Networks: Introduction

Introduction to Network Science

Instructor: Michele Starnini — https://github.com/chatox/networks-science-course

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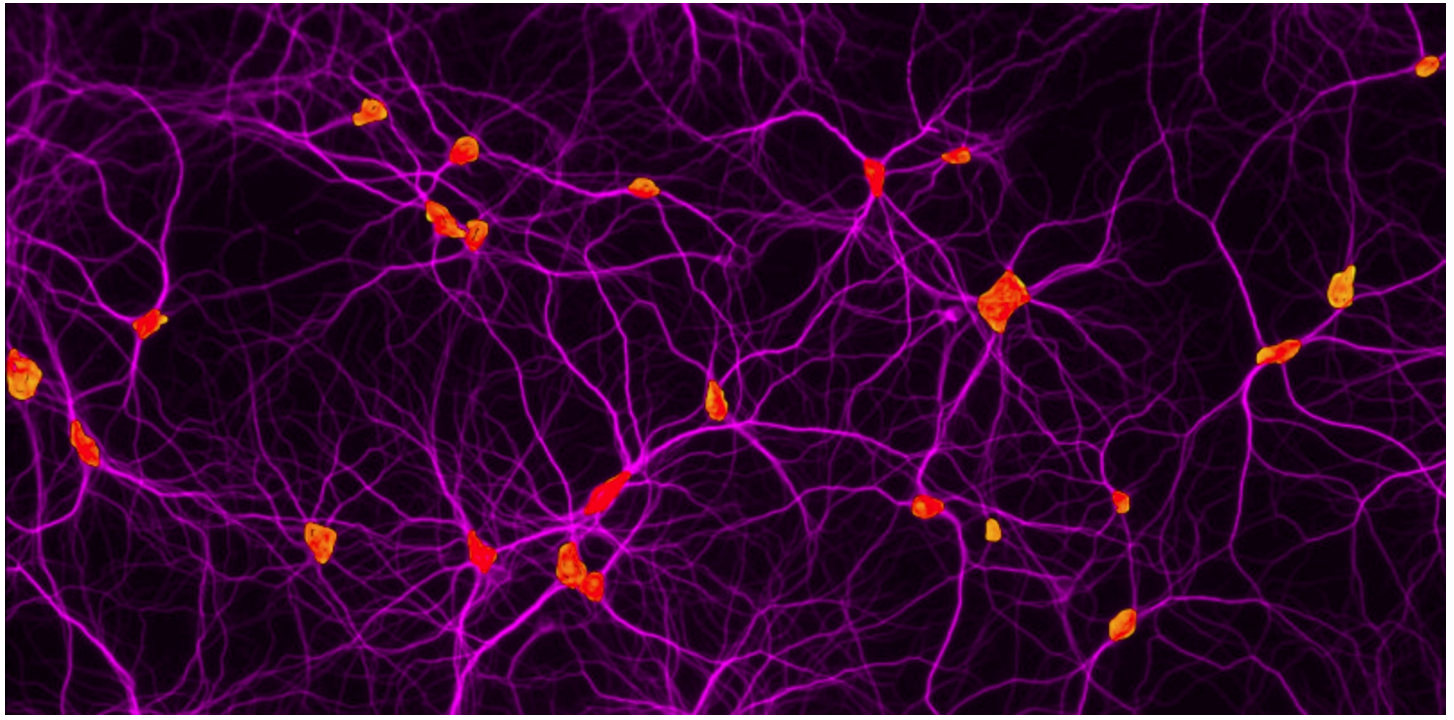
Introductory video (00:00-01:20) by Albert-László Barabási,

https://www.youtube.com/watch?v=RfgjHoVCZwU

What is networks science?

- **Network science** studies **complex networks**:
  - Complex: **Non-trivial** structure and properties
  - Examples: social, telecommunication, computer, biological, cognitive, semantic (...) networks
- A network is an interconnected object with:
  - elements or actors represented by **nodes**
  - connections between them represented as **links**

