Network Science

INFO 5613; Fall 2021

Tuesday, Thursday 11:10–12:25
https://cuboulder.zoom.us/j/96935610716

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Course Description

Data involving relationships and interactions are pervasive in contemporary information society but these data require distinct methods and theories for analysis and interpretation. *Network science* is an umbrella term that encompasses interdisciplinary theories and methods for analyzing social, information, and other complex networks. Network science provides tools to develop quantitative representations linking micro-level processes to macro-level structures across diverse empirical settings like organizations, online communities, and archives. Students will develop their familiarity with the methods and theories to understand the fundamentals of networks, metrics for characterizing their structure, and the dynamics *of* and *on* networks.

Learning objectives

- Understand the theoretical and methodological implications of relational data
- Apply and interpret metrics for understanding network structure and dynamics
- Develop familiarity with computational tools for analyzing and visualizing networks
- Integrate and explain network methods and theories for general audiences

Course Design

Class will meet twice per week on Tuesdays and Thursdays from 11:10 to 12:30 on Zoom. The format of each class will vary between lectures, exercizes, discussions, and presentations. Student performance will be evaluated through a combination of Module Assignments, Reading Responses, and a Final Project (see *Evaluation* below). There is no final exam.

The class is split up into four modules: (1) *Fundamentals* introduces the unique vocabulary of network science and its unique data and visualizations; (2) *Structure* covers the metrics for describing networks across multiple levels of analysis; (3) *Dynamics* explores how networks can explain change in social systems; (4) *Applications* extends the network framework to more advanced methods. See Table 1 on page 5 and the Course Outline on pages 6–16 for more details.

Each week will cover a new topic. The Tuesday class will consist of (1) a lecture introducing the core concepts and (2) a computational notebook implementing these concepts. The notebook may include exercises for students to explore following class, but these notebooks will not be formally evaluated. The Thursday class will (1) finish or review concepts from the previous class, (2) discuss students' reading responses, and (3) introduce and work through the Module Assignment.

Prerequisites

There are no prerequisites for this class. While we will be using the Python programming language and related libraries, students do not need any previous programming experience: the class activities and exercises will be documented and structured to allow students to "tinker" with code rather than expecting them to write it from scratch. For more details about programming, please see the *Statistical Computing* section.

Attendance

Students' regular and sustained participation in all class activities as well as punctual and thorough completion of assignments are essential. If you need to be excused from attending a class session or need an extension to an assignment, please email instructor as soon as possible.

Course Website and Materials

There is no textbook required for class, but there will be required readings, tutorials, and other material, which will be made available through Canvas:

https://canvas.colorado.edu/courses/76045

Once the semester begins, this PDF version of the syllabus will be revised infrequently and any revised requirements will be posted as announcements and updated course schedule to Canvas. The instructor reserves the right to make changes to the course's schedule, evaluation criteria, policies, *etc.* through announcements in class and on Canvas, so please check Canvas regularly. Students should email the instructor if there are any discrepancies or ambiguities.

I will also be making a public-facing version of the course materials available through GitHub. However, the GitHub materials will likely go live after they are put on Canvas and introduced in class. Please use Canvas as the primary source of course materials but share the public-facing GitHub repository with interested friends and colleagues.

Statistical Computing

Students will need to use statistical computing software. Jupyter notebooks written in Python 3 will be used for all in-class examples and assignments. The Anaconda distribution of Python 3.8 (or above) is *strongly* recommended to provide all of these programs and other libraries. Lectures will include exercises and presentations with the expectation that students participate with their own laptop computers. If students cannot bring a laptop to class, they should email the instructor to work out an alternative arrangement. If students wish to use an alternative data analysis environment (R, Matlab, Julia, *etc.*) they are welcome to do so, but instructional support will only be provided for Anaconda and Python.

Evaluation

Students will be evaluated through four different mechanisms.

Attendance (15%). Attendance in class is required and will be captured via Zoom. We will be covering technical methods that are cumulative and require sustained effort. Although I expect this to be rare, if you will be logging in jointly with another person (two or more people using the same computer) please let me know via email so that I can note this. If there are personal, professional, medical, or other circumstances that will prevent your attendance, please notify me via e-mail and we can develop an accommodation plan together. Although there will be no opportunities to make up missed attendance, videos of the class will be posted to Canvas. If you need to miss multiple classes, please make an effort to come to office hours so we can check-in about course material and progress.

Reading Responses. (26%). Reading Responses are intended to ground new concepts with students' research interests, personal experiences, and reflecting on contemporary or historical issues. Each response will be approximately 500 words and will be submitted on Canvas. Although I may include prompts, the format will remain open-ended: outlining applications to research interests, interpreting historical or contemporary issues, reflecting on personal experiences, and exploratory data analyses using the concepts introduced in the readings and Tuesday's lecture. There will be one Reading Response per week for the first 13 weeks. Each Reading Response will be due Wednesdays by 5pm. In the absence of an approved excuse students who do no submit their response on time and/or do not submit peer feedback will lose a portion of the credit at my discretion. The Reading Responses will structure discussions in Thursday classes.

Module Assignments (30%). Module Assignments are intended to develop students' skill applying, synthesizing, and interpreting the methods and theories introduced during classes. There will be three Module Assignments in total corresponding to the first three modules (Fundamentals, Structure, and Dynamics). There will be no Module Assignment for the fourth module Applications so that students can prioritize their Final Projects. Each Module Assignment is worth 10% of the final grade (30% cumulative) and they are due by 11:59pm the Friday following the close of the module (see Table 1). The format and evaluation criteria of each Module Assignment will vary, but will build on the exercises from each Tuesday class. In the absence of an approved excuse, late submissions will be docked 2% of their value per hour.

