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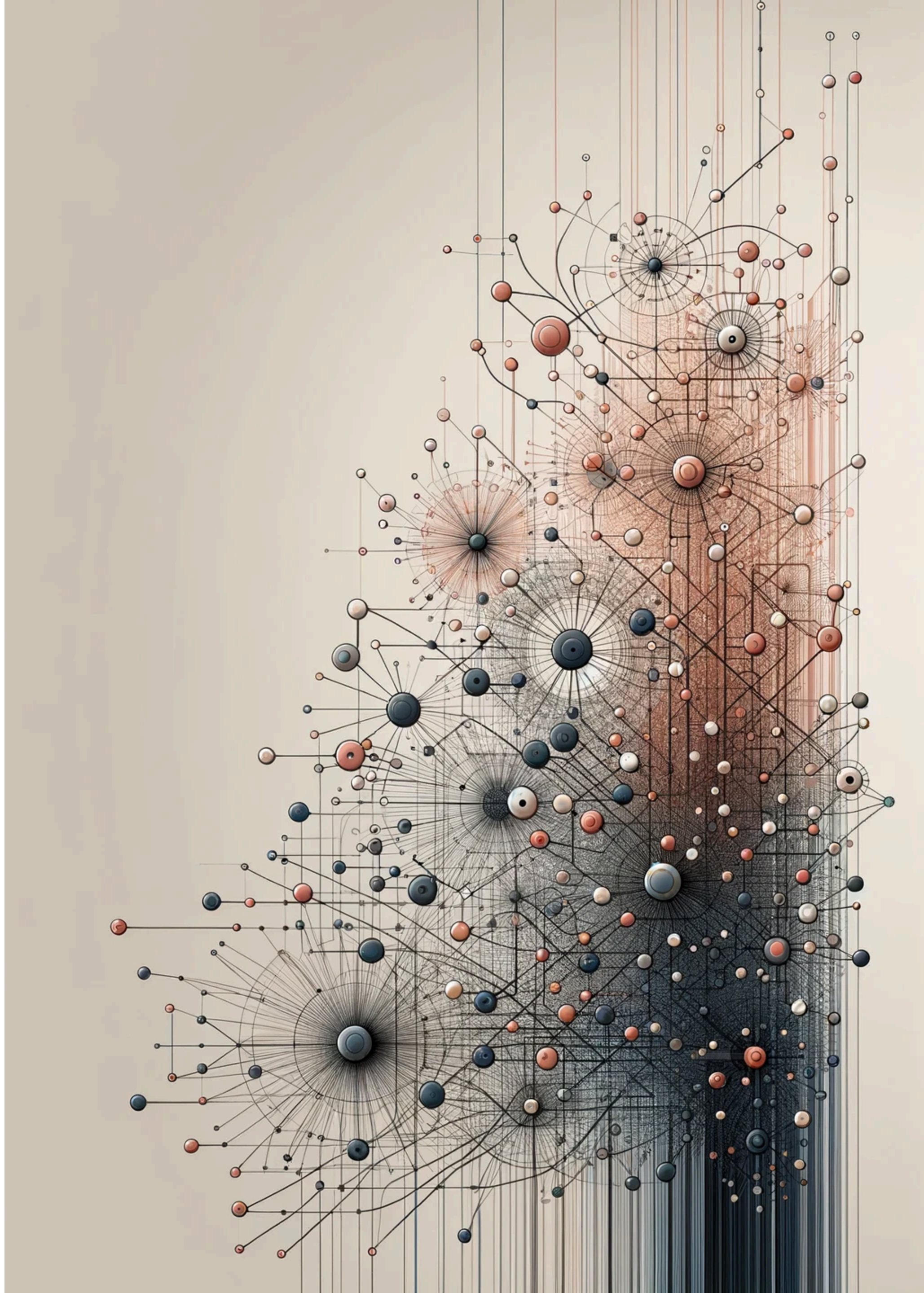
Analisi e Visualizzazione di Reti Complesse

NS01 - Introduction to the course

Prof. Rossano Schifanella



Instructor

Prof. Rossano Schifanella

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- Researcher at ISI Foundation

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Course

- **INF0007 Analisi e Visualizzazione delle Reti Complesse** (9 credits)
  - Magistrale in Informatica
- Borrowed by:
  - **MFN0954 Reti Complesse** (6 credits)
    - Magistrale in Informatica
- The course is divided into two sub-modules:
  - **Network Science** (NS) (48h)
  - **Data Vizualization** (DV) (24h)

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Schedule

	Tuesday	Wednesday	Friday
Module	**NetSci**	DataViz	**NetSci**
When	**2pm-4pm**	11am-1pm	**2pm-4pm**
Where	**Aula F**	Aula E	**Aula E**

The schedule could be subject to variations that will be communicated via the proper channels (e.g., Moodle forum, email).

This is why it is **crucial** that all students are registered to the Moodle module to be up-to-date.

Material

- Course on Moodle:
  - https://informatica.i-learn.unito.it/course/view.php?id=3026
- GitHub code repo:
  - https://github.com/rschifan/avrc-2425
- External references listed in Moodle
- The material will be updated throughout the course, so make sure to **download the latest version** when available.

Textbooks

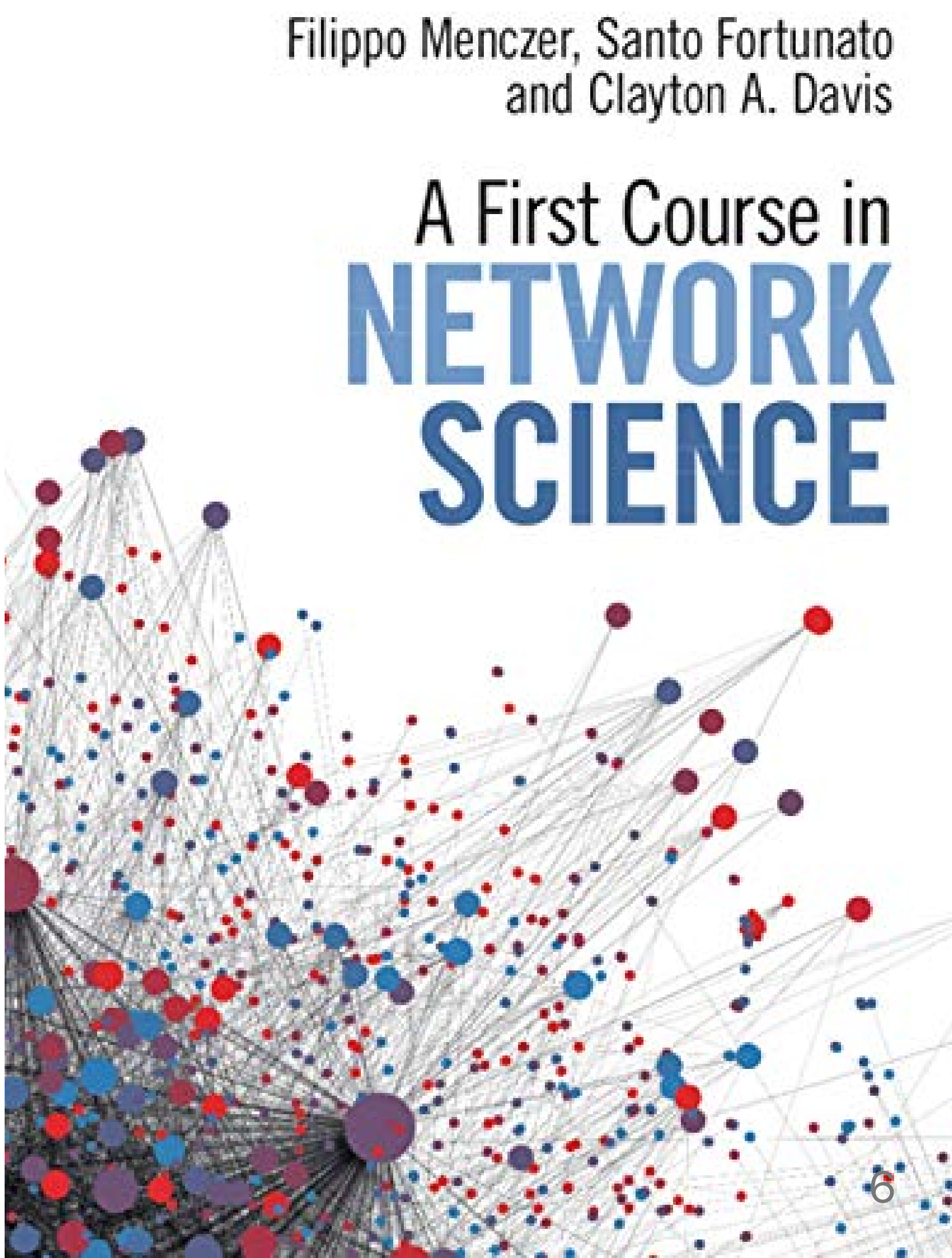
> Filippo **Menczer**, Santo **Fortunato**, Clayton A. **Davis**, *A First Course in Network Science*, Cambridge University Press, 2020