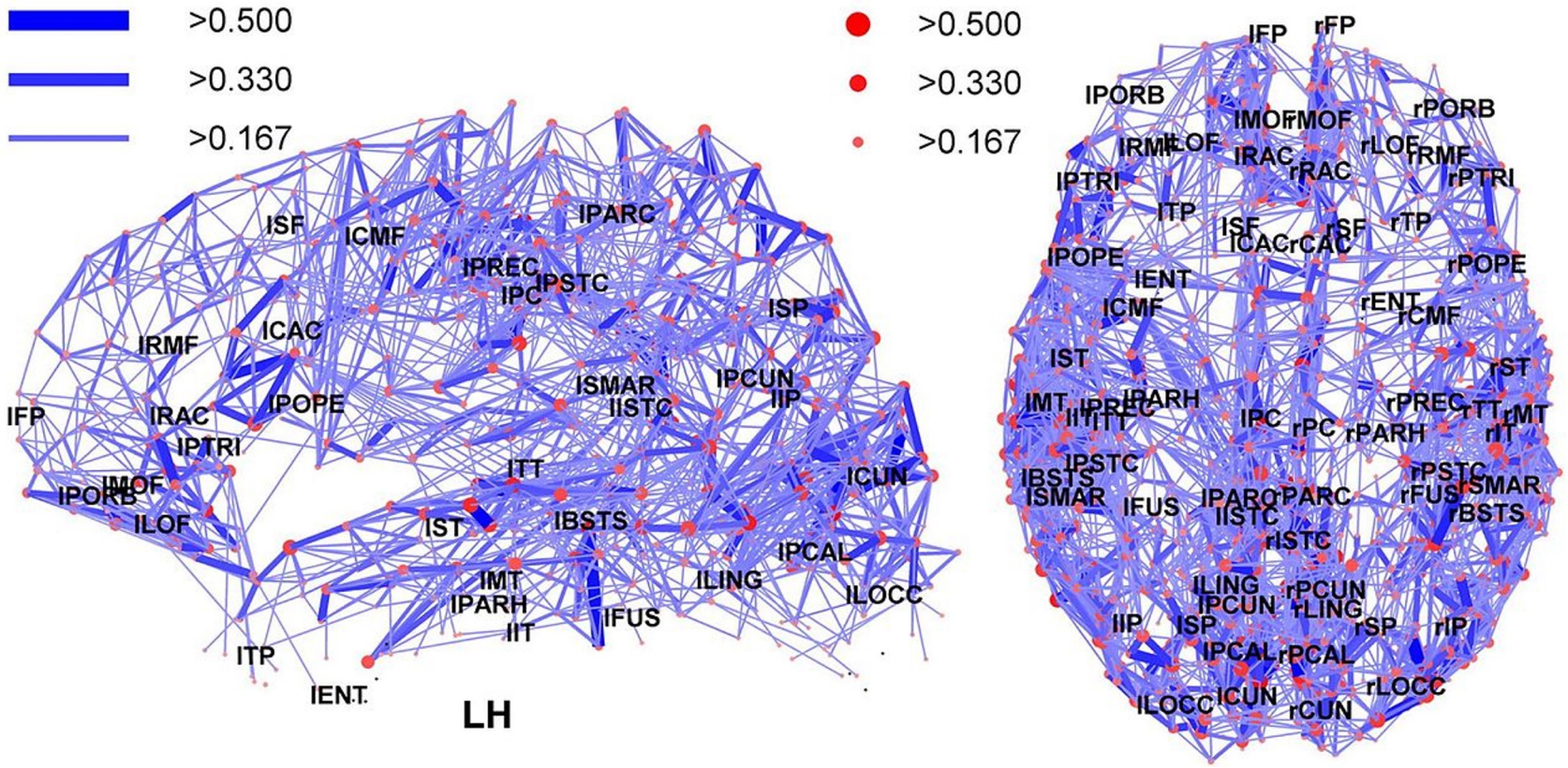
Human brain: $N \simeq 90 \times 10^9$



https://health.uconn.edu/cell-analysis-modeling/microscopy-facility-2/

https://dx.doi.org/10.1371%2Fjournal.pone.0004006

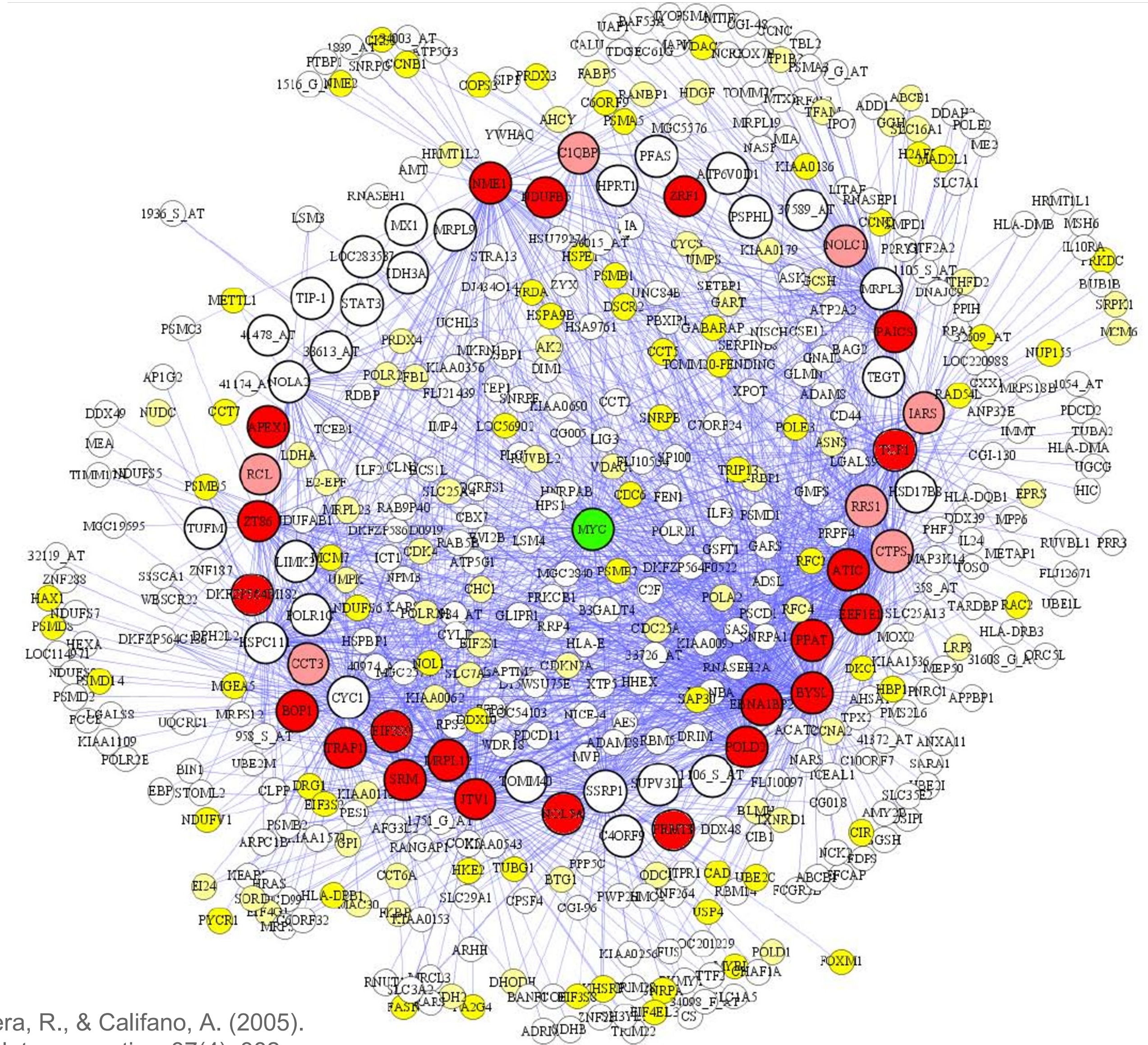
Regions in the human brain



https://en.m.wikipedia.org/wiki/File:Network_representation_of_brain_connectivity.JPG

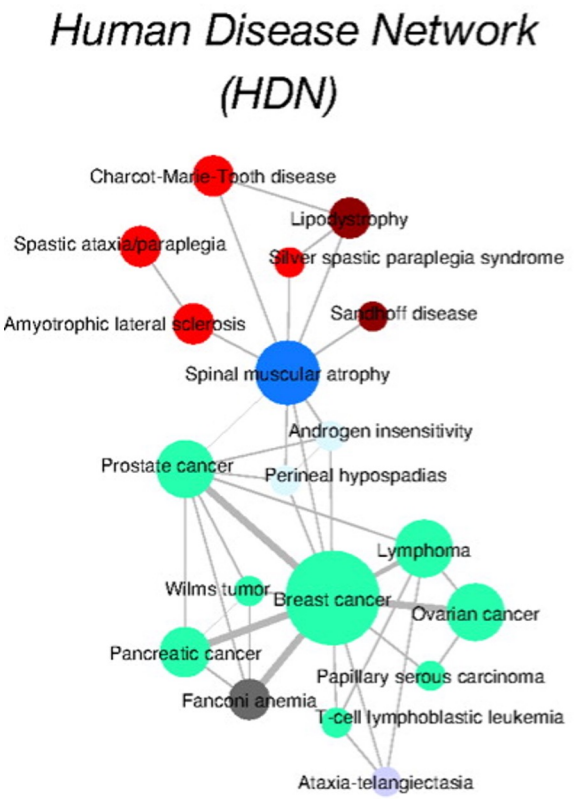
Genes

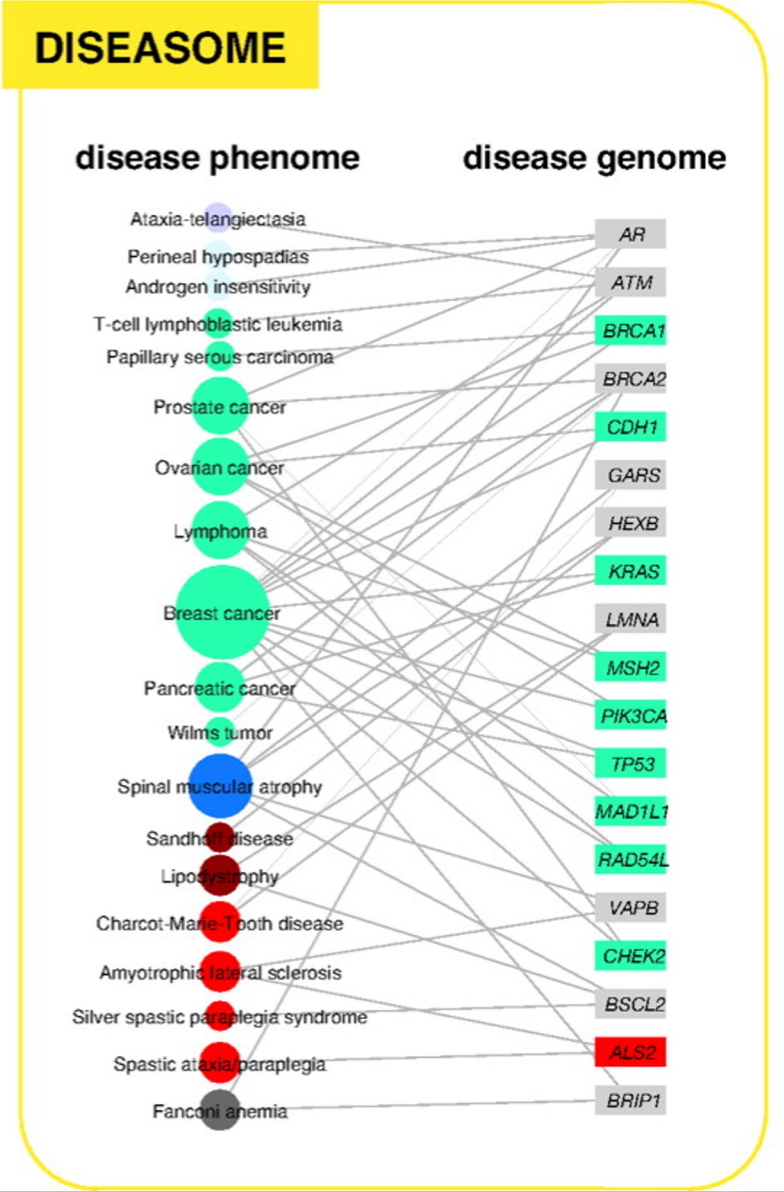
N=500 in this plot



Basso, K., Margolin, A. A., Stolovitzky, G., Klein, U., Dalla-Favera, R., & Califano, A. (2005). Reverse engineering of regulatory networks in human B cells. Nature genetics, 37(4), 382.