Final Project (29%). The Final Project is intended to be a deeper synthesis and application of the concepts covered in the class. Like the reading responses, the genre is open-ended: a literature review, a research proposal, an empirical analysis, a research paper, or an op-ed are among the possibilities. The Final Project will be evaluated by the appropriate application of network science concepts; persuasiveness of the theoretical mechanisms and empirical setting; and the clarity of writing, tables, and figures. Further details about the Final Project will be collaboratively developed and detailed later in the course. The final two weeks of class following the Fall Break will provide students an opportunity to workshop or present on their Final Project progress to receive peer feedback. The Final Project will be due on Tuesday, December 14 by 11:59pm. In the absence of an approved excuse, late Final Project submissions will be docked 2% of their value per hour.

Course Policies

Classroom Behavior

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on class behavior and the student code.

Accommodations for Disabilities

I am committed to providing everyone the support and services needed to participate in this course. If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to the instructor in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website and discuss your needs with the instructor.

Religious Observance

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required assignments/attendance. If this applies to you, please email the instructor as soon as possible to make the appropriate accommodations.

Harassment, Discrimination, and Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by or against members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or email cureport@colorado.edu. Information about OIEC, university policies, reporting options, and the campus resources can be found on the OIEC website.

Please know that faculty and graduate instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about their rights, support resources, and reporting options.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred

names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the academic integrity policy of the institution. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, resubmission, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code Council as well as academic sanctions from the faculty member. Additional information can be found at honorcode.colorado.edu.

COVID-19 Contingencies

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. See the policies on COVID-19 Health and Safety. Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct and Conflict Resolution. For more information, see the policy on classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

Should a student contract any illness that requires mandatory sequestration, intensive medical treatment, or extended convalescence and disrupts their ability to participate in class and complete assignments, I will try to accommodate their condition without penalty with extensions and incompletes. This also applies if the student has a family member whose diagnosis, treatment, and recovery will affect their ability to participate. *Please do not ghost me*: students should email me as soon as possible of events that will impact their engagement with the class so that I can triage and develop an accommodation plan rather than scrambling at the end of the semester.

Certificate Credit

This course counts as an elective toward the Digital Humanities Graduate Certificate, an interdisciplinary nine-credit program that prepares students to implement computational or digital approaches to humanities inquiry and/or develop humanities perspectives on technology. It is open to any CU Boulder graduate student in good standing, regardless of discipline. For more information visit `https://www.colorado.edu/crdds/dhgc` or email digital.humanities@colorado.edu.

Faculty Interaction

In addition to teaching this class, Professor Keegan also (1) manages a research program; (2) advises students; (3) performs service for the academic community; and (4) lives his life as a private citizen. He will check e-mail between 9:00 and 17:00 on non-holiday business days and will try to respond to emails within 24 hours. He welcomes online or offline interactions outside of class, however

these are not appropriate spaces for discussing class matters. E-mailing me or coming to my office hours are the best ways to get feedback outside of lecture.

In-class Confidentiality
The success of this class depends on students feeling comfortable sharing questions, ideas, concerns, and confusions about assignments, work-in-progress, and their personal experiences. Students may read, comment, and run on classmates' writing, code, and other class-related content for the sole purpose of use within this class. However, students may not use, run, copy, perform, display, distribute, modify, translate, or create derivative works of another student's work outside of this class without that student's expressed written consent or formal license. Furthermore, students may not create any audio, video, or other records during class time without the instructor's permission nor may students publicly share comments made in class attributable to another person's identity without that person's permission.

Acknowledgements

This syllabus was typeset in LaTeX using Overleaf with the fbb/Bembo font and is derived from the `memoir` styles adapted by Kieran Healy and Benjamin 'Mako' Hill.

Module	Week	Dates	Topics	Due Date
Fundamentals	1	Aug 24; Aug 26	Fundamentals of networks	*September 17*
	2	Aug 31; Sep 2	Data and ethics of networks	
	3	Sep 7; Sep 9	Visualizing networks	
Structure	4	Sep 14; Sep 16	Node-level structure	*October 15*
	5	Sep 21; Sep 23	Local-level structure	
	6	Sep 28; Sep 30	Network-level structure	
	7	Oct 5; Oct 7	Community structure	
Dynamics	8	Oct 12; Oct 14	Random networks	*November 12*
	9	Oct 19; Oct 21	Network growth	
	10	Oct 26; Oct 28	Diffusion and influence	
	11	Nov 2; Nov 4	Homophily and selection	
Applications	12	Nov 9; Nov 11	Bipartite networks	—
	13	Nov 16; Nov 18	Weighted networks	
	14	Nov 23; Nov 25	**No Class: Fall Break**	
Presentations	15	Nov 30; Dec 2	Presentations	*December 13*
	16	Dec 7; Dec 9		

Table 1: Course outline by week.

Course Outline

The schedule will evolve throughout the semester, so please consult the schedule online at Canvas for the most up-to-date information.

Week 1 – Fundamentals: Introductions

Tuesday, August 24; Thursday, August 26

Administrivia and computing environments; history and outline of network science.