"A First course": very **basic** , but wide and updated overview

Few mathematical formalisms, some **illustrative code** (in Python)

Some copies are available in the computer science library.

We will cover **every chapter**



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

Very **multidisciplinary** !

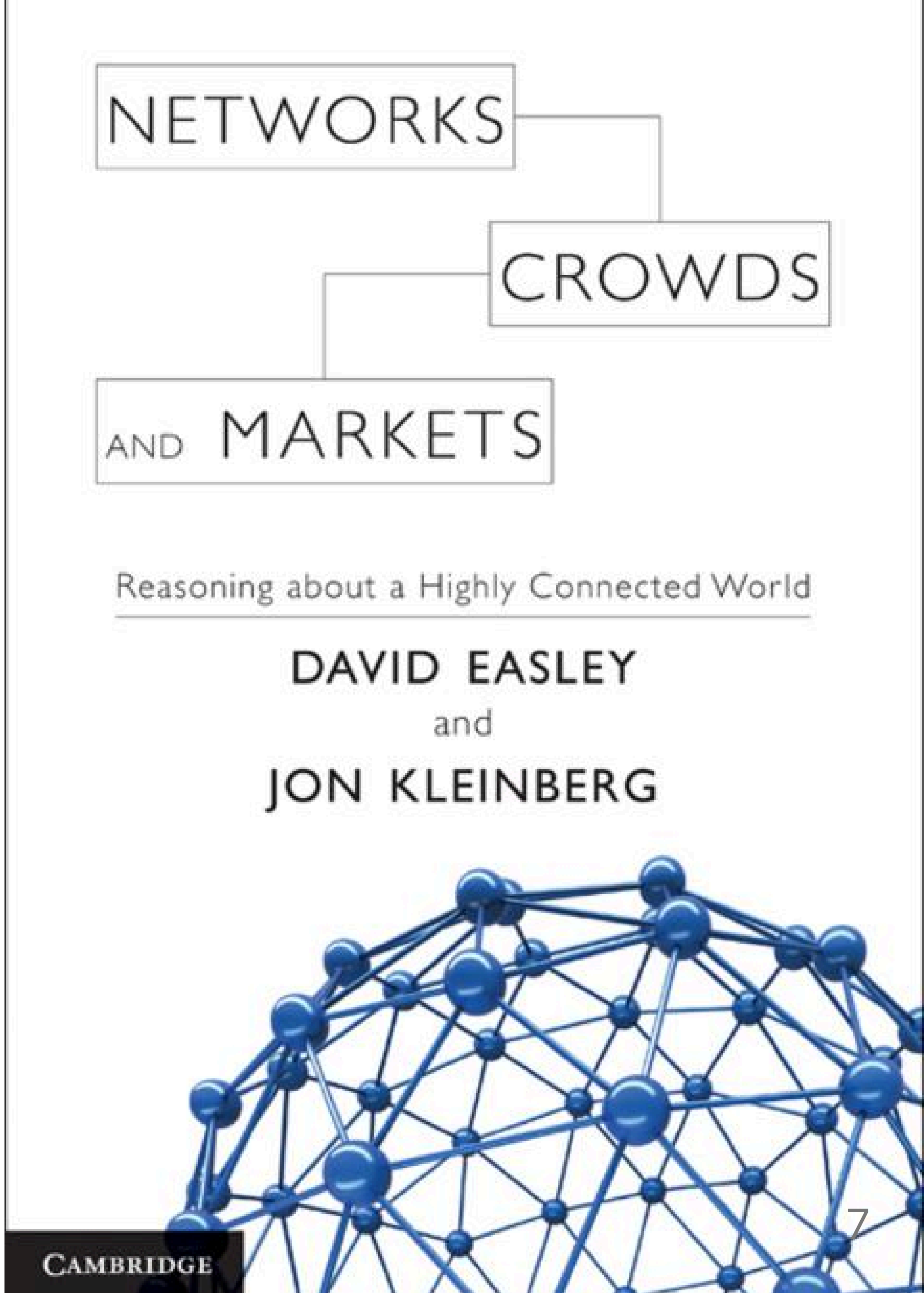
Richer overview (much beyond 'networks'); updated up to 2010

Few mathematical formalisms, **a lot of examples in many different applicative domains**, no illustrative code

Available in our libraries but also online (free pre-print)