Human disease network

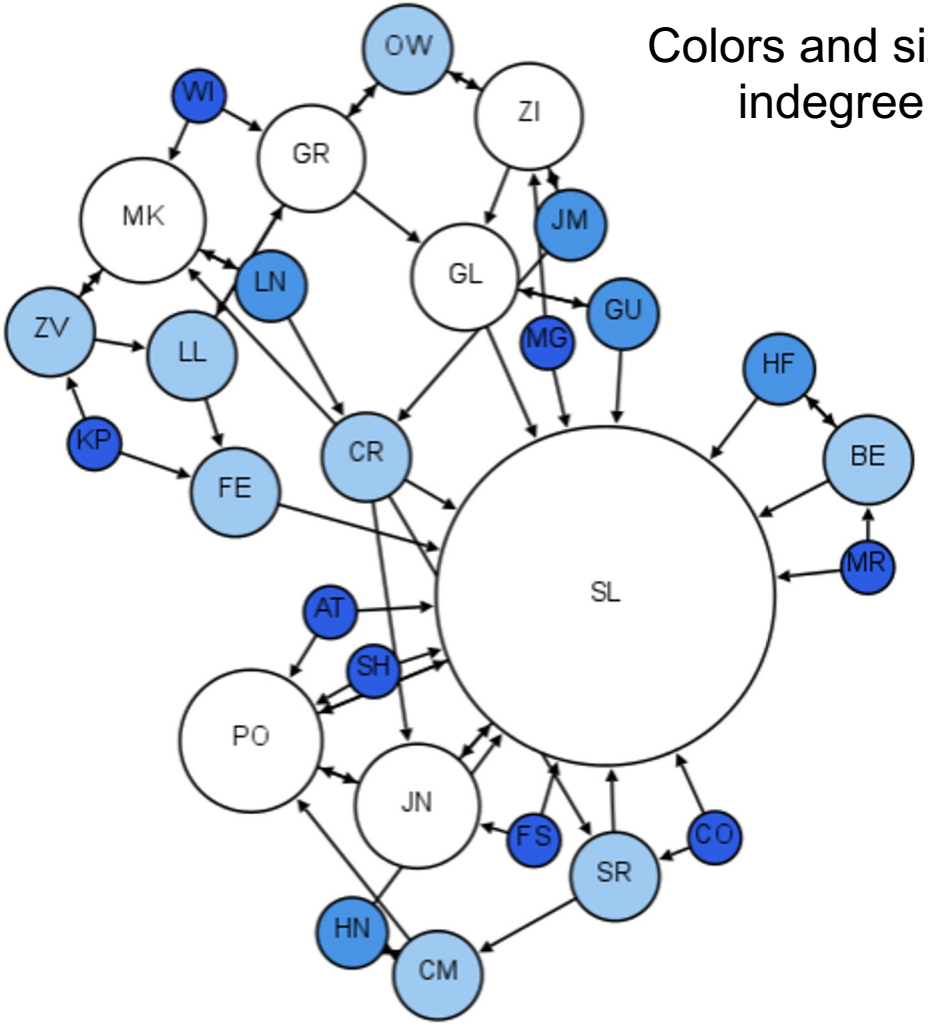




http://www.pnas.org/content/104/21/8685

Moreno's sociograms

- Early 1930s
- Children in 2nd grade
- Who would you like to sit with?

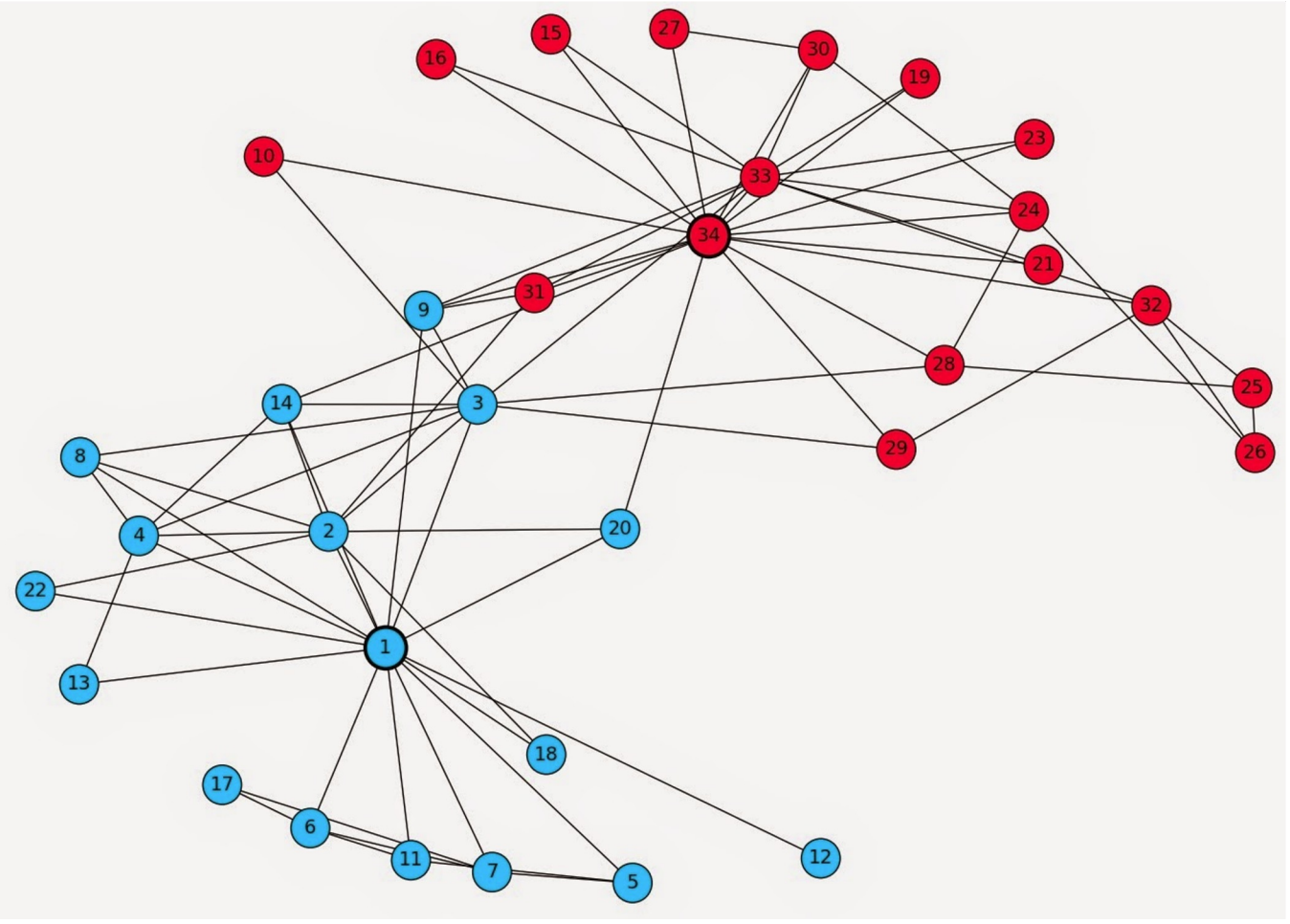


Colors and sizes: indegree

http://www.martingrandjean.ch/social-network-analysis-visualization-morenos-sociograms-revisited/