- **Concepts**
  - Borgatti, S. P., Mehra, A., Brass, D. J., and Labianca, G. (2009). Network analysis in the social sciences. *Science*, 323(5916):892–895
  - Butts, C. T. (2009). Revisiting the foundations of network analysis. *Science*, 325(5939):414–416
  - Brandes, U., Robins, G., McCranie, A., and Wasserman, S. (2013). What is network science? *Network Science*, 1(1):1–15

- **Reviews**
  - Burt, R. S. (1980). Models of network structure. *Annual Review of Sociology*, 6:79–141
  - Wellman, B. (1983). Network analysis: Some basic principles. *Sociological Theory*, 1:155–200
  - Scott, J. (1988). Social network analysis. *Sociology*, 22(1):109–127
  - Newman, M. (2003b). The structure and function of complex networks. *SIAM Review*, 45:167–256
  - Watts, D. J. (2004). The "new" science of networks. *Annual Review of Sociology*, 30(1):243–270
  - Boccaletti, S., Latora, V., Moreno, Y., Chavez, M., and Hwang, D. U. (2006). Complex networks: Structure and dynamics. *Physics Reports*, 424(4):175–308
  - Costa, L. d. F., Rodrigues, F. A., Travieso, G., and Boas, P. R. V. (2007). Characterization of complex networks: A survey of measurements. *Advances in Physics*, 56(1):167–242
  - Börner, K., Sanyal, S., and Vespignani, A. (2007). Network science. *Annual Review of Information Science and Technology*, 41(1):537–607
  - Butts, C. T. (2008). Social network analysis: A methodological introduction. *Asian Journal of Social Psychology*, 11(1):13–41
  - Costa, L. d. F., Jr, O. N. O., Travieso, G., Rodrigues, F. A., Boas, P. R. V., Antiqueira, L., Viana, M. P., and Rocha, L. E. C. (2011). Analyzing and modeling real-world phenomena with complex networks: A survey of applications. *Advances in Physics*, 60(3):329–412
  - Scott, J. (2011). Social network analysis: Developments, advances, and prospects. *Social Network Analysis and Mining*, 1(1):21–26

Week 2 – Fundamentals: Data and ethics of networks

Tuesday, August 31; Thursday, September 2

Representing nodes and links; data collection and validity; ethics of network analysis.

- **Concepts**
  - Marsden, P. V. (1990). Network data and measurement. *Annual Review of Sociology*, 16(1):435–463
  - Howison, J., Wiggins, A., and Crowston, K. (2011). Validity issues in the use of social network analysis with digital trace data. *Journal of the Association for Information Systems*, 12(12):767–797

  - Tubaro, P., Ryan, L., Casilli, A. A., and D'Angelo, A. (2020). Social network analysis: New ethical approaches through collective reflexivity. *Social Networks*

- **Tools**
  - Borgatti, S. P., Everett, M. G., and Freeman, L. C. (2002). UCINET for Windows: Software for social network analysis. https://sites.google.com/site/ucinetsoftware/
  - Csardi, G., Nepusz, T., et al. (2006). The igraph software package for complex network research. *InterJournal*, 1695(5):1–9. https://igraph.org/
  - Hagberg, A. A., Schult, D. A., and Swart, P. J. (2008). Exploring network structure, dynamics, and function using networkx. In Varoquaux, G., Vaught, T., and Millman, J., editors, *Seventh Python in Science Conference*, pages 11–15. https://networkx.org/
  - Smith, M. A., Ceni, A., Milic-Frayling, N., Shneiderman, B., Mendes Rodrigues, E., Leskovec, J., and Dunne, C. (2010). Nodexl: A free and open network overview, discovery and exploration add-in for Excel. https://www.smrfoundation.org/nodexl/
  - Peixoto, T. P. (2014). The graph-tool python library. *figshare*. https://graph-tool.skewed.de/
  - Bonald, T., de Lara, N., Lutz, Q., and Charpentier, B. (2020). Scikit-network: Graph analysis in pyth note=https://netwulf.readthedocs.io/ on. *Journal of Machine Learning Research*, 21(185):1–6. https://scikit-network.readthedocs.io/

- **Extensions**
  - Bernard, H., Kilworth, P., and Sailer, L. (1977). Information accuracy in social network data. *Human Communication Research*, 4:3–18
  - Bernard, H. R., Killworth, P., Kronenfeld, D., and Sailer, L. (1984). The problem of informant accuracy: The validity of retrospective data. *Annual Review of Anthropology*, 13(1):495–517
  - Borgatti, S. P. and Molina, J.-L. (2005). Toward ethical guidelines for network research in organizations. *Social Networks*, 27(2):107–117
  - D'Angelo, A. and Ryan, L. (2019). The presentation of the networked self: Ethics and epistemology in social network analysis. *Social Networks*
  - Diviák, T. (2019). Key aspects of covert networks data collection: Problems, challenges, and opportunities. *Social Networks*
  - Kadushin, C. (2005). Who benefits from network analysis: Ethics of social network research. *Social Networks*, 27(2):139–153
  - Kossinets, G. (2006a). Effects of missing data in social networks. *Social Networks*, 28:247–268
  - Molina, J. L. and Borgatti, S. P. (2019). Moral bureaucracies and social network research. *Social Networks*

Week 3 – Fundamentals: Visualizing networks

Tuesday, September 7; Thursday, September 9

Aesthetics, pruning, layout algorithms.

- **Concepts**
  - Pfeffer, J. and Freeman, L. C. (2019). Social network visualization, methods of. In Meyers, R. A., editor, *Encyclopedia of Complexity and Systems Science*, pages 1–25. Springer, Berlin, Heidelberg

  - Krempel, L. (2014). Network visualization. In *The SAGE Handbook of Social Network Analysis*, pages 558–577. SAGE Publications Ltd, London

- **Tools**
  - Ellson, J., Gansner, E., Koutsofios, L., North, S. C., and Woodhull, G. (2001). Graphviz—open source graph drawing tools. In *International Symposium on Graph Drawing*, pages 483–484. Springer. https://graphviz.org/
  - Borgatti, S. P. (2002). Netdraw: Software for network visualization. https://sites.google.com/site/netdrawsoftware/
  - Shannon, P., Markiel, A., Ozier, O., Baliga, N. S., Wang, J. T., Ramage, D., Amin, N., Schwikowski, B., and Ideker, T. (2003). Cytoscape: a software environment for integrated models of biomolecular interaction networks. *Genome Research*, 13(11):2498–2504. https://cytoscape.org/
  - Bastian, M., Heymann, S., and Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. In *Third International AAAI Conference on Web and Social Media*, ICWSM, pages 361–362. AAAI. https://gephi.org/
  - Aslak, U. and Maier, B. F. (2019). Netwulf: interactive visualization of networks in python. *Journal of Open Source Software*, 4(42):1425. https://netwulf.readthedocs.io/

