome limitations in network data and support analysis. Much of the training will be hands-on and participants will be given data and technologies to analyze. The data provided will be organized in scenarios that the participants will analyze and produce insights related to as they use the AI enabled network science methods and tools provided.

Course structure:
Course meets twice a week
Students will be provided with data and tools.
Grading is based on problem sets, presentation, and final course project.

Course Software:
ORA-PRO --- to be provided by Dr. Carley
NetMapper --- to be provided by Dr. Carley

Important Background Reading:

Kathleen M. Carley, 2017, "ORA: A Toolkit for Dynamic Network Analysis and Visualization." In Reda Alhajj and Jon Rokne (Eds.) Encyclopedia of Social Network Analysis and Mining, Springer. DOI:10.1007/978-1-4614-7163-9_309-1

Neal Altman, Kathleen M. Carley and Jeffrey Reminga, 2022, ORA User's Guide 2022, Carnegie Mellon University, School of Computer Science, Institute for Software Research, Pittsburgh, Pennsylvania, Technical Report CMU-ISR-22-107, https://www.cmu.edu/casos-center/publications/cmu-isr-22-107.pdf.

Timeline

Week 1 : Introduction to AI Enabled Network Science, data sets, and tools – key entities

August 25 and 27

Discussion of scenario based training

Readings

Zignani, Matteo, Fragkiskos D. Malliaros, Ingo Scholtes, Roberto Interdonato, and Manuel Dileo. "Network Science Meets AI: A Converging Frontier." In *ESANN 2025: Proceedings*. i6doc. com, 2025.

Freeman, L.C. 1979. Centrality in social networks: Conceptual clarification. Social Networks. 1: 215-239

Borgatti, Stephen P., 2005. "Centrality and network flow." Social networks 27(1): 55-71.

Newman, Mark EJ. "The structure and function of complex networks." *SIAM review* 45, no. 2 (2003): 167-256.

Week 2 : Key social network concepts and groups

September 1 and 3

–Core concepts, groups, and labeling

Readings

Burt, Ronald S. "Structural holes and good ideas." *American journal of sociology* 110, no. 2 (2004): 349-399.

Granovetter, Mark S. "The strength of weak ties." *American journal of sociology* 78, no. 6 (1973): 1360-1380.

Watts, Duncan J., and Steven H. Strogatz. "Collective dynamics of 'small-world'networks." *nature* 393, no. 6684 (1998): 440-442.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. Annual review of sociology, 415-444.

Traag, V. A., Waltman, L., & Van Eck, N. J. (2019). From Louvain to Leiden: guaranteeing well-connected communities. Scientific reports, 9(1), 1-12.

Newman, M. E. (2006). Modularity and community structure in networks. Proceedings of the national academy of sciences, 103(23), 8577-8582.

Week 3 : Data enhancement

September 8 and 10

Data enhancement – bots, hate-speech, actor categorization

Readings

Piper, A., & Wu, S. (2025, May). Evaluating Large Language Models for Narrative Topic Labeling. In Proceedings of the 5th International Conference on Natural Language Processing for Digital Humanities (pp. 281-291).

Ng, L. H. X., & Carley, K. M. (2023, June). Botbuster: Multi-platform bot detection using a mixture of experts. In Proceedings of the international AAAI conference on web and social media (Vol. 17, pp. 686-697).

Ng, L. H. X., & Carley, K. M. (2025). A global comparison of social media bot and human characteristics. *Scientific Reports*, *15*(1), 10973.

Uyheng, Joshua, and Kathleen M. Carley. "Bots and online hate during the COVID-19 pandemic: case studies in the United States and the Philippines." Journal of computational social science 3, no. 2 (2020): 445-468.

Week 4 : Semantic networks, cues, emotions, and stance

September 15 and 17

Readings

Nickel, Maximilian, Kevin Murphy, Volker Tresp, and Evgeniy Gabrilovich. "A review of relational machine learning for knowledge graphs." *Proceedings of the IEEE* 104, no. 1 (2015): 11-33.