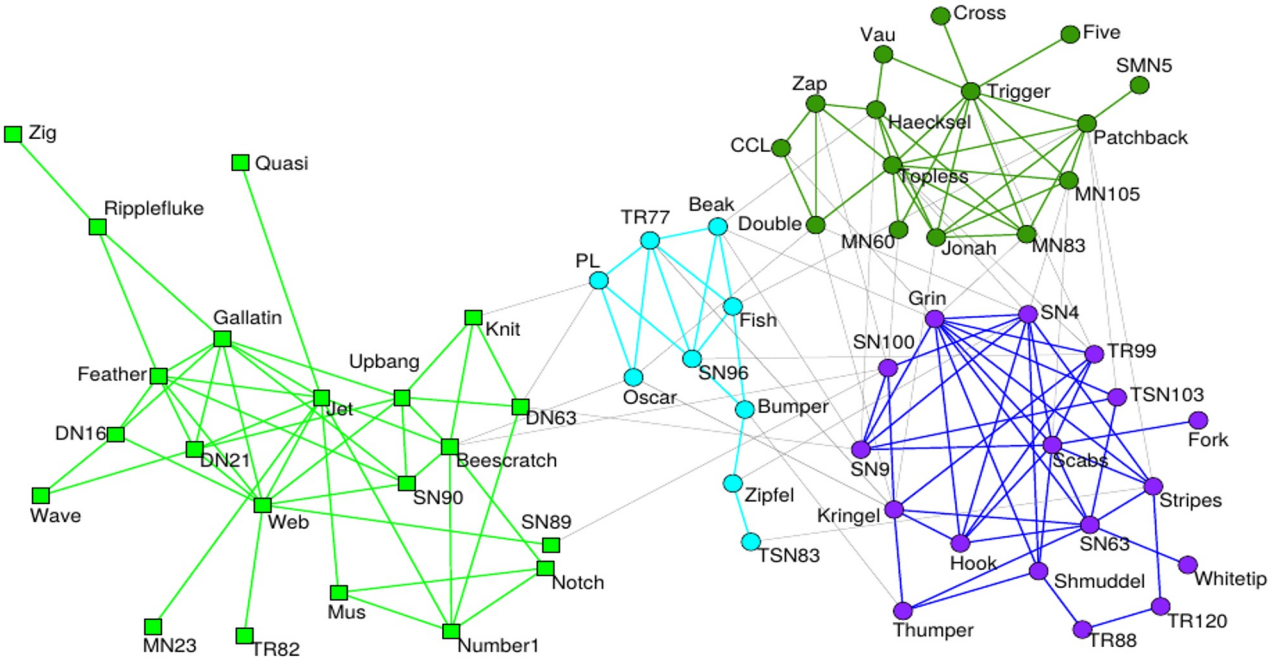
Zachary's Karate Club

Karate club that split into two clubs (led by 1 and 34)



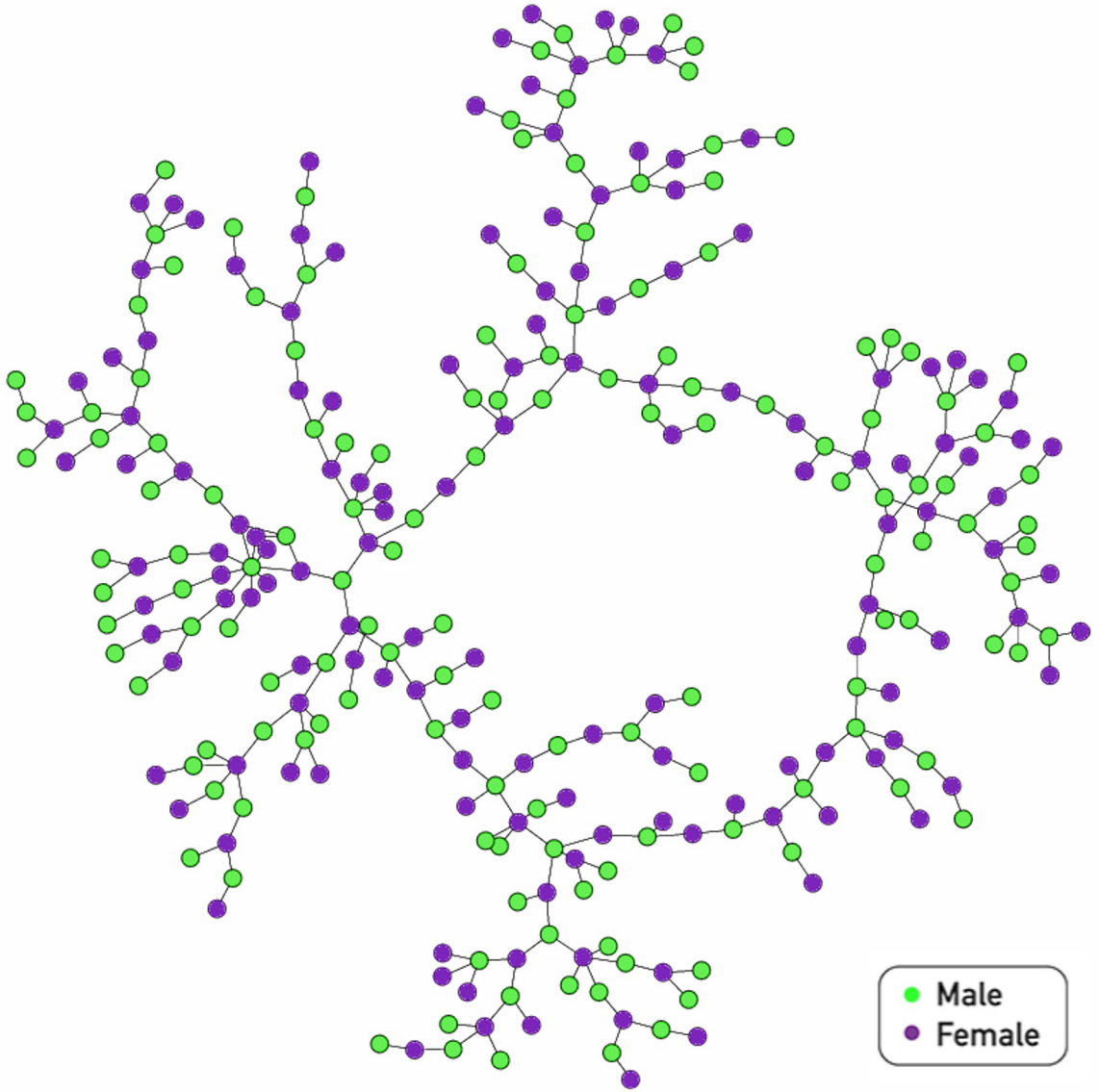
Dolphins in a fjord in New Zealand

- Research following a school of dolphins in the wild (2003)
- Look for dolphins swimming together
- Found **long-lasting associations;** research has been repeated with other non-human animals (e.g., sheep)