- **Extensions**
  - Bennett, C., Ryall, J., Spalteholz, L., and Gooch, A. (2007). The aesthetics of graph visualization. In Cunningham, D., Meyer, G., and Neumann, L., editors, *Computational Aesthetics in Graphics, Visualization, and Imaging*, pages 57–64. The Eurographics Association
  - Beck, F., Burch, M., Diehl, S., and Weiskopf, D. (2017). A taxonomy and survey of dynamic graph visualization. *Computer Graphics Forum*, 36(1):133–159
  - Brandes, U., Kenis, P., and Raab, J. (2006). Explanation through network visualization. *Methodology*, 2(1):16–23
  - Gibson, H., Faith, J., and Vickers, P. (2013). A survey of two-dimensional graph layout techniques for information visualisation. *Information Visualization*, 12(3-4):324–357
  - Healy, K. and Moody, J. (2014). Data visualization in sociology. *Annual Review of Sociology*, 40(1):105–128
  - Herman, I., Melancon, G., and Marshall, M. (2000). Graph visualization and navigation in information visualization: A survey. *IEEE Transactions on Visualization and Computer Graphics*, 6(1):24–43
  - Huang, W., Hong, S.-H., and Eades, P. (2006). Layout effects on sociogram perception. In *Graph Drawing*, volume 3843, pages 262–273. Springer, Berlin, Heidelberg
  - von Landesberger, T., Kuijper, A., Schreck, T., Kohlhammer, J., van Wijk, J. J., Fekete, J.-D., and Fellner, D. W. (2011). Visual analysis of large graphs: State-of-the-art and future research challenges. *Computer Graphics Forum*, 30(6):1719–1749
  - McGrath, C., Blythe, J., and Krackhardt, D. (1997). The effect of spatial arrangement on judgments and errors in interpreting graphs. *Social Networks*, 19(3):223–242
  - Moody, J., McFarland, D., and Bender-deMoll, S. (2005). Dynamic network visualization. *American Journal of Sociology*, 110(4):1206–1241
  - Pokorny, J. J., Norman, A., Zanesco, A. P., Bauer-Wu, S., Sahdra, B. K., , and Saron, C. D. (2018). Network analysis for the visualization and analysis of qualitative data. *Psychological Methods*, 23(1):169–183

- Zhu, B. and Watts, S. A. (2010). Visualization of network concepts: The impact of working memory capacity differences. *Information Systems Research*, 21(2):327–344

Week 4 – Structure: Node-level structure

Tuesday, September 14; Thursday, September 16

Metrics for centrality, reciprocity, and social capital.

- **Concepts**
  - Freeman, L. C. (1978). Centrality in social networks: Conceptual clarification. *Social Networks*, 1(3):215–239
  - Borgatti, S. P., Jones, C., and Everett, M. G. (1998). Network measures of social capital. *Connections*, 21(2):27–36
  - Lin, N. (1999). Building a network theory of social capital. *Connections*, 24(1):28–51

- **Extensions**
  - Burt, R. S. (2000). The network structure of social capital. *Research in Organizational Behavior*, 22:345–423
  - Borgatti, S. P. (2005). Centrality and network flow. *Social Networks*, 27(1):55–71
  - Borgatti, S. P. and Everett, M. G. (2006). A graph-theoretic perspective on centrality. *Social Networks*, 28(4):466–484
  - Kwom, S.-W. and Adler, P. S. (2014). Social capital: Maturation of a field of research. *The Academy of Management Review*, 39(4):412–422
  - Nahapiet, J. and Ghoshal, S. (1998). Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review*, pages 242–266

Week 5 – Structure: Local-level structure

Tuesday, September 21; Thursday, September 23

Ego networks, triadic structure, clustering, embeddedness, assortativity.

- **Concepts**
  - Feld, S. L. (1991). Why your friends have more friends than you do. *American Journal of Sociology*, 96(6):1464–1477
  - Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., and Alon, U. (2002). Network motifs: Simple building blocks of complex networks. *Science*, 298(5594):824–827
  - Newman, M. E. J. and Park, J. (2003). Why social networks are different from other types of networks. *Physical Review E*, 68(3):036122

- **Extensions**
  - Holland, P. W. and Leinhardt, S. (1976). Local structure in social networks. *Sociological Methodology*, 7:1–45
  - Granovetter, M. (1985). Economic action and social structure: The problem of embeddedness. *American Journal of Sociology*, 91(3):481–510
  - Bonacich, P. (1987). Power and centrality: A family of measures. *American Journal of Sociology*, 92(5):1170–1182

- Uzzi, B. (1997). Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly*, 42:35–67
- Newman, M. E. J. (2003c). Mixing patterns in networks. *Physical Review E*, 67(2):026126
- Milo, R., Itzkovitz, S., Kashtan, N., Levitt, R., and al, e. (2004). Superfamilies of evolved and designed networks. *Science*, 303(5663):1538–42
- Opsahl, T. and Panzarasa, P. (2009). Clustering in weighted networks. *Social Networks*, 31(2):155–163
- Aral, S. and Alstyne, M. V. (2011a). The diversity-bandwidth trade-off. *American Journal of Sociology*, 117(1):90–171
- Lerman, K., Yan, X., and Xin-Zeng, W. (2016). The "majority illusion" in social networks. *PLoS One*, 11(2):e0147617

Week 6 – Structure: Network-level structure

Tuesday, September 28; Thursday, September 30

Small worlds, structural holes, degree distributions, components, and paths.

