Network Science: Theory and applications

Instructor: Dr. Jacopo A. Baggio

Office Hours: (most likely Monday from 12 to 1.30pm and Wednesday from 11am to 1.30pm)

Office Location: Office Hours: Howard Phillips Hall Room 302 N
Under Appointment: Research 1, Room 344

Course Schedule: (Monday, 6:00-8:50 pm**)**

Course Motivation

The world is becoming increasingly complex and interlinked due to globalization and the advancements of technologies. In the last two decades, network science has gained traction and has been used to describe a wide variety of different phenomena in life and social sciences. In fact, it is well documented that structural properties of networks influence behaviors and outcomes in a wide range of systems: from social networks to food webs, from landscapes to power grids, from the internet to political and policy networks, not to mention epidemics and vaccines interactions, strategies and ideas, coalitions and teams.

Course Description:

Network theory dates its conceptual origins back to the 1730s thanks to Euler (1736); but the starting point of modern graph theory is considered to be the work of two Hungarian mathematicians on random graphs: Erdos and Reny in 1959 and 1960.

This course is an introduction to network theory. The course will focus on introducing concepts, metrics and applications in network analysis with a focus on policy networks, collaborations and interdependent systems. The course will also provide students with the ability to devise their own network survey, collect data, and to do their own network analysis in Python, via the NetworkX package. The course is thus divided into a general lecture in which concepts and metrics are explained to students via standard lecture format, and a technical lecture in which students will familiarize themselves with the analysis of Networks via NetworkX. The course will also include introductory lectures on how to write a script. This latter is an important transferable skill as scripts are used in many programs used in today world and academic environments: from SPSS, to STATA, from Matlab to R. The topics covered will be the following:

- **General concepts**: Networks, classes of networks, network metrics, exponential random graph models, multiplex networks, diffusion on networks. Applying network theoretical tools for the analysis of policy and political networks as well as integrated social-ecological networks.
- **Technical skills**: Survey instrument for devising networks; Python NetworkX package
- **Optional skills (to be discussed with the instructor)**: Integrating Networks and

computational modelling.

To facilitate learning, the course is divided into four main blocks:

1. The first block of the course will introduce what are networks, different network classes and the most common network metrics used to analyze networks.
2. The second block of the course will focus on (best) practices to collect data for network analysis, and application of network analysis to real world problems.
3. The third block will focus on advanced network topics (exponential random graph models and multiplex networks).
4. The final block of the course will be centered on group and individual final projects. We will work in class on defining meaningful research questions related to network analysis, how to gather relevant network data, analyze networks and interpret the results. Optional topics can be discussed with the instructor and addressed in this third block.

Course Objectives

Students that successfully complete this class will be able to:

1) Define and understand key concepts in network science
2) Use NetworkX package in Python to analyze networks
3) Apply theory and methods learned to interpret and analyze problems in their area of interest

To facilitate achieving these broad objectives, students will be assigned a variety of tasks to secure this knowledge. Students are expected to read the assigned materials ***before*** class and to participate in class discussions. This will not be a standard lecture class. *We will all need to engage in discussion*.

Requirements

To successfully complete this class you need access to a pc or laptop and the following software:

- Microsoft Office Excel or equivalent
- Microsoft Office Word or equivalent
- Microsoft Office Power Point or equivalent
- PDF Reader
- Python **3**(Anaconda distribution makes it easier to install packages and it comes with the main Python packages already installed. You can find Conda(Anaconda) here: https://conda.io/docs/index.html)

For Students interested in optional topics, software targeted to student interest is recommended (i.e. computational modelling software such as NetLogo).

Own research topics are welcome, but not required. If you have a specific research topic you want to work on, final and mid-term projects will be centered on your own research topic.