Carley, K. (1994). Extracting culture through textual analysis. *Poetics*, *22*(4), 291-312.

Carley, K.M., 1997, “Extracting Team Mental Models Through Textual Analysis.” Journal of Organizational Behavior, 18: 533-538.

Williams, E. M., & Carley, K. M. (2022, November). TSPA: efficient target-stance detection on twitter. In *2022 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)* (pp. 242-246). IEEE.

Villa-Cox, R., Williams, E. M., & Carley, K. M. (2025). Social context in political stance detection: Impact and extrapolation. *PloS one*, *20*(6), e0324697.

Lan, X., Gao, C., Jin, D., & Li, Y. (2024, May). Stance detection with collaborative role-infused llm-based agents. In *Proceedings of the international AAAI conference on web and social media* (Vol. 18, pp. 891-903).

Week 5 : Social influence and the BEND framework

September 22 and 24

Readings

Friedkin, N. E. and E. C. Johnsen. 1990. "Social Influence and Opinions." Journal of Mathematical Sociology 15(193-205).

Cruickshank, I. J., & Ng, L. H. X. (2023). Prompting and fine-tuning open-sourced large language models for stance classification. *arXiv preprint arXiv:2309.13734*.

Ng, L. H. X., & Carley, K. M. (2022). Pro or anti? a social influence model of online stance flipping. *IEEE Transactions on Network Science and Engineering*, *10*(1), 3-19.

Watts, Duncan, and Peter Sheridan Dodds. 2007. "Influentials, Networks, and Public Opinion Formation." *Journal of Consumer Research* 34:441-458.

BEND definitions

Blane, Janice T., Daniele Bellutta, and Kathleen M. Carley. "Social-cyber maneuvers during the COVID-19 vaccine initial rollout: content analysis of tweets." *Journal of Medical Internet Research* 24, no. 3 (2022): e34040.

Week 6 : Scenario generation and synthetic network data generation

September 29 and October 1

Readings

Park, J. S., O'Brien, J. C., Cai, C. J., Morris, M. R., Liang, P., & Bernstein, M. S. (2023). *Generative agents: Interactive simulacra of human behavior*. arXiv:2304.03442.

Vezhnevets, A., Agapiou, J. P., Aharon, A., Ziv, R., Matyas, J., Duéñez-Guzmán, E. A., … Leibo, J. Z. (2023). *Generative agent-based modeling with actions grounded in physical, social, or digital space using Concordia*. arXiv:2312.03664.

Argyle, L. P., Busby, E. C., Fulda, N., Gubler, J., Rytting, C., & Wingate, D. (2023). *Out of one, many: Using language models to simulate human samples*. arXiv:2305.20050.

Lewis, P., Perez, E., Piktus, A., Petroni, F., Karpukhin, V., Goyal, N., … Kiela, D. (2020). *Retrieval-augmented generation for knowledge-intensive NLP tasks*. In *Advances in Neural Information Processing Systems*.

Lu, Y., Huang, J., Han, Y., Bei, S., Xie, Y., Wang, D., Wang, Z., & He, Q. (n.d.). *Beyond Believability: Accurate Human Behavior Simulation with Fine-Tuned LLMs*.

Borysov, S. S., Rich, J., & Pereira, F. C. (2019). *Scalable population synthesis with deep generative modeling*. arXiv:1808.06910.

Week 7 : Applications

October 6 and 8

Readings

Thapa, Surendrabikram, Shuvam Shiwakoti, Siddhant Bikram Shah, Surabhi Adhikari, Hariram Veeramani, Mehwish Nasim, and Usman Naseem. "Large language models (llm) in computational social science: prospects, current state, and challenges." *Social Network Analysis and Mining* 15, no. 1 (2025): 1-30.