- **Concepts**
  - Borgatti, S. P. and Everett, M. G. (2000). Models of core/periphery structures. *Social Networks*, 21(4):375–395
  - Uzzi, B., Amaral, L. A., and Reed-Tsochas, F. (2007). Small-world networks and management science research: A review. *European Management Review*, 4(2):77–91
  - Barabási, A.-L. (2009). Scale-free networks: A decade and beyond. *Science*, 325(5939):412–413

- **Tools**
  - Alstott, J., Bullmore, E., and Plenz, D. (2014). Powerlaw: A python package for analysis of heavy-tailed distributions. *PLoS ONE*, 9(1):e85777. `https://github.com/jeffalstott/powerlaw`
  - Gillespie, C. S. (2015). Fitting heavy tailed distributions: The PoweRlaw package. *Journal of Statistical Software*, 64(1). `https://github.com/csgillespie/poweRlaw`

- **Extensions**
  - Broido, A. D. and Aaron, C. (2019). Scale-free networks are rare. *Nature Communications; London*, 10(1)
  - Burt, R. (2004). Structural holes and good ideas. *American Journal of Sociology*, 110(2):349–399
  - Clauset, A., Shalizi, C., and Newman, M. (2009). Power-law distributions in empirical data. *SIAM Review*, 51(4):661–703
  - Johnson, S. L., Faraj, S., and Kudaravalli, S. (2014). Emergence of power laws in online communities: The role of social mechanisms and preferential attachment. *MIS Quarterly*, 38(3):795–A13
  - Milojević, S. (2010). Power law distributions in information science: Making the case for logarithmic binning. *Journal of the American Society for Information Science and Technology*, 61(12):2417–2425
  - Mitzenmacher, M. (2004). A brief history of generative models for power law and lognormal distributions. *Internet Mathematics*, 1(2):226–251
  - Robins, G., Pattison, P., and Woolcock, J. (2005). Small and other worlds: Global network

structures from local processes. *American Journal of Sociology*, 110:894–936
- Rombach, P., Porter, M. A., Fowler, J. H., and Mucha, P. J. (2017). Core-periphery structure in networks (revisited). *SIAM Review*, 59(3):619–646
- Watts, D. J. and Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature*, 393(6684):440–442

Week 7 – Structure: Community structure

Tuesday, October 5; Thursday, October 7

Cohesion, community detection, cores-cliques-clans, blockmodels, modularity.

- **Concepts**
  - Friedkin, N. E. (2004). Social cohesion. *Annual Review of Sociology*, 30(1):409–425
  - Fortunato, S. and Hric, D. (2016). Community detection in networks: A user guide. *Physics Reports*, 659:1–44

- **Extensions**
  - Bedi, P. and Sharma, C. (2016). Community detection in social networks. *WIREs Data Mining and Knowledge Discovery*, 6(3):115–135
  - Doreian, P. and Woodard, K. L. (1994). Defining and locating cores and boundaries of social networks. *Social Networks*, 16(4):267–293
  - Fortunato, S. (2010). Community detection in graphs. *Physics Reports*, 486(3):75–174
  - Javed, M. A., Younis, M. S., Latif, S., Qadir, J., and Baig, A. (2018). Community detection in networks: A multidisciplinary review. *Journal of Network and Computer Applications*, 108:87–111
  - Ibarra, H., Kilduff, M., and Tsai, W. (2005). Zooming in and out: Connecting individuals and collectivities at the frontiers of organizational network research. *Organization Science*, 16(4):359–371
  - Moody, J. and White, D. R. (2003). Structural cohesion and embeddedness: A hierarchical concept of social groups. *American Sociological Review*, 68(1):103–127
  - Porter, M. A., Onnela, J.-P., Mucha, P. J., et al. (2009). Communities in networks. *Notices of the AMS*, 56(9):1082–1097

Week 8 – Dynamics: Random networks

Tuesday, October 12; Thursday, October 14

Erdös-Renyi models, permutation tests, null models, expontential random graph models.

- **Concepts**
  - Farine, D. R. (2017). A guide to null models for animal social network analysis. *Methods in Ecology and Evolution*, 8(10):1309–1320
  - Faust, K. and Skvoretz, J. (2002). Comparing networks across space and time, size and species. *Sociological Methodology*, 32(1):267–299

- **Extensions**
  - Fredrickson, M. M. and Chen, Y. (2019). Permutation and randomization tests for network analysis. *Social Networks*, 59:171–183

- Ghafouri, S. and Khasteh, S. H. (2020). A survey on exponential random graph models: An application perspective. *PeerJ Computer Science*, 6:e269
- Hanhijärvi, S., Garriga, G. C., and Puolamäki, K. (2009). Randomization techniques for graphs. In *Proceedings of the 2009 SIAM International Conference on Data Mining*, pages 780–791. Society for Industrial and Applied Mathematics
- Newman, M. E. J., Watts, D. J., and Strogatz, S. H. (2002). Random graph models of social networks. *Proceedings of the National Academy of Sciences*, 99(Supplement 1):2566–2572
- Robins, G., Pattison, P., Kalish, Y., and Lusher, D. (2007). An introduction to exponential random graph (p*) models for social networks. *Social Networks*, 29(2):173–191
- Shumate, M. and Palazzolo, E. T. (2010). Exponential random graph (p*) models as a method for social network analysis in communication research. *Communication Methods and Measures*, 4(4):341–371

Week 9 – Dynamics: Network growth

Tuesday, October 19; Thursday, October 21

Preferential attachment, robustness, percolation.