https://doi.org/10.1007/s00265-003-0651-y

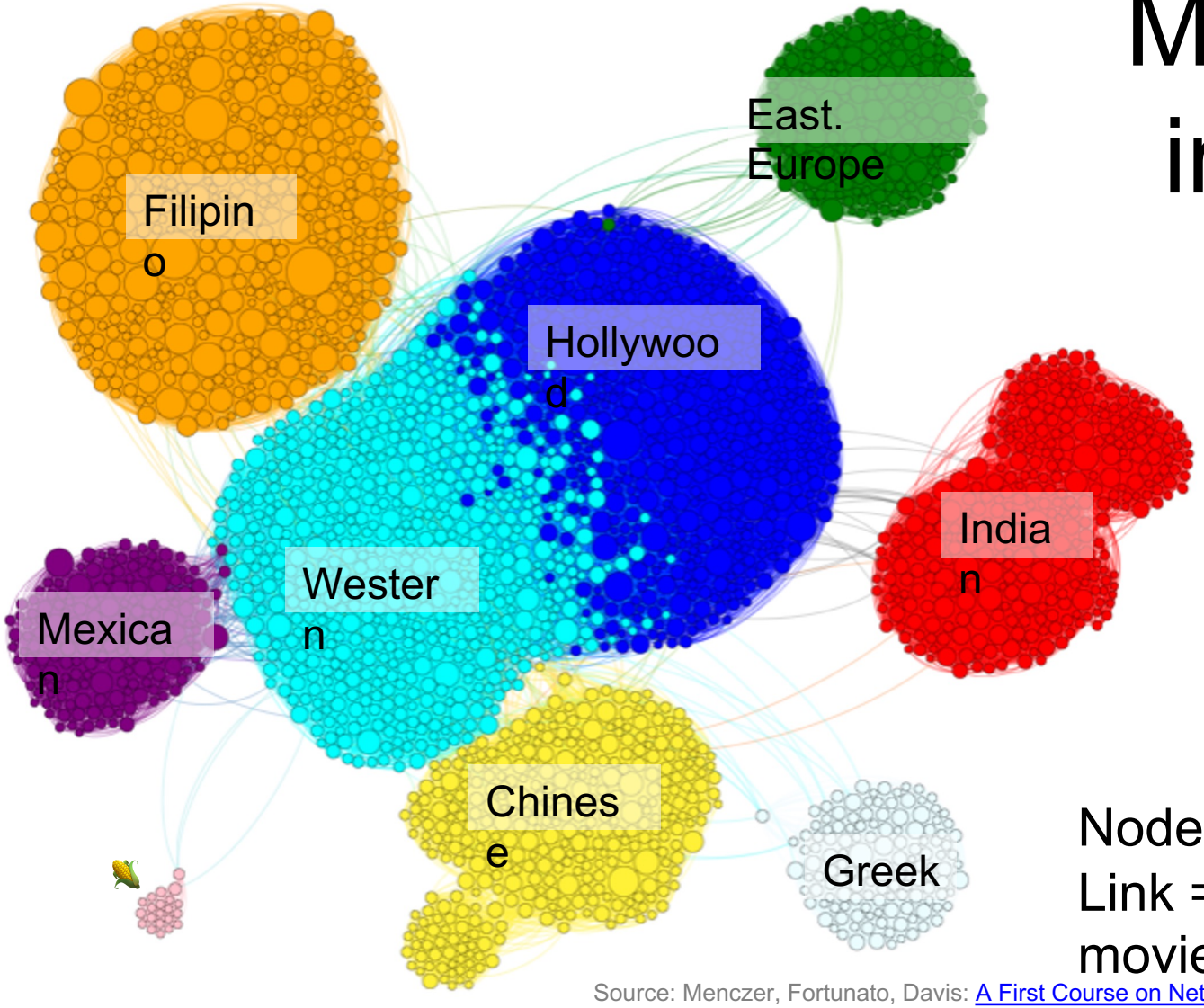
Chains of affection



- Early 2000s
- Adolescents in high school
- A "*special romantic relationship*" or a "*nonromantic sexual relationship*" in the past 18 months

Bearman, P. S., Moody, J., & Stovel, K. (2004). Chains of affection: The structure of adolescent romantic and sexual networks. American journal of sociology, 110(1), 44-91.

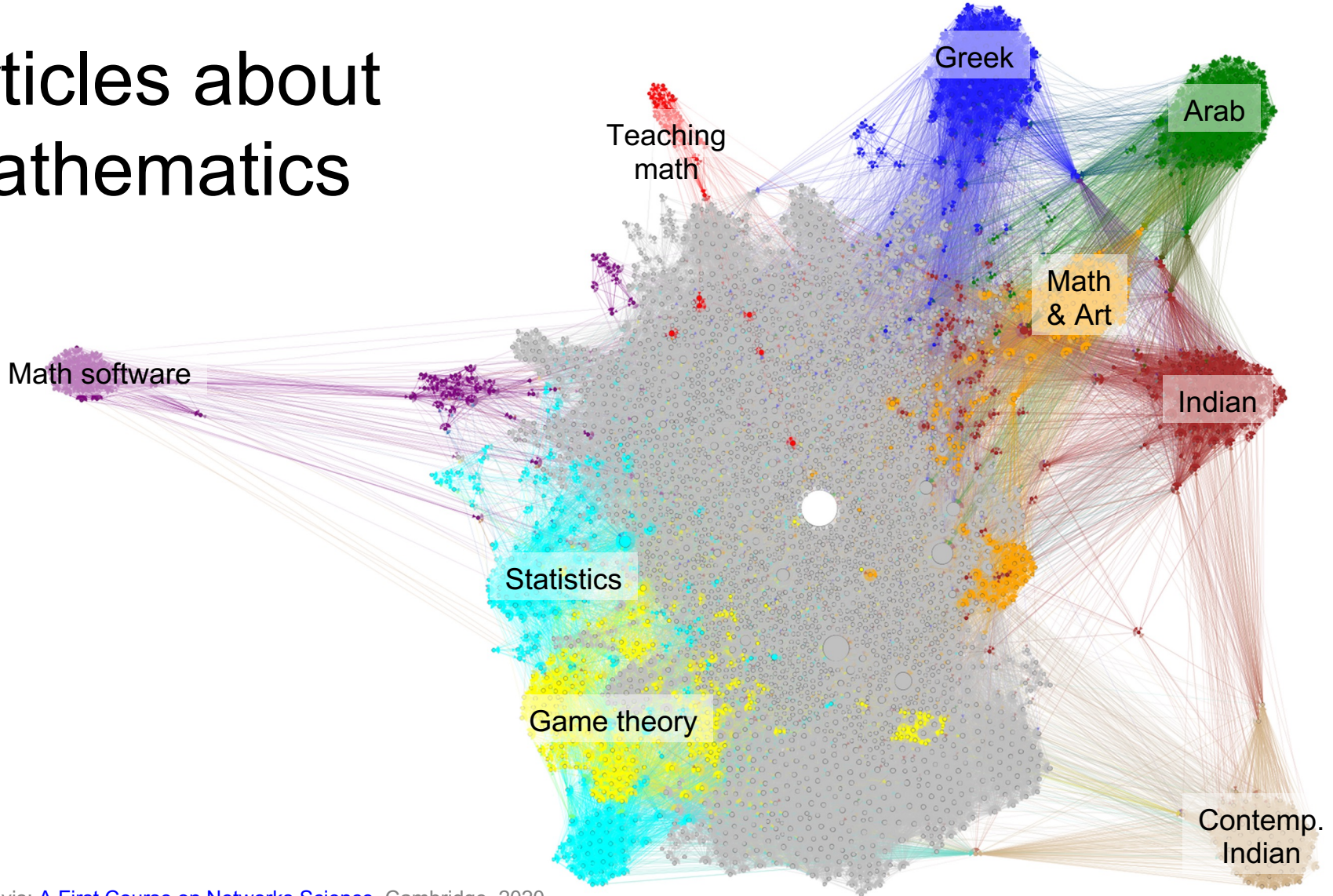
Movie stars in international cinema



Node = actor/actress
Link = appear in the same movie

Source: Menczer, Fortunato, Davis: A First Course on Networks Science. Cambridge, 2020.