Jones, Nathan, Christian Pamfile, Juli Dutta, Oscar Contreras-Velasco, and Michael Aspland. *Artificial Intelligence and Social Network Analysis for Cricial Infrastructure Response Networks and Dark Network Threat Analysis*. Institute for Homeland Security, 2024.

Ucer, Serkan, Tansel Ozyer, and Reda Alhajj. "Explainable artificial intelligence through graph theory by generalized social network analysis-based classifier." *Scientific Reports* 12, no. 1 (2022): 15210.

Mao, J., Zou, D., Sheng, L., Liu, S., Gao, C., Wang, Y., & Li, Y. (2024). Identify critical nodes in complex network with large language models. *arXiv preprint arXiv:2403.03962*.

Tinghuai Ma, Qin Liu, Jie Cao, Yuan Tian, Abdullah Al-Dhelaan, Mznah Al-Rodhaan, 2020, LGIEM: Global and local node influence based community detection, Future Generation Computer Systems, 105: 533-546, ISSN 0167-739X

Duan, J., Li, W., Bai, Q., Nguyen, M., Wang, X., & Jiang, J. (2025). Llm-botguard: A novel framework for detecting llm-driven bots with mixture of experts and graph neural networks. *IEEE Transactions on Computational Social Systems*.

Yang, K. C., & Menczer, F. (2023). Anatomy of an AI-powered malicious social botnet. *arXiv preprint arXiv:2307.16336*.

Feng, S., Wan, H., Wang, N., Tan, Z., Luo, M., & Tsvetkov, Y. (2024). What does the bot say? opportunities and risks of large language models in social media bot detection. *arXiv preprint arXiv:2402.00371*.

Week NA : no class fall break

October 13 and 15 – no class fall break

Readings

Week 8 : Missing data and Link prediction

October 20 and 22

Readings

Bellutta, D., & Carley, K. M. (2023). "Improving the Reliability of Network Analysis Using Link Prediction". IDeaS Conference 2023.

Haghani, Sogol, and Mohammad Reza Keyvanpour. "A systemic analysis of link prediction in social network." *Artificial Intelligence Review* 52, no. 3 (2019): 1961-1995.

W. Wang, F. Cai, P. Jiao, & L. Pan. (2016). “A perturbation-based framework for link prediction via non-negative matrix factorization”. Scientific Reports 6(38). https://doi.org/10.1038/srep38938

Z. He, J. Zhu, S. Qian, J. Chai, & D. Koutra. (2024). “LinkGPT: Teaching Large Language Models To Predict Missing Links”. ArXiv: 2406.04640v1. https://doi.org/10.48550/arXiv.2406.04640

Rossi, Andrea, et al. (2021) “Knowledge graph embedding for link prediction: A comparative analysis.” ACM Transactions on Knowledge Discovery from Data (TKDD) 15.2 (2021): 1-49.

Borgatti, Stephen, Kathleen Carley, and David Krackhardt. 2006. “On the Robustness of Centrality Measures under Conditions of Imperfect Data.” *Social Networks* 28:124- 136.

Wei Wei, Kenneth Joseph, Huan Liu and Kathleen M. Carley, 2016, “Exploring Characteristics of Suspended Users and Network Stability on Twitter.” Social network analysis and mining, 6:51.

Bernard, H. R., Killworth, P., Kronenfeld, D., & Sailer, L. 1984. The problem of informant accuracy: The validity of retrospective data. Annual review of anthropology, 13(1), 495-517.

Week 9 : Topic Modeling and Network Comparison

October 27 and 29

Readings

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). “Latent Dirichlet Allocation”. Journal of Machine Learning Research 3: 993–1022.

Grootendorst, M. (2022). “BERTopic: Neural topic modeling with a class-based TF-IDF procedure”. ArXiv: 2203.05794.

Mimno, D., Wallach, H., Talley, E., Leenders, M., & McCallum, A. (2011). “Optimizing Semantic Coherence in Topic Models”. Proceedings of the 2011 Conference on Empirical Methods in Natural Language Processing: 262–272.