- **Concepts**
  - Andriani, P. and McKelvey, B. (2009). From gaussian to paretian thinking: Causes and implications of power laws in organizations. *Organization Science*, 20(6):1053–1071
  - Kossinets, G. (2006b). Empirical analysis of an evolving social network. *Science*, 311(5757):88–90

- **Extensions**
  - Ahuja, G., Soda, G., and Zaheer, A. (March/April 2012). Introduction to the special issue: The genesis and dynamics of organizational networks. *Organization Science*, 23:434–448
  - Barabási, A. L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A., and Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica A: Statistical Mechanics and its Applications*, 311(3):590–614
  - Dorogovtsev, S. N. and Mendes, J. F. F. (2002). Evolution of networks. *Advances in Physics*, 51(4):1079–1187
  - Kilduff, M., Tsai, W., and Hanke, R. (2006). A paradigm too far? a dynamic stability reconsideration of the social network research program. *The Academy of Management Review*, 31(4):1031–1048
  - Leskovec, J., Kleinberg, J., and Faloutsos, C. (2007). Graph evolution: Densification and shrinking diameters. *ACM Transactions on Knowledge Discovery from Data*, 1(1):2
  - Leskovec, J., Backstrom, L., Kumar, R., and Tomkins, A. (2008). Microscopic evolution of social networks. In *Proceedings of the 14th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, KDD '08, pages 462–470, New York, NY, USA. ACM
  - Palla, G., Barabási, A.-L., and Vicsek, T. (2007). Quantifying social group evolution. *Nature*, 446(7136):664–667
  - Paranjape, A., Benson, A. R., and Leskovec, J. (2017). Motifs in temporal networks. In *Proceedings of the Tenth ACM International Conference on Web Search and Data Mining*, pages 601–610, Cambridge United Kingdom. ACM
  - Rosvall, M. and Bergstrom, C. T. (2010). Mapping change in large networks. *PLoS ONE*,

5(1):e8694
- Toivonen, R., Kovanen, L., Kivelä, M., Onnela, J.-P., Saramäki, J., and Kaski, K. (2009). A comparative study of social network models: Network evolution models and nodal attribute models. *Social Networks*, 31(4):240–254

Week 10 – Dynamics: Diffusion and influence

Tuesday, October 26; Thursday, October 28

Diffusion of innovation, simple contagion, complex contagion, threshold models.

- **Concepts**
  - Valente, T. W. (2012). Network interventions. *Science*, 337(6090):49–53
  - Guilbeault, D., Becker, J., and Centola, D. (2018). Complex contagions: A decade in review. In Lehmann, S. and Ahn, Y.-Y., editors, *Complex Spreading Phenomena in Social Systems*, pages 3–25. Springer International Publishing, Cham

- **Extensions**
  - Brockmann, D. and Helbing, D. (2013). The hidden geometry of complex, network-driven contagion phenomena. *Science*, 342(6164):1337–1342
  - Centola, D. and Macy, M. (2007). Complex contagions and the weakness of long ties. *American Journal of Sociology*, 113(3):702–734
  - Centola, D. (2015). The social origins of networks and diffusion. *American Journal of Sociology*, 120(5):1295–1338
  - Granovetter, M. (1978). Threshold models of collective behavior. *American Journal of Sociology*, 83(6):1420–1443
  - Hodas, N. O. and Lerman, K. (2014). The simple rules of social contagion. *Scientific Reports*, 4(1):4343
  - Pastor-Satorras, R., Castellano, C., Van Mieghem, P., and Vespignani, A. (2015). Epidemic processes in complex networks. *Reviews of Modern Physics*, 87(3):925–979
  - Strang, D. and Soule, S. A. (1998). Diffusion in organizations and social movements: From hybrid corn to poison pills. *Annual Review of Sociology*, 24(1):265–290
  - Ugander, J., Backstrom, L., Marlow, C., and Kleinberg, J. (2012). Structural diversity in social contagion. *Proceedings of the National Academy of Sciences*, 109(16):5962–5966
  - Watts, D. J. and Dodds, P. S. (2007). Influentials, networks, and public opinion formation. *Journal of Consumer Research*, 34(4):441–458
  - Wejnert, B. (2002). Integrating models of diffusion of innovations: A conceptual framework. *Annual Review of Sociology*, 28(1):297–326

Week 11 – Dynamics: Homophily and selection

Tuesday, November 2; Thursday, November 4

Homophily, node attributes, similarity, network endogeneity.

- **Concepts**
  - McPherson, M., Smith-Lovin, L., and Cook, J. (2001). Birds of a feather: Homophily in social networks. *Annual Review of Sociology*, 27:415–444

- Rivera, M. T., Soderstrom, S. B., and Uzzi, B. (2010). Dynamics of dyads in social networks: Assortative, relational, and proximity mechanisms. *Annual Review of Sociology*, 36(1):91–115

- **Extensions**
  - Aral, S., Muchnik, L., and Sundararajan, A. (2009). Distinguishing influence-based contagion from homophily-driven diffusion in dynamic networks. *Proceedings of the National Academy of Sciences*, 106(51):21544–21549
  - Aral, S., Muchnik, L., and Sundararajan, A. (2013). Engineering social contagions: Optimal network seeding in the presence of homophily. *Network Science*, 1(2):125–153
  - Centola, D. (2011). An experimental study of homophily in the adoption of health behavior. *Science*, 334(6060):1269–1272
  - DiMaggio, P. and Garip, F. (2012). Network effects and social inequality. *Annual Review of Sociology*, 38(1):93–118
  - Ibarra, H. (1992). Homophily and differential returns: Sex differences in network structure and access in an advertising firm. *Administrative Science Quarterly*, 37(3):422
  - Jackson, M. O. and López-Pintado, D. (2013). Diffusion and contagion in networks with heterogeneous agents and homophily. *Network Science*, 1(1):49–67
  - Kossinets, G. and Watts, D. J. (2009). Origins of homophily in an evolving social network. *American Journal of Sociology*, 115(2):405–450
  - Newman, M. (2003a). Mixing patterns in networks. *Physical Review E*, 67:26126
  - Shalizi, C. R. and Thomas, A. C. (2011). Homophily and contagion are generically confounded in observational social network studies. *Sociological Methods & Research*, 40(2):211–239

Week 12 – Applications: Bipartite networks

Tuesday, November 9; Thursday, November 11

Duality of people and groups, affiliation relationships, one-mode projections.

