Spring 2020 Syllabus

Complex Networks

Prof. Dr. Dr. Frank Schweitzer
Dr. Giona Casiraghi
Christoph Gote
Chair of Systems Design
ETH Zurich
fschweitzer@ethz.ch

Lecture: Tuesday, 10:15-11:55 (V), HG E 1.2
Exercise: Tuesday, 09:15-10:00 (U), HG E 21

Exercises are predominantly programming assignments that can be solved using `python`*. Sample programs and code skeletons will be provided. During the exercise sessions, students are expected to present their solutions, which will then be discussed. Sample solutions are provided after the exercise session.*

1. Introduction to Networks: Basic and Advanced Metrics

Lecture 01 – Motivation *18.02.2020*

Educational Objective: In this lecture, participants will get an overview of the course and will learn the differences between an agent-based modeling and a complex networks perspective.

- Administrative issues and overview of the course
- Introduction: Agent-based modeling vs. a network approach
- Motivation: The role of network structures in complex systems
- Illustrative examples of complex networks in nature, society, economy and technology

Exercise 01: Introduction to `pathpy` *and* `python` *due 25.02.2020*

Lecture 02 – Introduction to Networks *25.02.2020*

Educational Objective: In this lecture, students will learn how to mathematically represent complex networks and how to quantitatively analyse the importance of nodes.

- Basic definitions: graph, network, adjacency matrix, path, cut, degree
- Importance of nodes: betweenness, closeness and degree centrality
- Modules and clusters: clustering coefficient and modularity
- Example: Open Source collaboration network

Exercise 02: Paths, Centralities, and Community Structure *due 03.03.2020*

2. Stochastic Models of Complex Networks

Lecture 03 – Ensemble Perspective of Complex Networks *03.03.2020*

Educational Objective: In this lecture, participants will learn how networks can be represented and analysed from a statistical point of view.

- Graph theory vs. network science: the ensemble perspective
- Erdös-Renyi (ER) random graph model
- Degree distribution and average degree in ER graphs
- Counterexample: degree distribution in OSS collaboration network

Exercise 03: Empirical Networks and Random Graphs *due 10.03.2020*

Lecture 04 – Small-world networks and Ensembles with fixed degree distributions *10.03.2020*

Educational Objective: In this lecture, participants will learn how to generate networks that reproduce the small diameter and large clustering coefficient observed in a number of real-world networks.

- Degree distribution, diameter and clustering coefficient of random networks
- Navigability and funneling in small-world networks
- Watts-Strogatz model: average shortest path length and clustering coefficient
- Ensembles with fixed distribution of degrees: Molloy-Reed algorithm

Exercise 04: Random Graphs and Small World Networks *due 17.03.2020*

Lecture 05 – Generating Functions and the Friendship Paradox *17.03.2020*

Educational Objective: In this lecture, students will learn how to can make statements about the properties of a network if one only knows the distribution of node degrees.

- The generating functions framework
- Properties of generating functions
- Application to the friendship paradox

Exercise 05: Ensembles with fixed degree sequences and the Friendship Paradox *due 24.03.2020*

Lecture 06 – Generating Functions: the giant connected component *24.03.2020*

Educational Objective: In this lecture, participants will learn how the framework of generating functions can be applied to study the emergence of a giant connected component in complex networks with arbitrary degree distributions.

- Reminder: generating functions and complex networks
- friendship paradox and sampling biases
- emergence of a giant connected component
- the Molloy-Reed criterion

Exercise 06: Robustness and Scale Free Networks *due 31.03.2020*

Lecture 07 – Scale-Free Networks and Limitations of Ensemble Studies *31.03.2020*

Educational Objective: In this lecture, participants will learn what fallacies one encounters when applying findings from ensemble studies to real-world networks.

- Analyzing robustness with generating functions
- Robustness of Scale-free networks
- Limitations of ensemble-based approaches
- Example: AS-level Internet topology

Exercise 07: Limitations of Ensemble Studies *due 7.04.2020*

3. Dynamical Processes on Complex Networks

Lecture 08 – Random Walks and Diffusion in Complex Networks *7.04.2020*

Educational Objective: In this lecture, students will learn how we can model diffusion in complex networks by means of random walks.

- Dynamical processes in networks
- Diffusion processes in networks
- Random walks as model for diffusion processes
- Markov chain convergence theorem

Exercise 08: Simulating diffusion with `pathpy` *due 21.04.2020*

Easter break *14.04.2020*

Lecture 09 – Spectral Properties of Complex Networks *21.04.2020*

Educational Objective: In this lecture, students will learn how the influence of a network on diffusion processes is captured in the eigenvalues of matrix representations and how eigenvectors of these representations can be used to define feedback centrality measures.

- Stationary distributions of random walks
- Feedback centrality measures
- Diffusion speed in complex networks
- Eigenvalue gap of transition matrices

Exercise 09: Spectral analysis using `numpy` *and* `scipy` *due 28.04.2020*

4. Generative Models and Statistical Inference

Lecture 10 – Block Models and Statistical Inference *28.04.2020*

Educational Objective: In this lecture, students will learn how the ensemble perspective on complex networks can be used to infer community structures in relational data.

- Statistical ensembles and statistical inference
- Maximum likelihood approach and stochastic models of networks
- Stochastic block model and community detection
- Minimum description length approach

Exercise 10: Inferring communities with `pathpy` *due 05.05.2020*

Lecture 11 – Learning in Networks: Model Selection *05.05.2020*

Educational Objective: n this lecture, students will learn how information-theoretic concepts can be used to avoid an overfitting of community structures.

- Motivation: overfitting and model selection
- Entropy of statistical ensembles
- Stochastic block model: minimising description length
- Flow compression: InfoMap

Exercise 11: Statistical inference with `pathpy` *due 12.05.2020*

Lecture 12 – Exponential Random Graph Models *12.05.2020*

Educational Objective: In this lecture, students will learn how Exponential Random Graph Models can be used to model and analyze relational data on complex systems.

- Generative models of complex networks

- Exponential Random Graph Models
- Statistical Inference with ERGMs
- Example: Analyzing a social network using ERGMs

There will be no exercise class on the *19.05.2020*

.....

5. Temporal Networks

.....

Lecture 13 – Research Trend: Analyzing Sequential Data *19.05.2020*

Educational Objective: In this lecture, students will get an overview of limitations of network-based methods for the modeling of time-stamped and sequential relational data.

- Motivation: Limitations of the network perspective
- Network evolution and dynamical processes
- Temporal networks: Basics
- A novel perspective on temporal networks

Exercise 13: Time Series Network Data *due 26.05.2020*

.....

Lecture 14 – Summary/ Wrap-up of the course *26.05.2020*

Educational Objective: In this lecture, students will have to chance to ask questions about the course and about the examination.

.....

Session Examination

.....