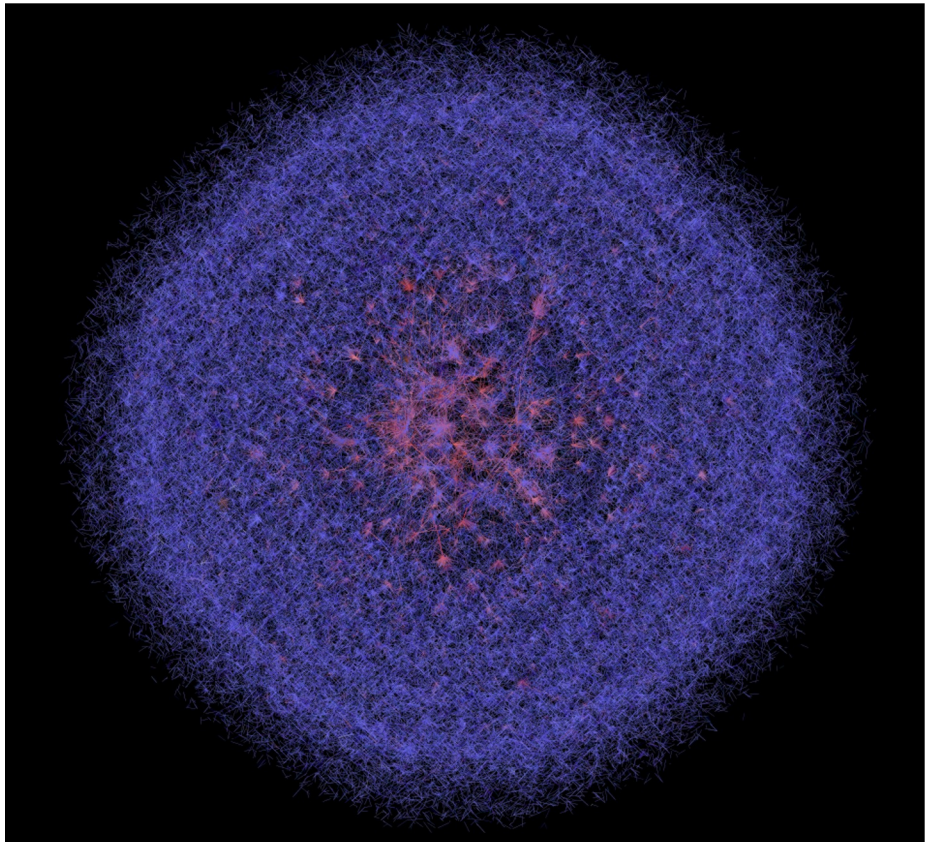
Articles about mathematics

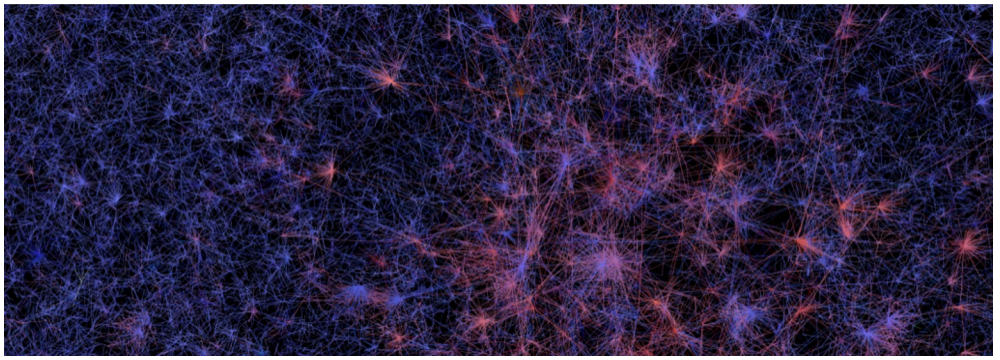


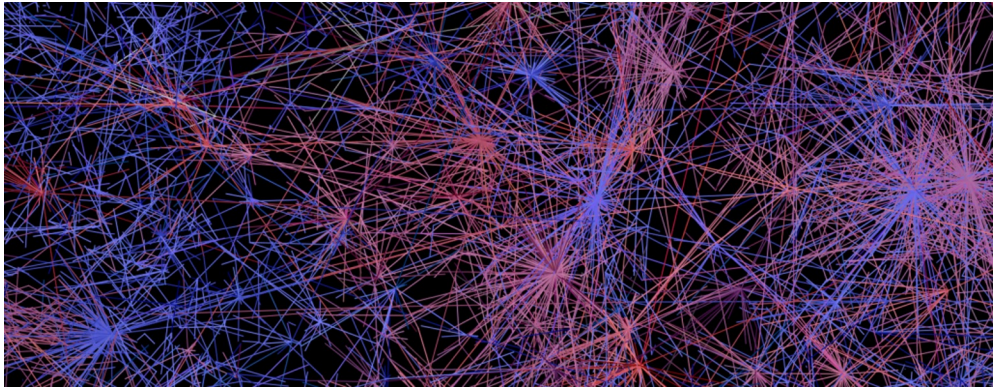
Node = article
Link = link

Source: Menczer, Fortunato, Davis: A First Course on Networks Science. Cambridge, 2020.