- https://www.cs.cornell.edu/home/kleinber/networks-book/

We will cover **many chapters**



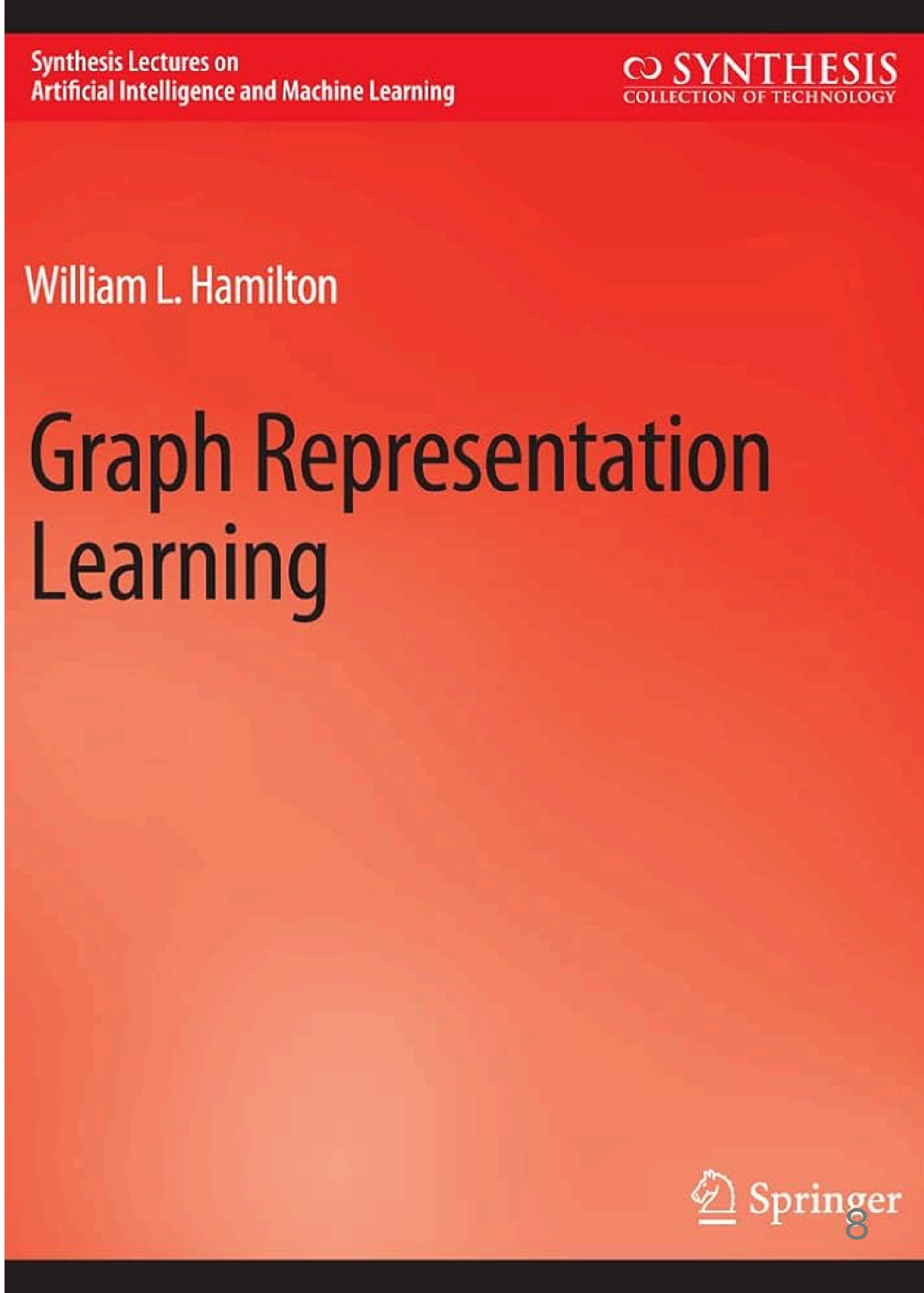
> Hamilton, William L.. Graph Representation Learning. Switzerland: Springer International Publishing, 2022.

Updated to 2020 (the research area is changing very rapidly and constantly)

We will cover **a few concepts**

There are several equivalent books and online resources that you can adopt instead

- https://www.cs.mcgill.ca/~wlh/grl_book/



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Textbooks - Optional

> Albert-László **Barabási**, *Network Science*,
> Cambridge University Press

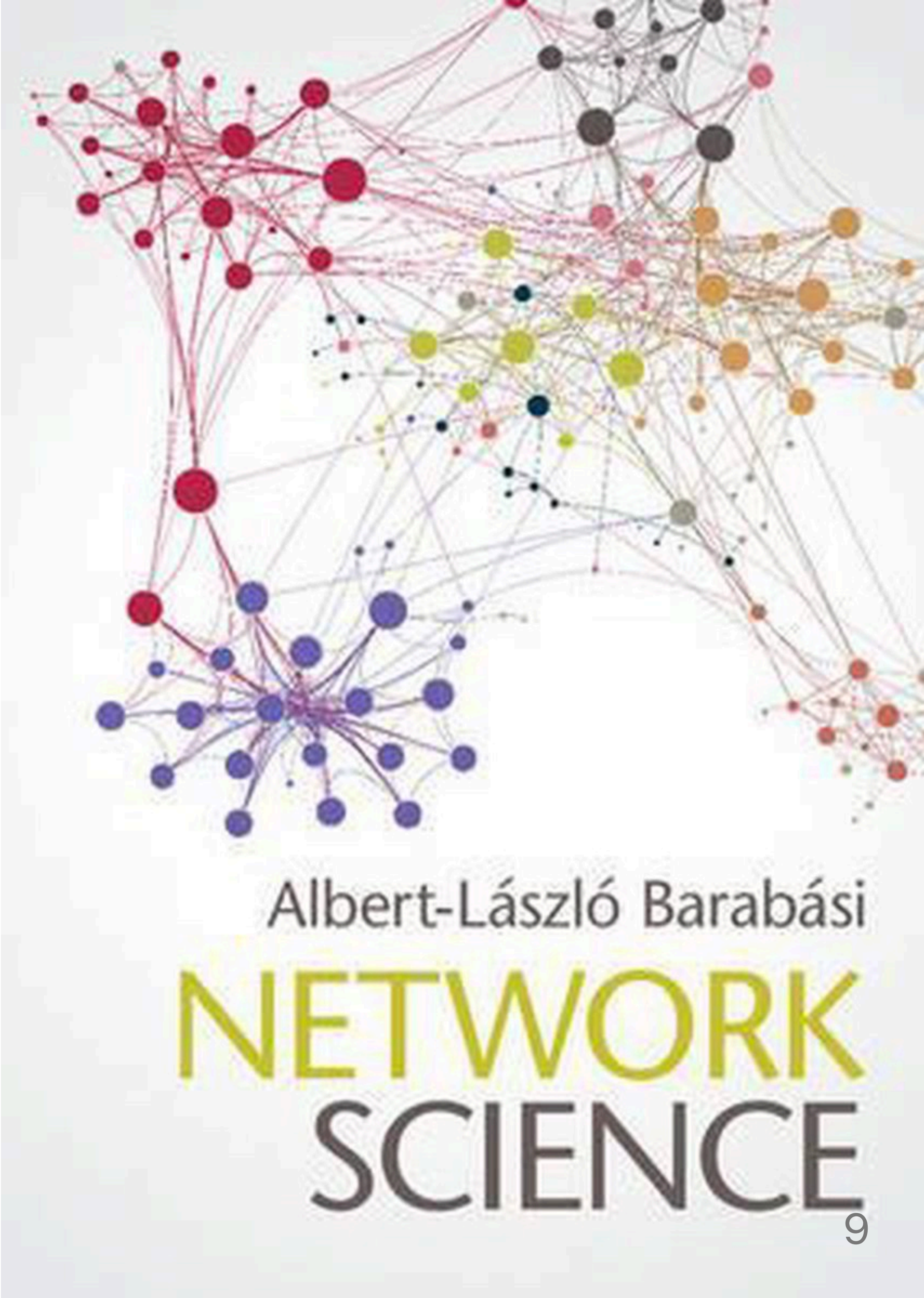
Read it if you are interested in **models** more than in data science.

Plenty of mathematical formalisms (even if simplified), many plots, some applicative examples, no illustrative code

Available in our libraries but also on-line (free!)

- http://networksciencebook.com

This is mainly **optional,** even if we may adopt some parts.