- **Concepts**
  - Borgatti, S. and Everett, M. (1997). Network analysis of 2-mode data. *Social Networks*, 19:243–269
  - Latapy, M., Magnien, C., and Vecchio, N. D. (2008). Basic notions for the analysis of large two-mode networks. *Social Networks*, 30:31–48

- **Extensions**
  - Breiger, R. L. (1974). The duality of persons and groups. *Social Forces*, 53(2):181–190
  - Börner, K., Maru, J. T., and Goldstone, R. L. (2004). The simultaneous evolution of author and paper networks. *Proceedings of the National Academy of Sciences*, 101(suppl 1):5266–5273
  - Faust, K. (1997). Centrality in affiliation networks. *Social Networks*, 19:157–191
  - Feld, S. (1981). The focused organization of social ties. *American Journal of Sociology*, 86:1015–1035
  - Keegan, B., Gergle, D., and Contractor, N. (2012). Do editors or articles drive collaboration?: Multilevel statistical network analysis of wikipedia coauthorship. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, CSCW '12, pages 427–436, New York, NY, USA. ACM
  - Mizruchi, M. S. (1996). What do interlocks do? an analysis, critique, and assessment of research

on interlocking directorates. *Annual Review of Sociology*, 22(1):271–298
- Neal, Z. (2014). The backbone of bipartite projections: Inferring relationships from co-authorship, co-sponsorship, co-attendance and other co-behaviors. *Social Networks*, 39:84–97
- Opsahl, T. (2013). Triadic closure in two-mode networks: Redefining the global and local clustering coefficients. *Social Networks*, 35(2):159–167
- Robins, G. and Alexander, M. (2004). Small worlds among interlocking directors: Network structure and distance in bipartite graphs. *Computational & Mathematical Organization Theory*, 10(1):69–94
- Wang, P., Sharpe, K., Robins, G. L., and Pattison, P. E. (2009). Exponential random graph (p*) models for affiliation networks. *Social Networks*, 31(1):12–25

Week 13 – Applications: Weighted networks

Tuesday, November 16; Thursday, November 18

Overlapping relationships, backbone extraction methods.

- **Concepts**
  - Barrat, A., Barthelemy, M., Pastor-Satorras, R., and Vespignani, A. (2004a). The architecture of complex weighted networks. *Proceedings of the National Academy of Sciences*, 101(11):3747–3752
  - Marsden, P. V. and Campbell, K. E. (2012). Reflections on conceptualizing and measuring tie strength. *Social Forces*, 91(1):17–23
  - Stopczynski, A., Sekara, V., Sapiezynski, P., Cuttone, A., Madsen, M. M., Larsen, J. E., and Lehmann, S. (2014). Measuring large-scale social networks with high resolution. *PLOS ONE*, 9(4):e95978

- **Extensions**
  - Aral, S. and Alstyne, M. V. (2011b). The diversity-bandwidth trade-off. *American Journal of Sociology*, 117(1):90–171
  - Barrat, A., Barthélemy, M., and Vespignani, A. (2004b). Weighted evolving networks: Coupling topology and weight dynamics. *Physical review letters*, 92(22):228701
  - Brashears, M. E. and Quintane, E. (2018). The weakness of tie strength. *Social Networks*, 55:104–115
  - Bonacich, P., Cody Holdren, A., and Johnston, M. (2004). Hyper-edges and multidimensional centrality. *Social Networks*, 26(3):189–203
  - Gilbert, E. and Karahalios, K. (2009). Predicting tie strength with social media. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 211–220, Boston MA USA. ACM
  - Granovetter, M. S. (1973). The strength of weak ties. *American Journal of Sociology*, 78:1360
  - Serrano, M. Á., Boguñá, M., and Vespignani, A. (2009). Extracting the multiscale backbone of complex weighted networks. *Proceedings of the National Academy of Sciences*, 106(16):6483–6488
  - Opsahl, T., Agneessens, F., and Skvoretz, J. (2010). Node centrality in weighted networks: Generalizing degree and shortest paths. *Social Networks*, 32(3):245–251

Week 14 – Fall Break

Tuesday, November 23; Thursday, November 25

No class.

Week 15 – Presentations

Tuesday, November 30; Thursday, December 2

Presentations of final projects.

Week 16 – Presentations

Tuesday, December 7; Thursday, December 9

Presentations of final projects.

Miscellaneous papers

These papers did not fit cleanly into any of the weeks, but I wanted to share them as resources for anyone building out reading lists for comprehensive exams. This list is obviously not exhaustive and I welcome your suggestions for additions!

- **Theory**
  - Borgatti, S. P. and Halgin, D. S. (2011). On network theory. *Organization Science*, 22(5):1168–1181
  - Burt, R. S., Kilduff, M., and Tasselli, S. (2013). Social network analysis: Foundations and frontiers on advantage. *Annual Review of Psychology*, 64(1):527–547
  - Emirbayer, M. and Goodwin, J. (1994). Network analysis, culture, and the problem of agency. *American Journal of Sociology*, 99(6):1411–1454
  - Emirbayer, M. (1997). Manifesto for a relational sociology. *American Journal of Sociology*, 103(2):281–317
  - Healy, K. (2015). The performativity of networks. *European Journal of Sociology*, 56(02):175–205
  - Jackson, M. O. (2009). Networks and economic behavior. *Annual Review of Economics*, 1(1):489–511
  - Jones, C., Hesterly, W. S., and Borgatti, S. P. (1997). A general theory of network governance: Exchange conditions and social mechanisms. *The Academy of Management Review*, 22(4):911–945
  - Sundararajan, A., Provost, F., Oestreicher-Singer, G., and Aral, S. (2013). Information in digital, economic, and social networks. *Information Systems Research*, 24(4):883–905