Kloo, I., Cruickshank, I. J., & Carley, K. M. (2024). A cross-platform topic analysis of the nazi narrative on twitter and telegram during the 2022 russian invasion of ukraine. In Proceedings of the international AAAI conference on web and social media (Vol. 18, pp. 839-850).

Hunzaker, M. F., & Valentino, L. (2019). Mapping cultural schemas: From theory to method. *American Sociological Review*, *84*(5), 950-981.

Bearman, P. S., & Stovel, K. (2000). Becoming a Nazi: A model for narrative networks. *Poetics*, *27*(2-3), 69-90.

Krackhardt, David. 1988. “Predicting with Networks: Nonparametric Multiple Regression Analysis of Dyadic Data.” *Social Networks* 10:359-381.

Week 10: Polarization and Coordination

November 3 and 5

Readings

Liu, Z., Zhang, J., & Ding, Y. (2024). A more advanced group polarization measurement approach based on LLM-based agents and graphs. *arXiv preprint arXiv:2411.12196*.

Haque, A., Ajmeri, N., & Singh, M. P. (2023). Understanding dynamics of polarization via multiagent social simulation. *AI & society*, *38*(4), 1373-1389.

Donkers, T., & Ziegler, J. (2025, June). Understanding Online Polarization Through Human-Agent Interaction in a Synthetic LLM-Based Social Network. In *Proceedings of the International AAAI Conference on Web and Social Media* (Vol. 19, pp. 457-478).

Ng, L. H. X., & Carley, K. M. (2022, June). Online coordination: methods and comparative case studies of coordinated groups across four events in the united states. In *Proceedings of the 14th ACM Web Science Conference 2022* (pp. 12-21).

Ng, L. H. X., & Carley, K. M. (2023). A combined synchronization index for evaluating collective action social media. *Applied network science*, *8*(1), 1.

Samantha C. Phillips and Kathleen M. Carley, 2024, "An organizational form framework to measure and interpret online polarization." *Information, Communication & Society,* 27(6): 1163-1195.

Samantha Phillips, Joshua Uyheng, and Kathleen M. Carley, 2023, "A High-dimensional Approach to Measuring Online Polarization," *Journal of Computational Social Science*, 25:1-32. DOI: 10.1007/s42001-023-00227-6 .

Week 11: Applications

November 10 and 12

Readings

Hung, Man, Evelyn Lauren, Eric S. Hon, Wendy C. Birmingham, Julie Xu, Sharon Su, Shirley D. Hon, Jungweon Park, Peter Dang, and Martin S. Lipsky. "Social network analysis of COVID-19 sentiments: Application of artificial intelligence." *Journal of medical Internet research* 22, no. 8 (2020): e22590.

Viswanathan, V., Gashteovski, K., Gashteovski, K., Lawrence, C., Wu, T., & Neubig, G. (2024). Large language models enable few-shot clustering. *Transactions of the Association for Computational Linguistics*, *12*, 321-333.

Hrudya, P., Vinayak, K. S., Sreelakshmy, A. J., & Prabaharan, P. (2024, September). A Multilayered Approach to Identifying Social Media Events Using LLM. In *World Conference on Information Systems for Business Management* (pp. 189-201). Singapore: Springer Nature Singapore.

A. Ghasemiana, H. Hosseinmardib, A. Galstyanb, E. M. Airoldic, & A. Clauseta. (2020). "Stacking models for nearly optimal link prediction in complex networks". Proceedings of the National Academy of Sciences 117(38). https://doi.org/10.1073/pnas.1914950117

M. E. J. Newman. (2001). "Clustering and preferential attachment in growing networks". Physical Review E 64(2).

Meier, R. (2024). Llm-aided social media influence operations. *Large Language Models in Cybersecurity: Threats, Exposure and Mitigation*, 105-112.

Zhang, Y., Sharma, K., Du, L., & Liu, Y. (2024, May). Toward mitigating misinformation and social media manipulation in llm era. In Companion Proceedings of the ACM Web Conference 2024 (pp. 1302-1305).