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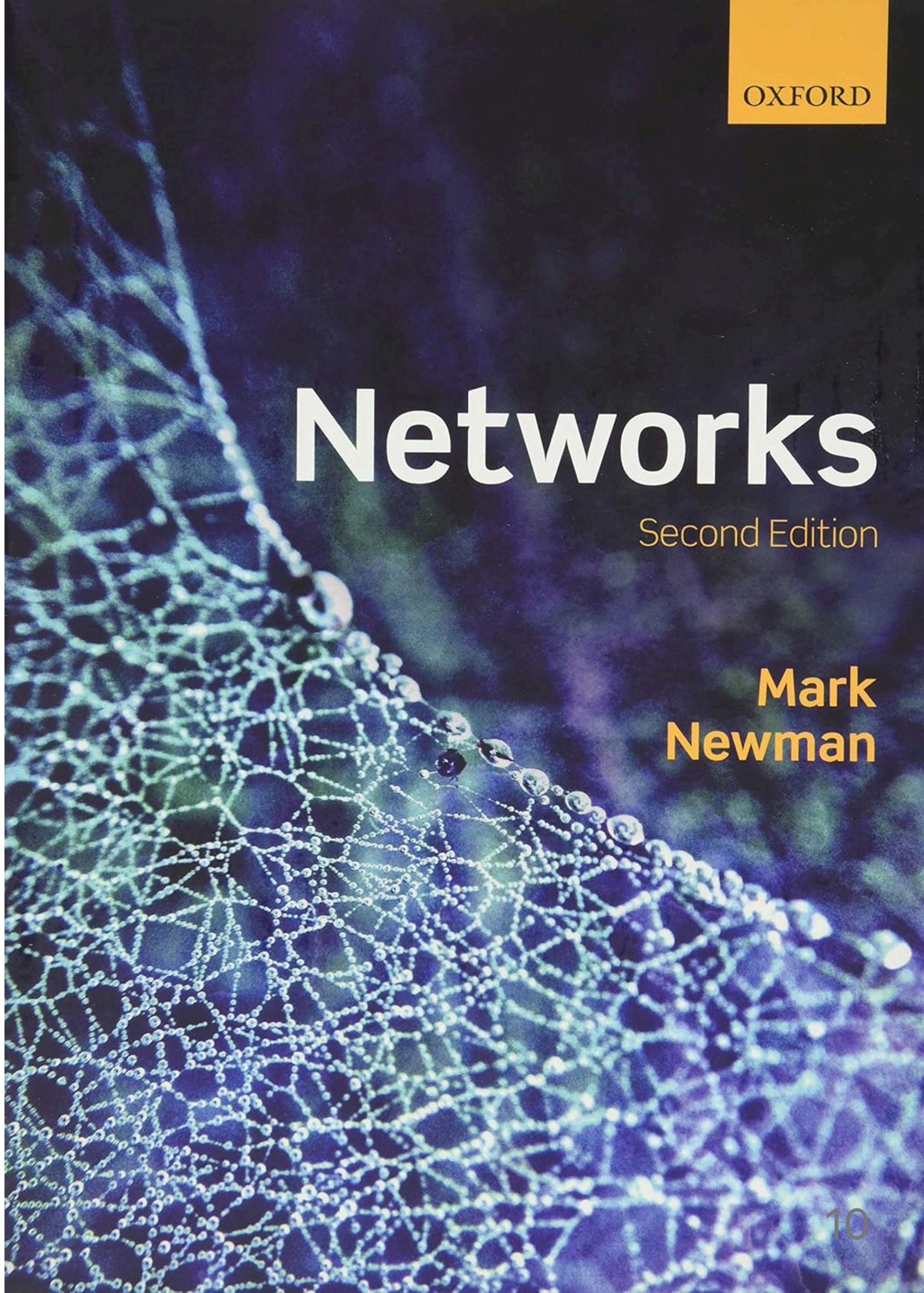
> Mark **Newman**, *Networks*, Oxford University Press

The **Bible** for network scientists: it is a must if you undergo graduate studies or have a master's degree thesis on such topics

Read it if interested to: **models**, deep understanding of **measures**, and **algorithms**

Very elegant mathematical formalisms, many examples, no illustrative code

Available in our libraries



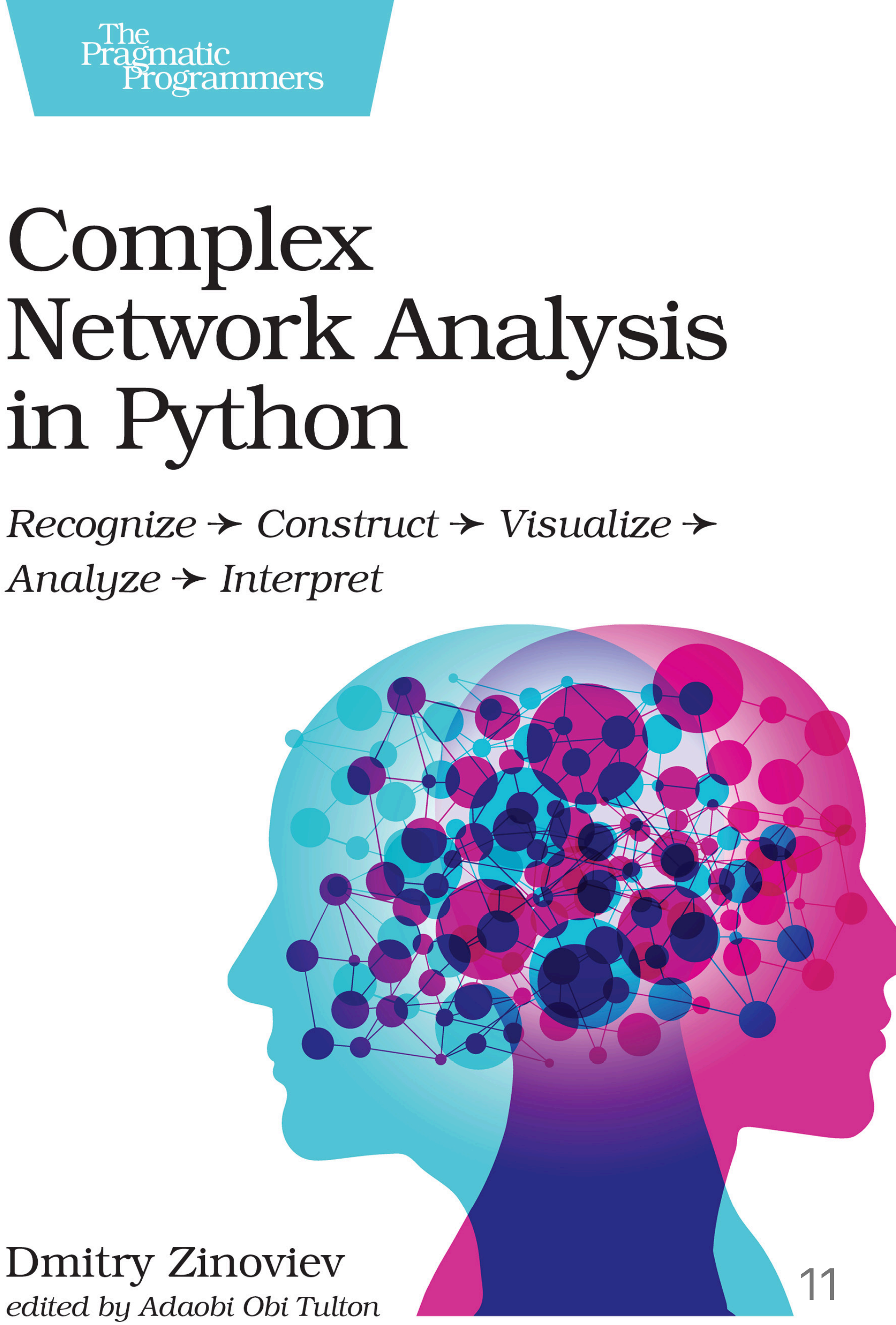
> Dmitry **Zinoviev** , *Complex Network Analysis in Python, Recognize → Construct → Visualize → Analyze → Interpret* , The Pragmatic Bookshelf

Read it if interested to: **practical data science**, **network analysis**;

Very **practical:** not much space for ideas, concepts, and limitations behind network measures

Many illustrative examples, A LOT of illustrative code (Python) with many different datasets