Expectations

It is expected that students come prepared to lectures. This means that students are expected to have **read** the material provided ***prior*** the general lecture class. The papers and book chapter in **BOLD are mandatory**, but it is **expected** that students will engage with **all the material provided**. The course is designed as follows (but subject to modification depending on class educational needs):

- *General lecture*: will be based on basic concepts for the week topic and discussion of the readings assigned
- *Technical lecture*: will be centered upon increasing skills and ability in collecting and analyzing network data.

Typical Class Format

Although class may follow the format described below, the format is not fixed and will depend on the educational needs of the class and the number of students.

General lecture:

- If there is a discussion paper:
  - Discussion Leads for the assigned reading – 10 minutes
  - Discussion on the assigned reading – 10 minutes
  - Discussion of the readings and summary of the discussion – 25 or more minutes
  - Point raised that needs clarification, q&a, "traditional lecture" – remaining time
- If the format is a standard lecture:
  - Standard lecture on the weekly topic
  - Q & A (during the lecture and after, please feel free to interrupt at anytime).

- **Remember:** the more you are engaged, the more you will learn and the more fun the class can be!

Technical Lecture:

- Revising and discuss previous exercises and concepts
- Exercises in class (this will be varied)

SYLLABUS DISCLAIMER:

This syllabus is NOT a contract. All parts of this syllabus can be amended by the instructor given students' educational needs and assessment.

Assignments

For Essay type assignments you are asked to use word processing that your instructor can access. Therefore, preferably use Word, pdf, or plain text files. If you use software that is different and you may not sure whether it will be accessible by your instructor, contact Dr. Baggio. Files that cannot be opened will not be graded. The total available is 110%.

Assignments deadline:

Discussion Assessment: Friday after leading the tuesday in-class discussion.

Technical Assessment: Friday at 11.59 pm (week 2 technical assignment is due friday of week 3).

Late Assignments:

Continuous Evaluation: Late assignments are penalized 1 point each 3 hours late. (after 9hrs, 0 points are awarded).

Final Project: Late assignment will be evaluated with 0 points.

Exception to late assignments: only medical (WITH doctor's note) late assignments can be accepted, unless otherwise stated by the university policies.

Continuous Evaluation

Discussion Assessment: Discussion Leads (20 points)

During block 2 of this course and relating only to application of network analysis papers (depending on enrollment) one course participants will need to read and discuss a peer-reviewed article. Each discussion lead will have 3 main tasks – (all have to participate in the discussion as all receive points for participation)

1. Critically assess the validity of the paper assigned. You can use a power point or not. You are encouraged to search for critiques/validation of the paper assigned. If you have doubts or do not know how to proceed you can organize a meeting with me and I will provide guidelines for critiquing the paper assigned.
2. If the class does not discuss the paper, randomly someone will be chosen to lead the discussion on limitations strengths of the paper assigned.
3. Each participation is evaluated each week. If you do not participate you will get 0 points for a specific week.

Technical Assessment: Exercises take-home assignments (40 points)

Each week all students will be expected to complete the assignments given. Assignments vary. For example, take-home assignments can be related to simple "script language questions" (i.e. build an if-then statement or a for loop statement), network analysis questions, loading network data into python. Other technical assignment can relate to how to gather network data, potential biases in network datasets etc…

Final Project

Project Presentation (15 points) – open to faculty and other students.

- The project presentations can be done individually or in groups. Presentation cannot be longer than 15 minutes (and they will be timed, going over time will result in a penalization in points).
- If in groups, all the names of all the group members have to be reported by each individual.
- Each individual will have to present part of the project to receive a grade.
- If an individual part of a group does not actually present, s/he will receive 0 points for this assignment.
- A group can be of no more than 4 people.

Final Project Paper (35 points)

The final project is due the last week of class

- The final project can be discussed with me at any time during the course. If you have your own topic, we will work on that, if not, you can choose any topic covered during the course or you will be assigned one.
- The final project has to showcase your technical skills. It has to involve an in-depth analysis of a topic of your choices centered upon network analysis.
- The final project can be done individually or in groups. If in groups, all the names of all the group member have to be reported by each individual.
- Contribution of each member should be stated, if not all members will be assumed to have participated equally.
- Groups can be of no more than 4 people.