Labatut, V., & Bost, X. (2019). Extraction and analysis of fictional character networks: A survey. *ACM Computing Surveys (CSUR)*, *52*(5), 1-40.

Week 12: Statistical Robustness in network analysis and student presentations

November 17 and 19

Readings

Levin, K. D., & Levina, E. (2021). "Bootstrapping Networks with Latent Space Structure". ArXiv: 1907.10821v2. https://doi.org/10.48550/arXiv.1907.10821

Van Borkulo, C. D., van Bork, R., Boschloo, L., Kossakowski, J. J., Tio, P., Schoevers, R. A., Borsboom, D., & Waldorp, L. J. (2023). "Comparing Network Structures on Three Aspects: A Permutation Test". Psychological Methods 28(6). https://doi.org/10.1037/met0000476

Peel, L., Peixoto, T. P., & De Domenico, M. (2022). "Statistical inference links data and theory in network science". Nature Communications 13. https://doi.org/10.1038/s41467-022-34267-9

Week 13: Student presentations

November 24

Readings

Week 14: Student presentations – Gaps in linking AI and Network Science

December 1 and 3

Readings

Auxiliary Reading

Wasserman, S. & K. Faust, 1994, Social Network Analysis: Methods and Applications.

Cambridge University Press.

Marina Hennig, Ulrik Brandes, Jürgen Pfeffer, and Ines Mergel, 2014, *Studying Social Networks: A Guide to Empirical Research*, University of Chicago Press

Ian McCulloh, Helen Armstrong & Anthony Johnson, 2013, *Social Network Analysis with Applications*, Wiley

Sean Everton, 2012, *Disrupting Dark Networks,* Cambridge University Press

John Scott and Peter J Carrington, 2011, *The SAGE handbook of social network analysis*, Sage Publications

David Easley and Jon Kleinberg. 2010, Networks, Crowds, and Markets: Reasoning About a Highly Connected World. Cambridge University Press.

National Research Council, 2006. *Network Science* http://www.nap.edu/catalog/11516.html or http://www.nap.edu/books/0309100267/html/

Mark Newman, D.J. Watts and A. Barabasi, 2006, *The Structure and Dynamics of Networks,* Princeton University Press.

Carrington PJ, Scott S, and S. Wasserman, 2005, *Models and Methods in Social Network Analysis*. Vol. 28. Cambridge University Press

Ulrich Brandes and T. Erlebach, 2005, *Network analysis. Methodological Foundations*.

Springer: Heidelberg (Germany).

Linton Freeman, 2004, *The Development of Social Network Analysis: A Study in the Sociology of Science*. Vancouver: Empirical Press.

Ronald Breiger, Kathleen M. Carley, and Philippa Pattison (Eds.). 2003. Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers.

Committee on Human Factors, Board on Behavioral, Cognitive, and Sensory Sciences. Washington, DC: National Academy Press.

Albert-László Barabási and Jennifer Frangos. 2014. *Linked: the new science of networks science of networks*. Basic Books.

Duncan J. Watts, 1999. *Small worlds: the dynamics of networks between order and randomness*. Princeton university press, 1999.

Duncan J. Watts, 2002, *Six Degrees: The Science of a Connected Age,* New York & London: W.W. Norton & Company.

Jackson, Sarah J., Moya Bailey, and Brooke Foucault Welles, 2020, #HashtagActivism: Networks of race and gender justice**.** MIT Press

Generative AI

This course is designated as a Tier 3 course for Generative AI. This course will teach network science skills and techniques using AI alongside other skills or content with attention to advanced applications and real world problem solving with the emerging AI and network science technologies. The use of GenAI in this course will be incorporated alongside other skillbuilding and problem solving, as students learn to integrate AI into these professional tasks. Students will be offered guidance on using GenAI within the learning environment of the course and should expect to engage with GenAI regularly. Ethical use and appropriate citation of GenAI output is expected.