400,000 Twitter Users

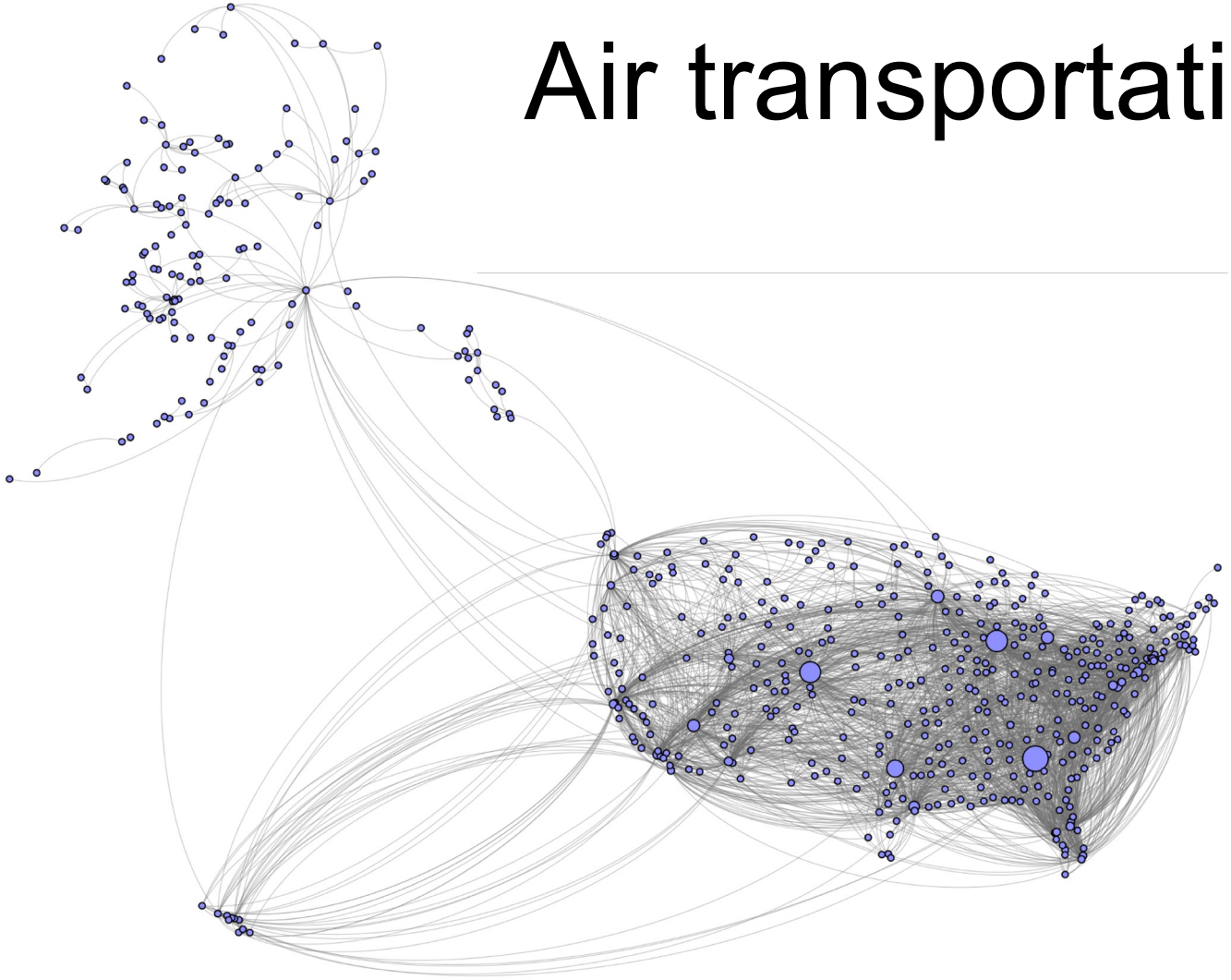






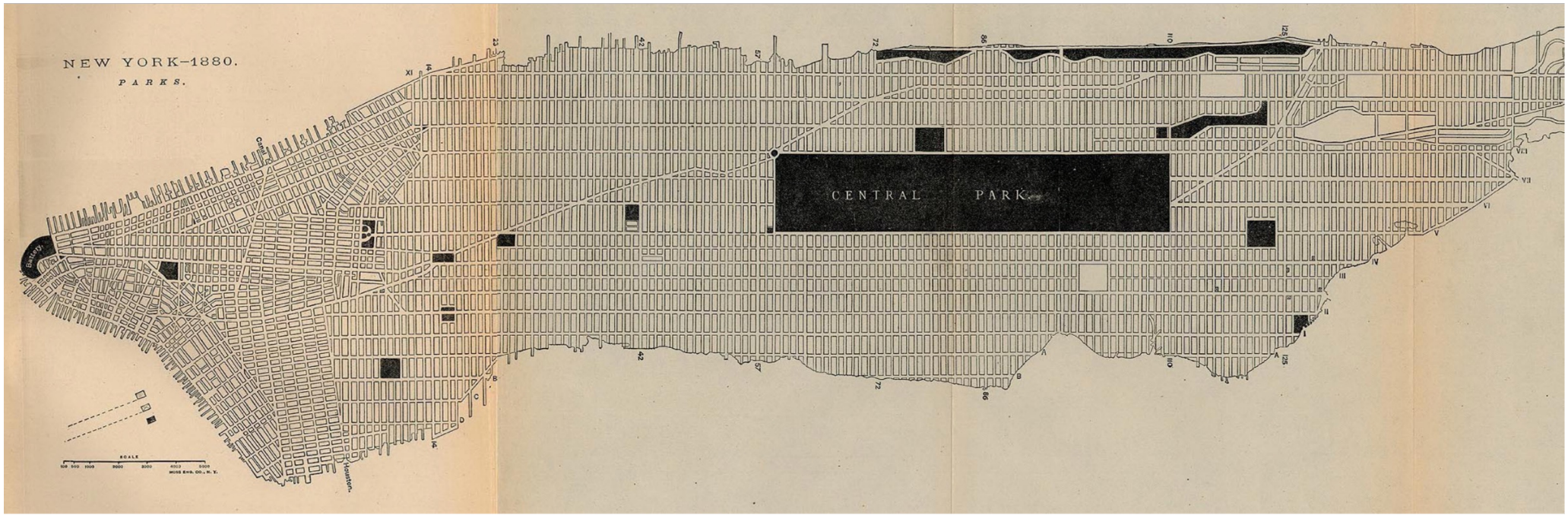
https://dhs.stanford.edu/gephi-workshop/twitter-network-gallery/

Air transportation network



Node = airport
Link = route

Map of New York in 1880



From Report on the Social Statistics of Cities, Compiled by George E. Waring, Jr., United States Census Office, 1886. Image courtesy of University of Texas Libraries

Relevant questions:

- What could complex networks have in common?
  - Why those regularities could be relevant?
    - How would you find out what they are?

Universality of complex networks

"*A key discovery of network science is that the architectures of networks emerging in various domains of science, nature and technology are similar to each other, a consequence of being governed by the same organizing principles.*"
(Barabási 2016)

Exercise

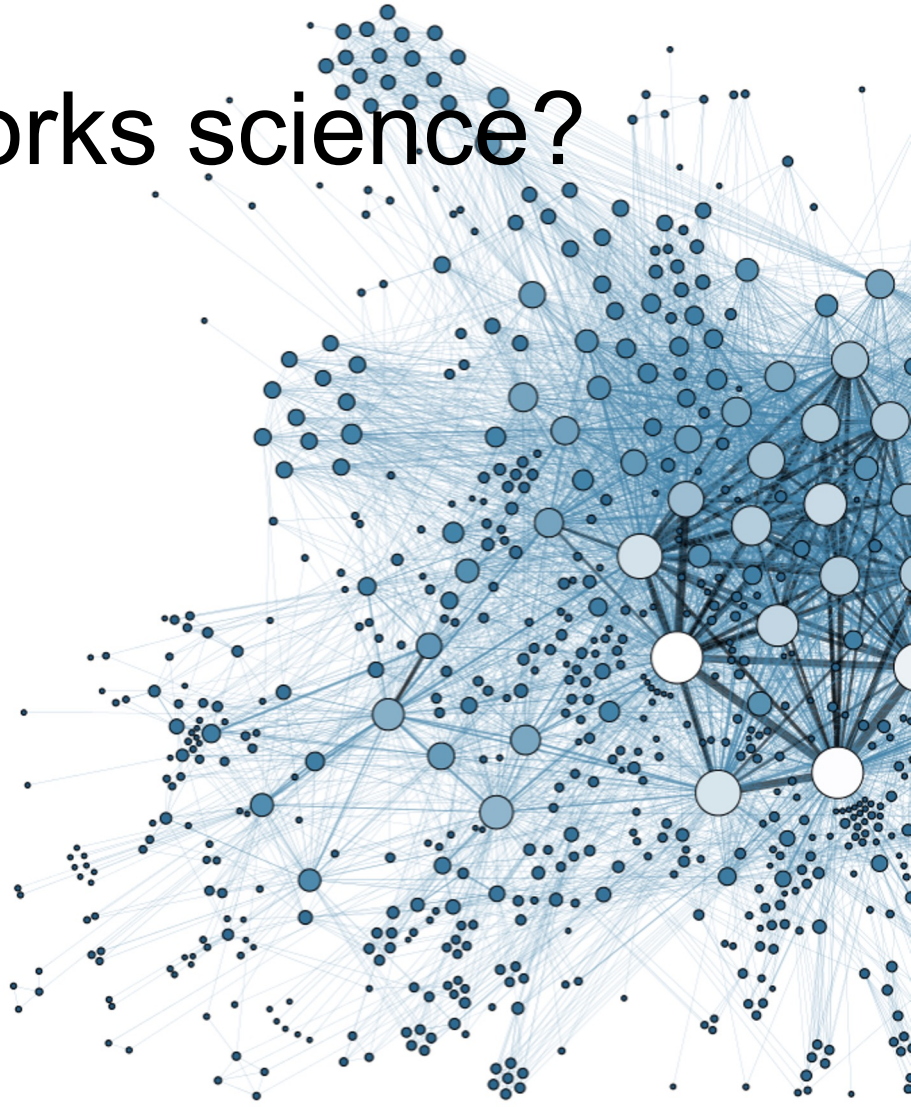
Find examples of networks

- Find examples of networks, just indicating:
  - Name
  - Number of nodes (approximately)
  - Number of edges (approximately)