- Your final project must consist of a thoughtful analysis on a topic of your choice:
    - You can choose to analyze and critique an existing paper that uses network analysis and try to replicate their results.
    - The final essay should contain a brief literature review on the topic you are working on, description of the analysis and why you are using specific network metrics), results, limitations, discussion and conclusion.
    - You need to cite at least 5 peer review articles that deal with the topic of your choice.
- APA style is required as well as proper citation.

The essay must be at least 2000 words, not to exceed 3500 words.

Summary of impact of the different assignment on your final grade:

Continuous Learning	Discussion	20 points
	Take-Home Assignments	40 points
Final Evaluation	Project Presentation	15 points
	Final Project Paper	35 points

Course Schedule

This course schedule as well as the syllabus can change depending on class educational needs. Some topics / skills may require more time than envisioned and in such cases the course schedule will be adjusted. All readings will be uploaded into Canvas. The course is divided in three main blocks

General Readings: the following papers, books and book chapter do not refer to a specific weekly topic but are useful summary reports on network science.

- Albert, R., & Barabási, A.-L. (2002). Statistical mechanics of complex networks. Reviews of Modern Physics, 74(1), 47-97.
- Boccaletti, S., Latora, V., Moreno, Y., Chavez, M., & Hwang, D.-H. (2006). Complex networks: Structure and dynamics. Physics Reports, 424(4-5), 175-308.
- da Fontoura Costa, L., Rodrigues, F. A., Travieso, G., & Villas Boas, P. R. (2007). Characterization of complex networks : A survey of measurements. Advances in Physics, 56(1-2), 167-242.
- Newman, M. E. J. (2003). The structure and function of complex networks. SIAM review, 45(2), 167-256.
- Barabasi A.-L.: Network Science Book online http://barabasi.com/networksciencebook/

BLOCK 1: Introducing Networks, Network Classes and Network Metrics

Week 1:

- **Introduction to the course.** What we will do, what is expected, what are the aims and objectives and the philosophy behind the teaching of this course. Introduction to Networks and the story behind them.
- **Technical: Introducing Python:** how to install python and python packages, what is python, what are the basics concept of scripting in python?
- **Readings:**
    - **Barabasi Book Ch 1 and 2.1, 2.2, 2.4, 2.5 and 2.6**
    - Borgatti S., Mehra, A., Brass, D.J., Labianca, G. (2009). Network Analysis in the Social Sciences, *Science* 323, 892-895.
    - **Watts, D. J. (2004). The "New" Science of Networks. Annual Review of Sociology, 30, 243-270.**
    - Amaral, L. A. N., & Ottino, J. M. (2004). Complex networks: Augmenting the framework for the study of complex systems The European Physical Journal B, 34(2), 147-162.
    - Granovetter (1973): The Strength of Weak Ties, American Journal of Sociology 78 , pp. 1360-1380

Week 2:

- **General: Network Metrics:** Centrality, distance and clustering: the most common network metrics used, and how can we interpret them?
- **Technical: Basics of Python programming:** How to write simple statements in python.
    - **Assignment:** Write simple statements in Python
- **Readings:**
    - **Barabasi Book Section 2.3, 2.8, 2.9 and 2.10**
    - Everett M, Borgatti SP (2005) Extending centrality. Models and Methods in Social Network Analysis, eds Carrington P, Scott J, Wasserman S (Cambridge Univ Press, Cambridge, UK), pp 57–76.
    - Bonacich, Phillip. (1987). Power and centrality: A family of measures.American Journal
    - of Sociology:1170–82.
    - **Börner, K., Sanyal, S., & Vespignani, A. (2007). Network Science. In B. Cronin (Ed.), Annual Review of Information Science & Technology (Vol. 41, pp. 537-607). Medford, NJ: Information Today, Inc./American Society for Information Science and Technology.**
    - da Fontoura Costa, L., Rodrigues, F. A., Travieso, G., & Villas Boas, P. R. (2007). Characterization of complex networks : A survey of measurements. Advances in Physics, 56(1-2), 167-242 -> *Read par*t 1, 2, 3, 4, 5, 6, and 9
    - Freeman, L. C. (1978). Centrality in social networks conceptual clarification. Social networks, 1(3), 215-239.