Available in our libraries



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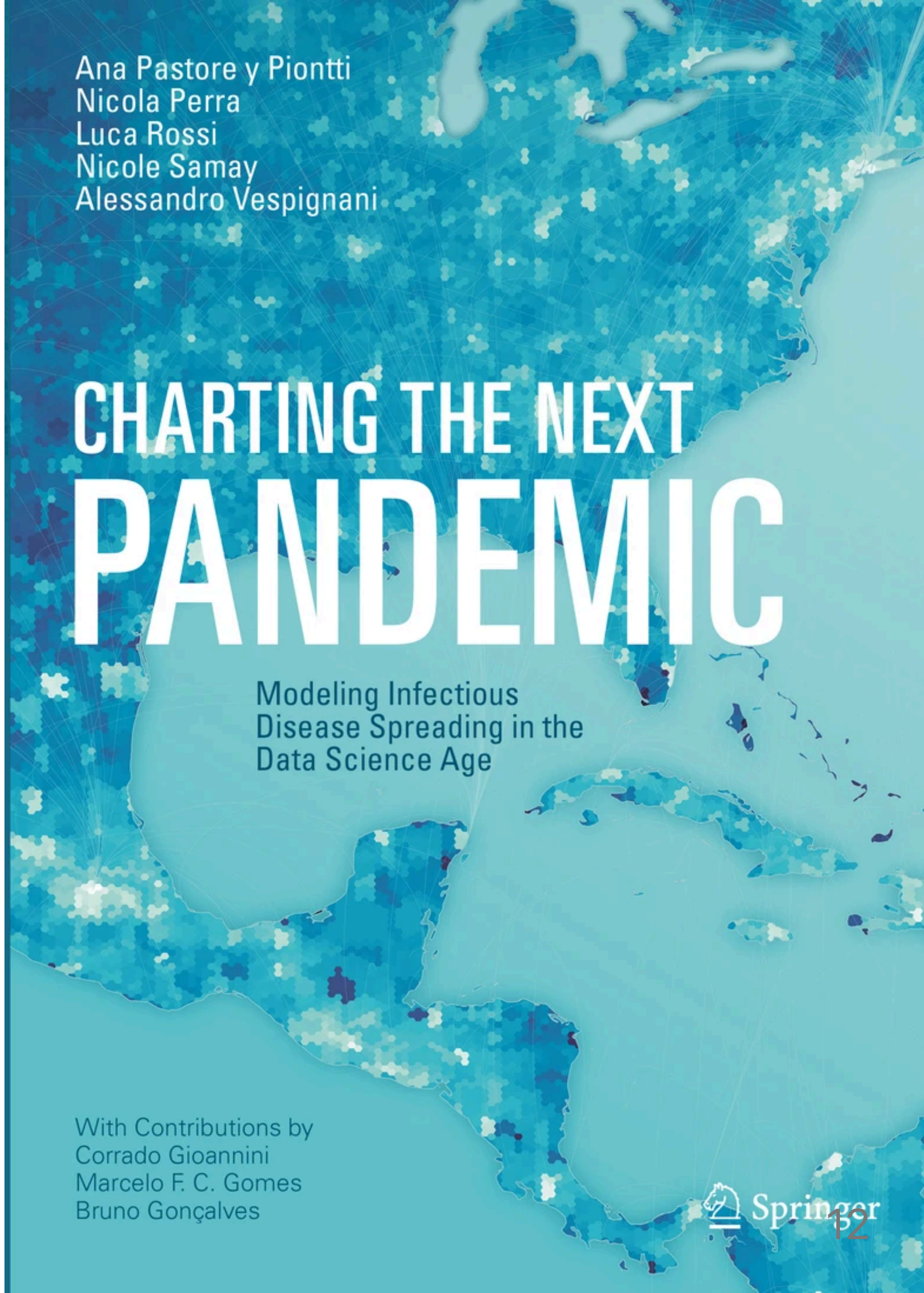
> **Pastore y Piontti** , A., **Perra** , N., **Rossi** , L., **Samay** , N., **Vespignani** , A., Charting the Next Pandemic: Modeling Infectious Disease Spreading in the Data Science Age, Springer, 2019

Read it if interested in: **dynamical processes in networks**, **epidemics**, **visualization**, **data science**;

Focused on how to model infectious diseases in networks

Many illustrative examples, a lot of plots, and a great link between ideas and reality

This is mainly **optional,** BUT we will use part of it for our dataviz module and when introducing epidemics.



Exam

- **Network Science**:
  - Report: network analysis with real data and interpretation of the results
    - E.g., in the form of a commented Jupyter Notebook
  - Oral Examination
- **Data Visualization**:
  - Project: design and implementation of a data visualization platform to explore some real dataset(s)
    - It could take different forms: e.g., a d3.js project, a Jupyter Notebook using Python visualization libraries
- **Active class participation**:
  - up to +10%
  - You can get the maximum evaluation even if you do not attend classes actively. However, students who participate in Q&A sessions will be more likely to get some extra points.

Network Science Module (NetSci): Description and Objectives

- **Networks are pervasive in our lives,** influencing friendships, communication, computer systems, the Web, transportation, brain function, protein interactions, and much more.
- This module introduces the fundamental concepts, principles, and methods of network science, with a focus on exploratory analysis and modeling, particularly in the context of the World Wide Web and online social media.
- Key topics include network graph structures, mathematical models, common network topologies, large-scale graph structures, community structures, epidemic spreading, PageRank and centrality measures, dynamic processes, and graph visualization.
- Students will learn to apply network science principles to perform Complex Network Analysis (CNA) on real data using Python and libraries such as NetworkX, as well as advanced graph visualization tools.

DataViz description and objectives

- **Visualizations are extremely powerful** ("a picture is worth a thousand words")
- However, not all the visualizations are designed or implemented correctly, and sometimes they misrepresent underlying data.
- Students will learn basic visualization design and evaluation principles and how to acquire, parse, analyze, and visualize large datasets.
- Students will learn techniques for visualizing multivariate, temporal, text-based, geospatial, hierarchical, and network/graph-based data.
- Students will utilize Gephi, D3.js, Python, matplotlib, and many other tools to prototype these techniques on existing datasets.

Introduction to Networks

Reading material

[ns1] **Chapter 0**

[ns2] **Chapter 1**

Complex Systems (1)

- **Complex** != Complicated
- Composed by many **interacting elements**
  - Consider a flock of birds. Each bird interacts with its neighbors, adjusting its speed and direction to stay close to the group.
  - The flock's overall movement is not dictated by a central controller but emerges from these local interactions.
- They give rise to emergent **collective phenomena**
  - Think about the human brain. Billions of neurons interact, and from these interactions, consciousness emerges.
  - Consciousness is not a property of individual neurons but a collective phenomenon.
- **Emergence**: not directly related to individual phenomena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Complex Systems (2)

- Linearity vs **non linearity**
  - A simple linear system: the more you push a swing, the higher it goes.
  - A non-linear system: the stock market. Small changes can lead to disproportionately large effects (crashes, bubbles).
- **Heterogeneous** vs homogeneous
  - A hypothetical social network where everyone has approximately the same number of friends.
  - The real Internet, where some websites (e.g., Google, Facebook) have billions of links, while most small websites have very few.