- **Mixed methods**
  - Coviello, N. E. (2005). Integrating qualitative and quantitative techniques in network analysis. *Qualitative Market Research: An International Journal*, 8(1):39–60
  - Crossley, N. (2010). The social world of the network. combining qualitative and quantitative elements in social network analysis. *Sociologica*, (1/2010)
  - Hollstein, B. (2014). *Qualitative Approaches*, pages 404–416. SAGE Publications Ltd, 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom
  - Yousefi Nooraie, R., Sale, J. E. M., Marin, A., and Ross, L. E. (2020). Social network analysis: An example of fusion between quantitative and qualitative methods. *Journal of Mixed Methods Research*, 14(1):110–124

- **Computational social science**
  - Edelmann, A., Wolff, T., Montagne, D., and Bail, C. A. (2020). Computational social science and sociology. *Annual Review of Sociology*, 46(1):61–81
  - Freelon, D. (2014). On the interpretation of digital trace data in communication and social computing research. *Journal of Broadcasting & Electronic Media*, 58(1):59–75
  - Golder, S. A. and Macy, M. W. (2014). Digital footprints: Opportunities and challenges for online social research. *Annual Review of Sociology*, 40(1):129–152
  - Hampton, K. N. (2017). Studying the digital: Directions and challenges for digital methods. *Annual Review of Sociology*, 43(1):167–188
  - Lazer, D., Pentland, A., Adamic, L., Aral, S., Barabasi, A., Brewer, D., Christakis, N., Con-

tractor, N., Fowler, J., and Gutmann, M. (2009). Life in the network: the coming age of computational social science. *Science*, 323:721–723
- Lazer, D. and Radford, J. (2017). Data ex machina: Introduction to big data. *Annual Review of Sociology*, 43(1):19–39
- Lazer, D. M. J., Pentland, A., Watts, D. J., Aral, S., Athey, S., Contractor, N., Freelon, D., Gonzalez-Bailon, S., King, G., Margetts, H., Nelson, A., Salganik, M. J., Strohmaier, M., Vespignani, A., and Wagner, C. (2020). Computational social science: Obstacles and opportunities. *Science*, 369(6507):1060–1062
- Kleinberg, J. (2008). The convergence of social and technological networks. *Communications of the ACM*, 51(11):66–72

• **Disciplines**
  - **Information**
    * Haythornthwaite, C. (1996). Social network analysis: An approach and technique for the study of information exchange. *Library & Information Science Research*, 18(4):323–342
    * Otte, E. and Rousseau, R. (2002). Social network analysis: A powerful strategy, also for the information sciences. *Journal of Information Science*, 28(6):441–453
    * Sundararajan, A., Provost, F., Oestreicher-Singer, G., and Aral, S. (2013). Information in digital, economic, and social networks. *Information Systems Research*, 24(4):883–905

  - **Journalism**
    * Fu, J. S. (2016). Leveraging social network analysis for research on journalism in the information age. *Journal of Communication*, 66(2):299–313
    * Ke Jiang, Barnett, G. A., and Taylor, L. D. (2016). Dynamics of culture frames in international news coverage: A semantic network analysis. *International Journal of Communication (19328036)*, 10:3710–3736
    * KIM, K. and BARNETT, G. A. (1996). The determinants of international news flow: A network analysis. *Communication Research*, 23(3):323–352
    * Robinson, S. and Anderson, C. W. (2020). Network ethnography in journalism studies: A mixed-method approach to studying media ecologies. *Journalism Studies*, 21(7):984–1001

  - **Communication**
    * Monge, P. R. and Contractor, N. S. (2001). Emergence of communication networks. In Jablin, F. and Putnam, L., editors, *The New Handbook of Organizational Communication*, pages 440–502. SAGE Publications, Inc
    * Doerfel, M. L. (1998). What constitutes semantic network analysis? a comparison of research and methodologies. *Connections*, 21(2):16–26

  - **Media**
    * Guo, L. (2012). The application of social network analysis in agenda setting research: A methodological exploration. *Journal of Broadcasting & Electronic Media*, 56(4):616–631
    * Moon, S.-I., Barnett, G. A., and Lim, Y. S. (2010). The structure of international music flows using network analysis. *New Media & Society*, 12(3):379–399

  - **Organizations**
    * Borgatti, S. P. and Foster, P. C. (2003). The network paradigm in organizational research:

A review and typology. *Journal of Management*, 29(6):991–1013

* Brass, D. J., Galaskiewicz, J., Greve, H. R., and Wenpin Tsai (2004). Taking stock of networks and organizations: A multilevel perspective. *Academy of Management Journal*, 47(6):795–817
* Katz, N., Lazer, D., Arrow, H., and Contractor, N. (2004). Network theory and small groups. *Small Group Research*, 35(3):307–332
* Kilduff, M. and Brass, D. J. (2010). Organizational social network research: Core ideas and key debates. *Academy of Management Annals*, 4(1):317–357
* Obstfeld, D. (2005). Social networks, the tertius iungens orientation, and involvement in innovation. *Administrative Science Quarterly*, 50:100
* Podolny, J. and Page, K. (1998). Network forms of organization. *Annual Review of Sociology*, 24
* Powell, W. W. (1990). Neither market nor hierarchy: Network forms of organization. *Research in Organizational Behavior*, 12:295–336
* Zaheer, A., Gözübüyük, R., and Milanov, H. (2010). It's the connections: The network perspective in interorganizational research. *The Academy of Management Perspectives*, 24(1):62–77