Week 3:

- **General: Network Metrics II:** Communities, page rank, eigenvector: other important network metrics and their interpretation.

- **Technical: Basics of Python 2:** logic of programming: if-then-else statements
    - **Assignment:** Exercises on if-then else statements
- **Readings:**
    - **Barabasi Book Ch 7 (up to section 7.7), Ch 9 (up to section 9.7)**
    - da Fontoura Costa, L., Rodrigues, F. A., Travieso, G., & Villas Boas, P. R. (2007). Characterization of complex networks : A survey of measurements. Advances in Physics, 56(1-2), 167-242 -> *Read part* 7,10,11,12
    - **Latora, V., & Marchiori, M. (2001). Efficient Behavior of Small-World Networks. Physical Review Letters, 87(19), 198701-198701 198701-198704.**
    - Newman, M. E. J. (2002). Assortative Mixing in Networks. Physical Review Letters, 89(20), 208701.208701-208701.208704.
    - Newman, M. E. (2006). Modularity and community structure in networks. Proceedings of the national academy of sciences, 103(23), 8577-8582.

Week 4:

- **General: Network Classes:** What are network classes? Why are the important?
- **Technical: Basics of Python 3:** logic of programming: for and while loops
    - **Assignment:** Exercises on for and while loops
- **Readings:**
    - **Barabasi Section 3.1, 3.2, 3.3, 3.4, 3.5 and 4.1, 4.2, 4.3, 4.4**
    - **Barabási, A.-L., & Albert, R. (1999). Emergence of Scaling in Random Networks. Science, 286(5439), 509-512.**
    - **Barabasi, A.L. and Bonabeau, E. (2003) Scale-free networks. Scientific American, 50- 59.**
    - Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. Nature, 393 (6684), 440-442.
    - **Watts, D. J. (1999). Networks, dynamics, and the small-world phenomenon. American Journal of sociology, 105(2), 493-527.**
    - Albert, R., Jeong, H., & Barabási, A.-L. (2000). Error and attack tolerance of complex networks. Nature, 406(6794), 378-382.

BLOCK 2: Gathering Network Data and Network Applications

Week 5:

- **General: Collecting Network data**: how we gather network data? What are the different techniques that we can use? What are the typical questions you would like to ask if using survey>
    - **Discussion**: Each "lead" will discuss one paper chosen from the ones below.
- **Technical: NetworkX:** Upload your own data in NetworkX
    - **Assignment:** upload data in specific formats (dataset will be provided) in NetworkX
- **Readings (on applications)**
    - Costa, L. D. F., Oliveira Jr, O. N., Travieso, G., Rodrigues, F. A., Villas Boas, P. R., Antiqueira, L., ... & Correa Rocha, L. E. (2011). Analyzing and modeling real-world phenomena with complex networks: a survey of applications. *Advances in Physics*, *60*(3), 329-412.

- Padgett, J. F., Ansell, C.K., (1993). Robust action and the rise of the medici 1400-1434 The *American Journal of Sociology*, 98, 1259-1319.
- Pitts, F.R., (1979). The medieval trade network of Russia revisited. *Social Networks*, 1, 285-292.