An example of emergent synchronization

Watch this: https://www.youtube.com/watch?v=5v5eBf2KwF8

Networks are Everywhere

- **Social Networks**:
    - Friendships: connections between individuals based on mutual affection.
    - Co-workers: professional relationships in a workplace.
    - Family ties: bonds between relatives.
    - Political affiliations: connections based on shared political beliefs.
    - Sports teams: connections between individuals playing the same sport.
- **Information Systems**:
    - Web pages (links): URLs connected by hyperlinks
        - Citations between documents: academic papers referencing each other
- **Economic Systems**:
    - Financial transactions: tracking the flow of money
        - Supply chains: networks connecting production and distribution

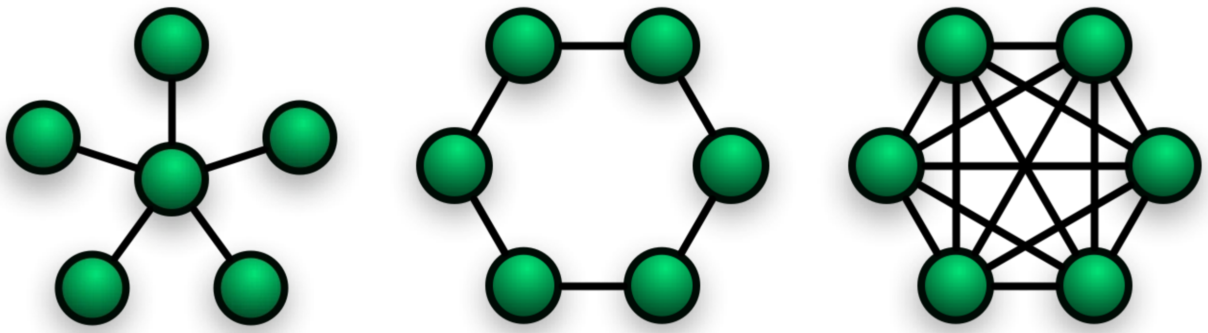
- **Infrastructure Networks**:
  - Power grids: networks that deliver electricity
  - Transportation networks: networks for moving people and goods
- **Biological Systems**:
  - Protein interactions: how proteins interact in a cell.
  - Neural networks: connections between neurons in the brain.
  - Food webs: who eats whom in an ecosystem.

... and many more!

Aspects of Networks: Structure

Summary **representation** of a complex system

Simple networks: A few characteristics describe the network



We need a **language** and a **framework** to describe complex networks.

Example: Zachary's Karate Club

It represents friendships between members of a karate club.

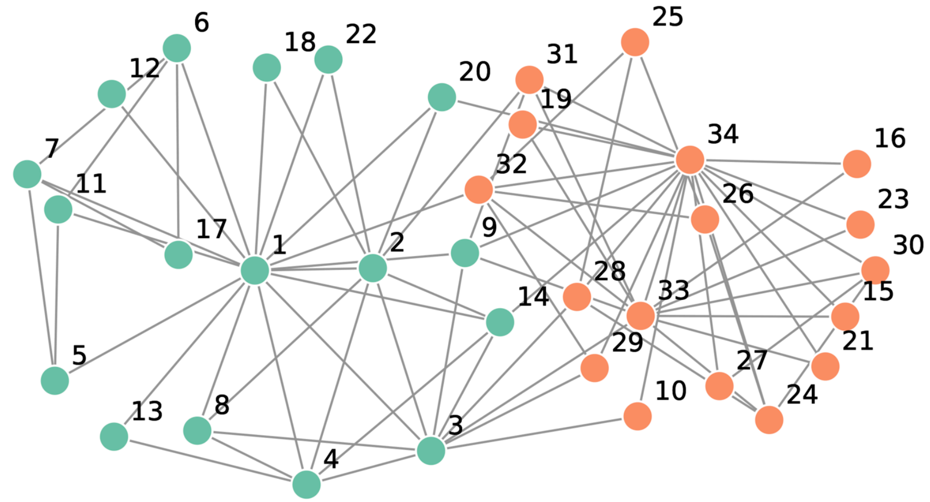
The network helps us understand the club's structure and dynamics.

No simple description is possible just by looking at it.

However, there are some **regularities**.

Some individuals are more **central** than others (they have more connections).

Does it resemble some **randomness**, or are there patterns?



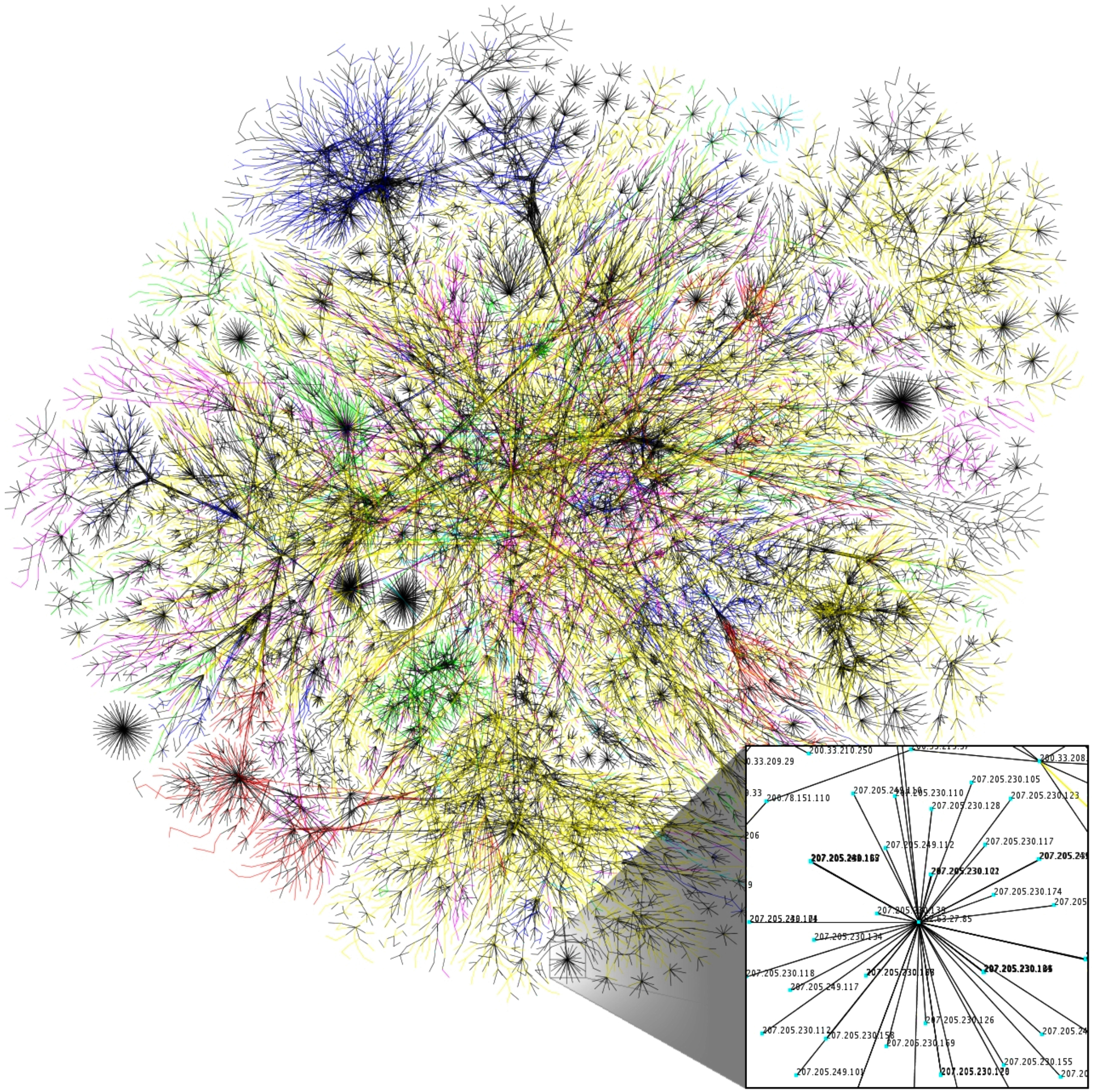
Example: the Internet

Some **order** emerges from chaos.