Student Expectations for GenAI Use in these courses:

- Students can expect GenAI specific instruction on skills like prompt engineering, managing GenAI output, often in tandem with instruction on other tools, techniques, and skills.
- Students can expect engagement with GenAI in producing course deliverables as well as engagement with GenAI principles, ethics, emerging risks, and policy.
- Students can expect discussion of GenAI tools within specific work contexts, which may include ethical use, case studies, challenges, opportunities

Reporting GenAI Use on Assignments:

- Students must note on each assignment, paper, presentation:
    - Whether GenAI was used
    - How it was used, i.e. what was done with GenAI
    - Which GenAI tool was used
    - If you use GenAI to help write a document – that should be noted and the parts written by GenAI highlighted

Where GenAI cannot be used:

- Do not use GenAI to read required course papers for you. Yes GenAI is good at generating summaries, but for the papers listed on the syllabus you are expected to read those yourself
- Do not use GenAI to generate the powerpoints you create to summarize the papers you read and report on to the group

ChatGPT Policy for papers: You may use ChatGPT to assist you in writing your paper or fixing any grammatical errors. However, you **must** abide by the following guidelines:

- Acknowledge any usage of ChatGPT and estimate the amount of verbiage that came from ChatGPT.
- Double check all references to ensure they are real and correct.
- Use best practices, which includes sculpting any text provided to make sure it has the

correct tense and that it flows naturally within the paper.

Use of Opensource Software

In this course you may find and use third party open source software for the various AI portions of the class. For these you must report:

- Which software was used
- The URL
- The license
- Why it was chosen

You are to use the network science tools provided and not use other open sources tools for network science.

Take care of yourself.

Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support.

Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at https://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

If you or someone you know is feeling suicidal or in danger of self-harm, call someone immediately, day or night:

CaPS: 412-268-2922

Re:solve Crisis Network: 888-796-8226

If the situation is life threatening, call the police:

On campus: CMU Police: 412-268-2323 Off campus: 911

Communication Support:

For assistance with the written or oral communication assignments in this class, visit the Global Communication Center (GCC). The GCC is a free service, open to all students, and located in the Hunt Library. GCC tutors can provide instruction on a range of communication topics and can help you improve your papers and presentations. You can make tutoring appointments directly on the GCC website: http://www.cmu.edu/gcc. You may also visit the GCC website to learn about communication workshops offered throughout the academic year. To find out more about any of the ways the GCC can help you, please email them at gcc-cmu@andrew.cmu.edu

University Policy on Cheating and Plagiarism

You are expected to read and attend to the information in - University Policy on Academic Integrity. The full policy is available by clicking the hyperlinked text above. Additional information about the university process for handling violations and links to resources is also available via this comprehensive website:

http://www.cmu.edu/academic-integrity/index.html .

It is extremely important that the homework, assignments, papers, and tests that you turn in during the course reflect your own understanding. To copy answers from another person not only denies you the necessary feedback on whether or not you really understand the material, but it also compromises your integrity. In addition, those who do not succumb to cheating feel that they are "getting the short end of the stick" when they see others getting away with it. For these reasons, we expect everyone to behave with integrity. It is also important that the work represents your work. Thus, any unauthorized assistance in doing the course project or homework is also considered cheating.

In this class, without explicit permission of the instructor, the following do not count as original work and would constitute cheating:

- Turning in the same or largely similar paper to another class or classes. Joint work with another student on a problem set or final project.
- Copying material from the internet without citing it correctly.
- Plagiarism, including – copying images, graphs, and tables from published work. Failure to correctly cite material produced by others regardless of whether it appeared in a blog, news article, web-post, journal publication, book, etc.
- Failure to correctly cite previously published works by yourself.
- Utilizing source code developed by others or drawn from the web for your project without explicit prior permission of the instructor, and appropriate reference.

Note, papers may be assessed using automatic tools for plagiarism detection.