Week 6:

- **General: Political Science and Networks**
  - **Discussion**: Each "lead" will discuss one paper chosen from the ones below.
- **Technical: NetworkX 2:** Analyzing networks!
  - **Assignment:** Analyze the networks uploaded last week and interpret the results.
- **Readings (on applications)**
  - Porter, M.A. et al. 2007. Community Structure in the United States House of Representatives. *Physica A.* 386(1): 414-438.
  - Cranmer, S. J., Desmarais, B. A., Kirkland J.H., (2012). Toward a Network Theory of Alliance Formation. *International Interactions* 38:295-324.
  - Saunders, C., (2007). Using Social Network Analysis to Explore Social Movements: A Relational Approach. *Social Movement Studies* 6:227-243.
  - Krackhardt, D. (1990). Assessing the political landscape: Structure, cognition, and power in organizations. Administrative science quarterly, 342-369.

Week 7:

- **General: Policy networks**
  - **Discussion**: Each "lead" will discuss one paper chosen from the ones below.
- **Technical: Using NetworkX to analyze multiple networks.**
  - Assignment: Analyze networks in a loop (data will be provided)
- **Readings:**
  - Ward, Michael D., Katherine Stovel, and Audrey Sacks. 2011. Network Analysis and Political Science. *Annual Review of Political Science* 14:245-64.
  - Maoz, Zeev, Lesley Terris, Ranan Kuperman and Ilan Talmud. 2007. "What is the Enemy of my Enemy: Causes and Consequence of Imbalanced International Relations, 1816-2001." *Journal of Politics* 69(1): 100-115.
  - Lubell, M., Scholz, J., Berardo, R., & Robins, G. (2012). Testing policy theory with statistical models of networks. Policy Studies Journal, 40(3), 351-374.
  - Berardo, R., & Scholz, J. T. (2010). Self-organizing policy networks: risk, partner selection, and cooperation in estuaries. American Journal of Political Science, 54(3), 632-649.
  - McAllister, R.R.J., McCrea, R., Lubell, M., 2013. Policy networks, stakeholder interactions and climate adaptation in the region of South East Queensland, Australia. Regional Environmental Change 14 (2), 527e539.
  - Schoon, M., York, A., Sullivan, A., Baggio, J., 2017. The emergence of an environmental governance network: the case of the Arizona borderlands. Reg. Environ. Chang. 17, 677–689. doi:10.1007/s10113-016-1060-x

Week 8:

- **General: Network analysis in natural resource management.**
  - **Discussion**: Each "lead" will discuss one paper chosen from the ones below.
- **Technical: Summary**: a recap of what we have learned so far.

- **Readings:**
    - Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., Ryan, P. (2006). Toward a Network Perspective of the Study of Resilience in Social-Ecological Systems. Ecology and Society, 11(1), 15.
    - Crona, B., Bodin, Ö. (2006). What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. Ecology and society, 11(2).
    - Bodin, O., Crona, B.I., 2009. The role of social networks in natural resource governance: what relational patterns make a difference? Global Environmental Change 19 (3), 366e374.
    - Prell, C., Hubacek, K., & Reed, M. (2009). Stakeholder analysis and social network analysis in natural resource management. Society and Natural Resources, 22(6), 501-518.
    - McAllister RRJ, et al. (2015) From local to central: A network analysis of who manages plant pest and disease outbreaks across scales. Ecology and Society 20(1):67.
    - Bodin, Ö. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, *357*(6352), eaan1114.
    - Sayles, J. S., & Baggio, J. A. (2017a). Who collaborates and why: Assessment and diagnostic of governance network integration for salmon restoration in Puget Sound, USA. Journal of environmental management, 186, 64-78.
    - Sayles, J. S., & Baggio, J. A. (2017b). Social–ecological network analysis of scale mismatches in estuary watershed restoration. Proceedings of the National Academy of Sciences, 114(10), E1776-E1785.