Core vs. periphery structure.

Other networks can show **hierarchical** structures.

We need a **language** to describe such regularities.



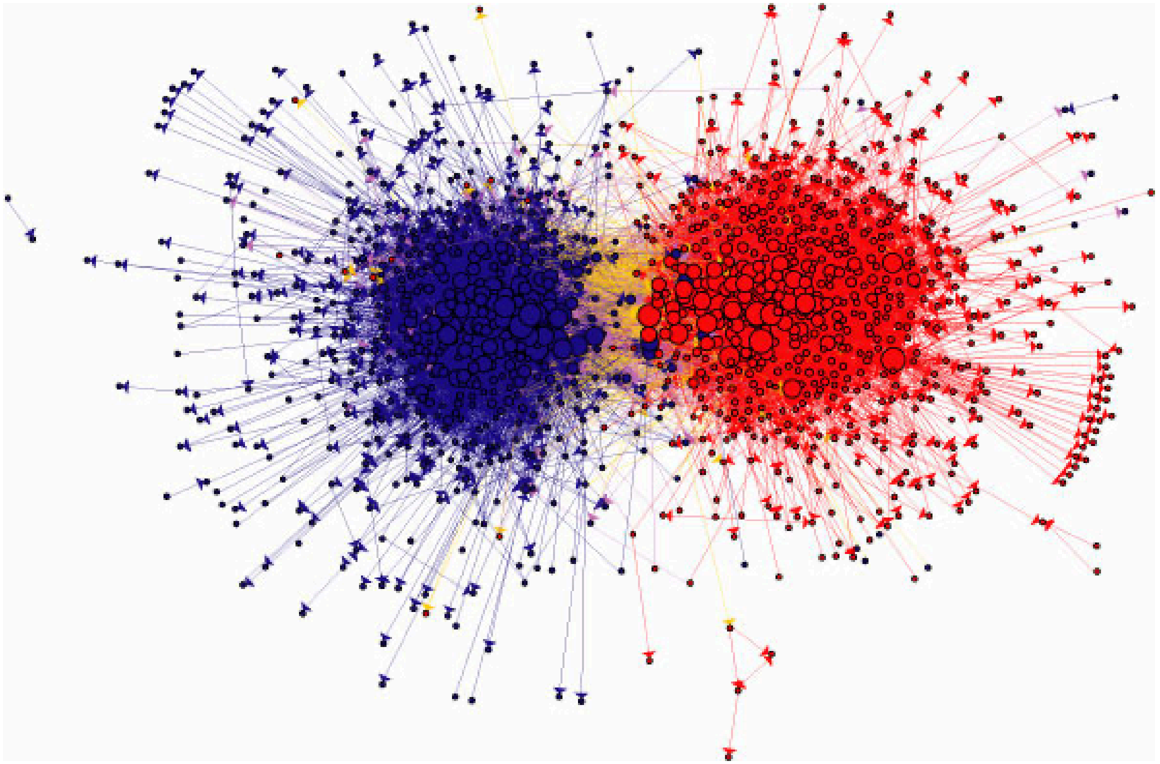
Example: retweet networks

communities or clusters (**partition**)

echo chambers

homophily : tendency of individuals to link with similar ones

warning: no trivial linear relationships but **interplay**



Visualization is not enough

- Visualizing a network suggests some **inherent** complexity
- this says a lot about the **structure** , but almost nothing about the **reasons**
- It is difficult to summarize succinctly the whole network
  - core vs periphery structure
  - hierarchical structure
  - tightly-linked regions
  - ...
- we need a **language** !

Aspects of Networks: Behavior and Dynamics

- Connectedness
  - structure
  - behavior
- each **individual's actions have consequences** for the outcomes of everyone in the system
- we need a **framework for reasoning** about behavior and interactions in networks
- we need to take into account a **rational behavior** that sometimes lead to **strategies**
- actions are not evaluated at individual level (in isolation), but at a **network level**

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From data to networks

We have **massive network datasets** available today, offering unprecedented opportunities for analysis and modeling.

However, data-driven models, while powerful for making predictions, can sometimes struggle with generalization. This is because networks can be fundamentally **different** in their structure, dynamics, and the underlying processes that shape them.

Therefore, it's crucial to understand the limitations of relying solely on data and to consider the theoretical underpinnings of network science when interpreting results and making predictions.

Individual vs Population level

- when a large group of people is tightly interconnected, they often respond in complex ways that can be observable only at the **population level**:
    - rich get richer
    - winner takes it all
    - viral ideas
    - ...
- At **individual level** : sometimes an information goes viral or one person becomes very popular, some other times this does not happen!
    - **Why**? no prediction at this level yet

Main topics: Graph Theory

paths/distances

clustering coefficient

degree and degree distribution

centralities

groups/clusters/partitions/communities

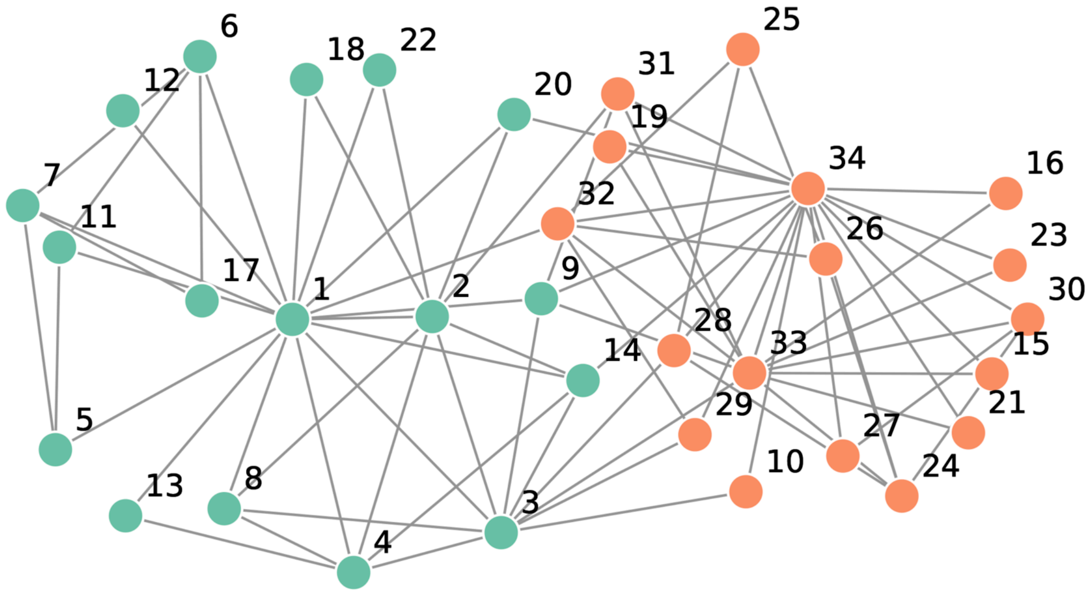
structural balance

homophily and spatial segregation

Main topics: Individuals vs groups

We can find clues to the latent schism that eventually split the group into two separate clubs.

We can have different roles.



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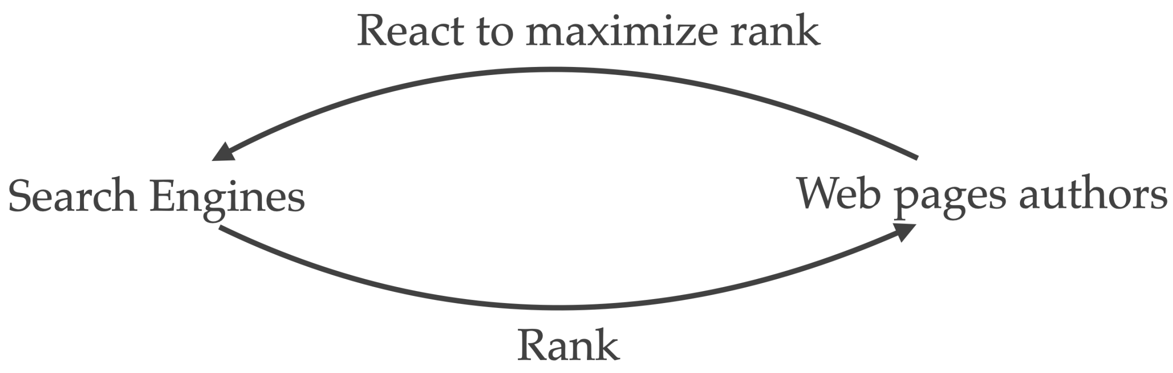
Main topics: Game Theory

- a framework where our decisions depend on others' decisions
- **strategy** -> **pay-off**
- ex. in transportation networks, choice of a route can bring to **congestion** (Braess' Paradox)
- **Equilibrium** : a state that is self-reinforcing.
    - no individual has an incentive to unilaterally change their strategy, even if those individuals know how others will behave

Main topics: Information Networks

E.g.: the Web



Interplay: if you define a measure (e.g., PageRank), the application of such measure may change the system

Main topics: Network dynamics: population effects

In large populations we have the emergence of new ideas, beliefs, opions, innovations, technologies, products, and social conventions

When and how are they established as **social practices**?

Individuals can **influence** or be influenced by others.

At the surface, humans tend to **conform**

Why ?

Main topics: Networks Dynamics: Structural Effects

- Populations vs local behaviors
- Individuals may have an incentive to adopt the behavior of their neighbors: **cascading behavior**
    - social contagion
    - epidemics
- The structure of the network has a role

Main topics: Social contagion

- Influence: the adoption of a new product or innovation can cascade through the network structure
- ex.: e-mail recommendations for a Japanese graphic novel
- We have:
  - spreaders
  - closed communities that can stop the contagion

Main topics: Epidemics

Epidemic disease is another form of cascading behavior in a network.

ex.: tuberculosis outbreak

Network-level dynamics are similar, and insights from the study of biological epidemics are also helpful in thinking about the process by which things spread in other networks (e.g., rumors and fake news)

Tools and Software

Network Analysis software

- Python 3 + Project Jupyter/JupyterLab
  - Alternatively: R
  - The use of the R ecosystem is out of the scope of this course; however, you can replicate all the practical sessions with alternative computational frameworks
- Students can pick the platform of their preference:
  - local distribution: Anaconda or base Python + pip
  - cloud distributions (many free): e.g., Google Colab, Binder Kaggle Kernels, Azure Notebooks,Datalore
- **networkX**
  - Even if there are other very valid alternative packages, e.g., igraph, graph-tool, this course will provide solutions to the practical sessions using networkX.

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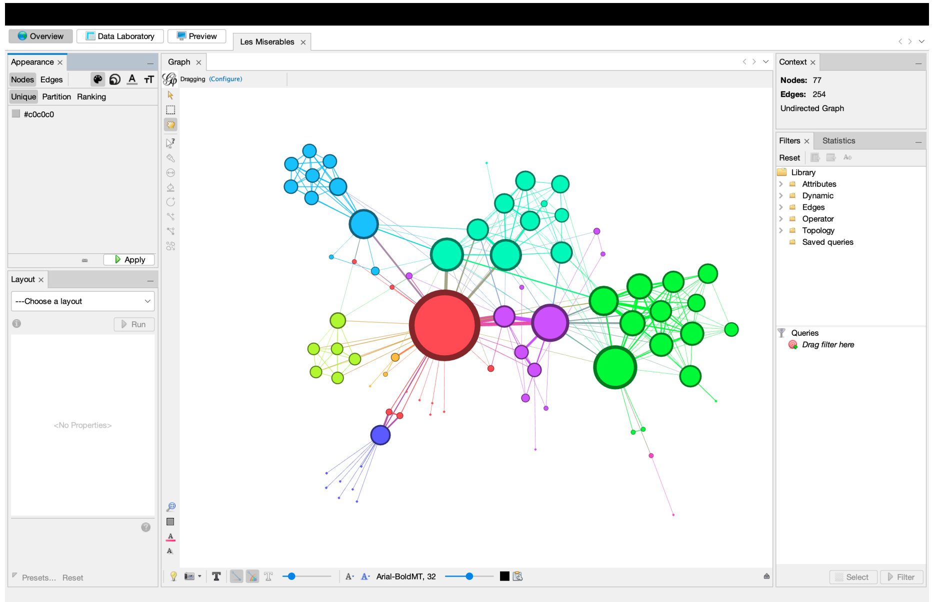
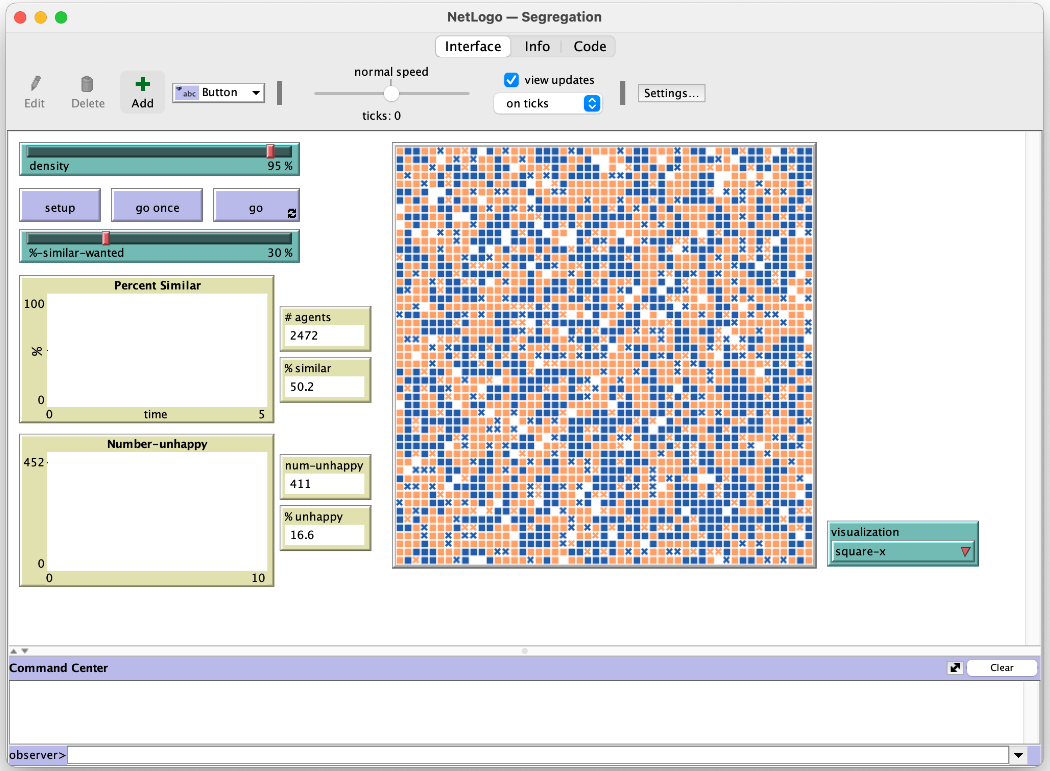
Other software and tools

- Gephi
  - Tutorials and learning resources



- NetLogo
  - Beginner's guide



Q&A