Week 9:

- **General: Spreading on networks**: What is the relationship between spreading of phenomena and the underlying network?
    - **Discussion:** (Depending on main reading chosen, most likely Centola 2010)
- **Technical: Networks and Diffusion in Python:** How to assess the relationship between network properties (metrics) and diffusion (or spreading) of ideas, strategies, epidemics, policies etc…
- **Readings:**
    - **Barabasi Book Ch 10 (up to 10.7)**
    - **Centola, Damon. (2010). The Spread of Behavior in an Online Social Network Experiment. Science 329: 1194-1197.**
    - Centola, D. and Macy, M.W. (2007). Complex contagion and the weakness of long ties. American Journal of Sociology, 113(3):702-734
    - Shalizi, Cosma Rohilla and Andrew C. Thomas. 2011. Homophily and Contagion Are Generically Confounded in Observational Social Network Studies. *Sociological Methods & Research* 40(2): 211–239.
    - Christakis, Nicholas A. and James H. Fowler. 2010. "Social Network Sensors for Early Detection of Contagious Outbreaks." *PLoS ONE* 5(9)
    - Pastor-Satorras, R., & Vespignani, A. (2001). Epidemic spreading in scale-free networks. *Physical review letters*, *86*(14), 3200.
    - De Domenico, M., Granell, C., Porter, M. A., & Arenas, A. (2016). The physics of spreading processes in multilayer networks. *Nature Physics*, *12*(10), 901-906.

BLOCK 3: Advanced Topics in Network Science

Week 10:

- **General: Summary:** Exponential Random Graph Models

- **Technical**: ERGM analysis in Python, using user-written ergm package.
    - **Assignment:** analyze the dataset provided and interpret the results using the ERGM user-written package in Python (need to re-test if it still works correctly with the last version)
- **Readings:**
    - Robins, G., Pattison, P., Kalish, Y., & Lusher, D. (2007). An introduction to exponential random graph (p*) models for social networks. Social networks, 29(2), 173-191.
    - Robins, G., Lewis, J. M., & Wang, P. (2012). Statistical network analysis for analyzing policy networks. Policy Studies Journal, 40(3), 375-401.
    - Gerber, E. R., Henry, A. D., & Lubell, M. (2013). Political homophily and collaboration in regional planning networks. American Journal of Political Science, 57(3), 598-610.
    - Barnes, M., Bodin, Ö., Guerrero, A., McAllister, R., Alexander, S., & Robins, G. (2017). The social structural foundations of adaptation and transformation in social–ecological systems. Ecology and Society, 22(4).
    - **Bodin, Ö., & Tengö, M. (2012). Disentangling intangible social–ecological systems. Global Environmental Change, 22(2), 430-439.**

Week 11:

- **General: Multiplex Networks**
- **Technical:** Analysis of multiplex networks in Python: using Pymnet.
    - **Assignment:** Analayze and interpret the results of the dataset provided using Pymnet.
- **Readings:**
    - **Baggio, J. A., BurnSilver, S. B., Arenas, A., Magdanz, J. S., Kofinas, G. P., & De Domenico, M. (2016). Multiplex social ecological network analysis reveals how social changes affect community robustness more than resource depletion. *Proceedings of the National Academy of Sciences*, *113*(48), 13708-13713.**
    - Buldyrev, S. V., Parshani, R., Paul, G., Stanley, H. E., & Havlin, S. (2010). Catastrophic cascade of failures in interdependent networks. Nature, 464, 1025-1028.
    - **Mucha, P. J., Richardson, T., Macon, K., Porter, M. A., & Onnela, J. P. (2010). Community structure in time-dependent, multiscale, and multiplex networks. *science*, *328*(5980), 876-878.**
    - De Domenico, M., Solé-Ribalta, A., Cozzo, E., Kivelä, M., Moreno, Y., Porter, M. A., ... & Arenas, A. (2013). Mathematical formulation of multilayer networks. Physical Review X, 3(4), 041022.
    - Kivelä, M., Arenas, A., Barthelemy, M., Gleeson, J. P., Moreno, Y., & Porter, M. A. (2014). Multilayer networks. Journal of complex networks, 2(3), 203-271.

BLOCK 4: Individual/Group projects and optional skills to be developed

Week 12:

- **Group Project, working in class –**

Week 13:

- **Group Project, working in class –**

Week 14:

- **Group Project –**

Week 15:

- **Presenting your Project**