Pin board: https://upfbarcelona.padlet.org/chato/xr8sktik56mnftuj

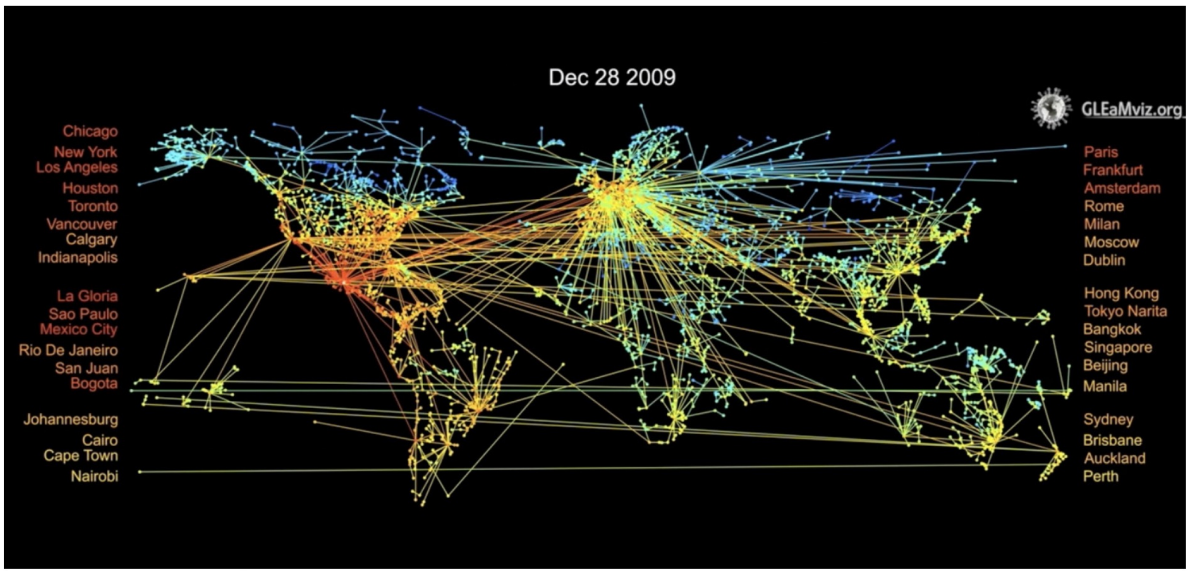
Why studying networks science?

- Understand Complex Systems
- Predict Real-world Phenomena
- Solve Optimization Problems
- Interdisciplinary Applications
- Data Visualization
- Play with nice networks ☺



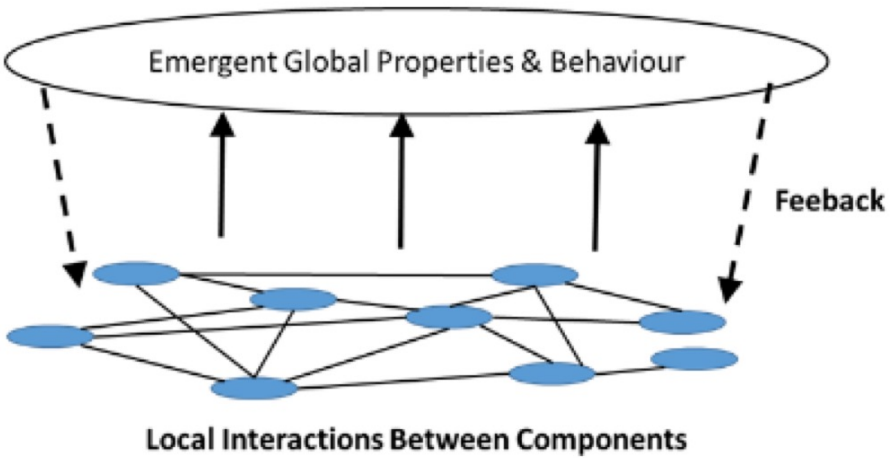
Networks describe complex systems

- Connections between neurons in the brain
- Interactions between genes and proteins
- Family/friendship links in human and non-human animals
- Telecom, power grids…
- Commerce/trade flows



Complex systems

- Many (up to 10^23…) elements
- Microscopic, local, nontrivial interactions
- **Macroscopic, Emerging properties**
- No universal laws (like gravity)



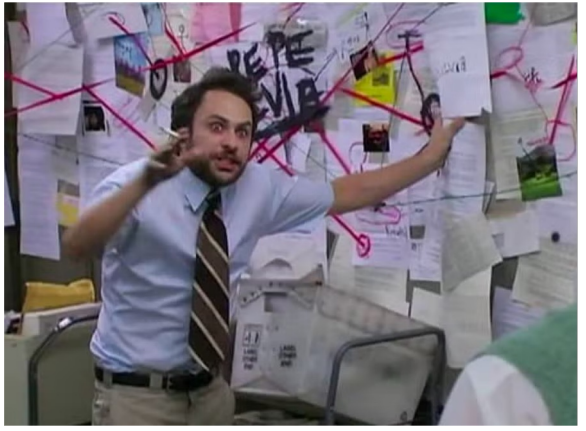
Anderson, P.W. (1972) **More Is Different**. Science, 177, 393-396.
http://dx.doi.org/10.1126/science.177.4047.393

Emergent phenomena

- ❑ Cooperation among individuals (social dilemma)
- ❑ Flocking (birds)
- ❑ Consensus (opinion dynamics)
- ❑ Languages (cooperation)
- ❑ Consciousness (brain networks)
- ❑ Viral propagation (social media)
- ❑ **Pandemics**

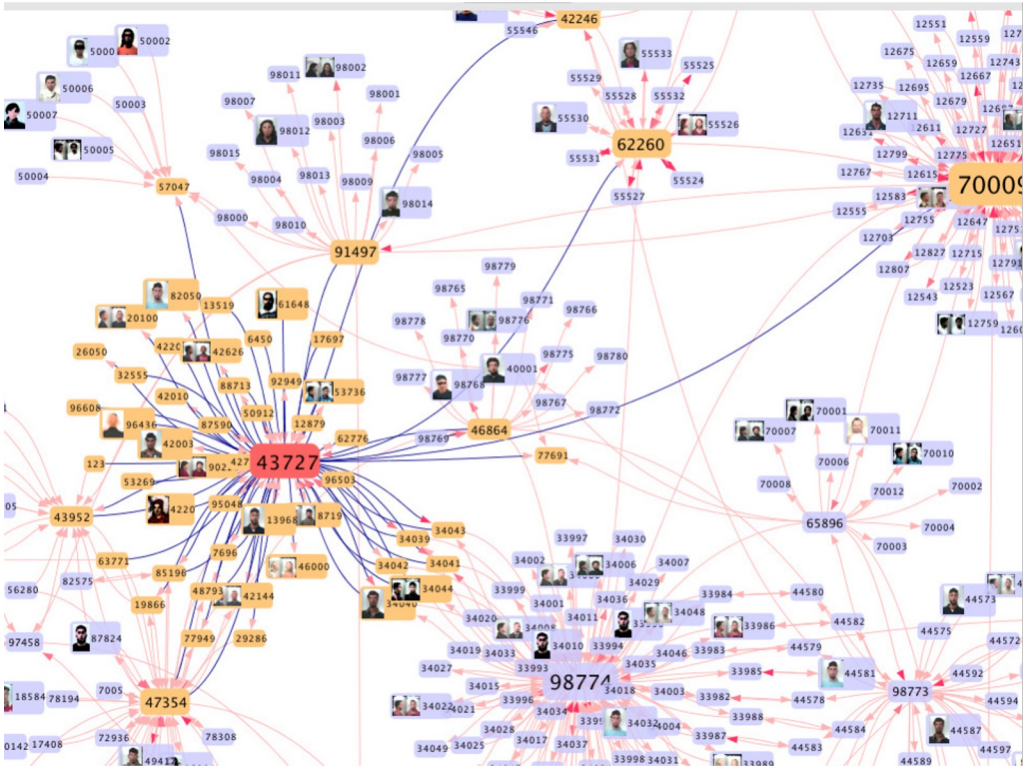
“Red string” suspect boards

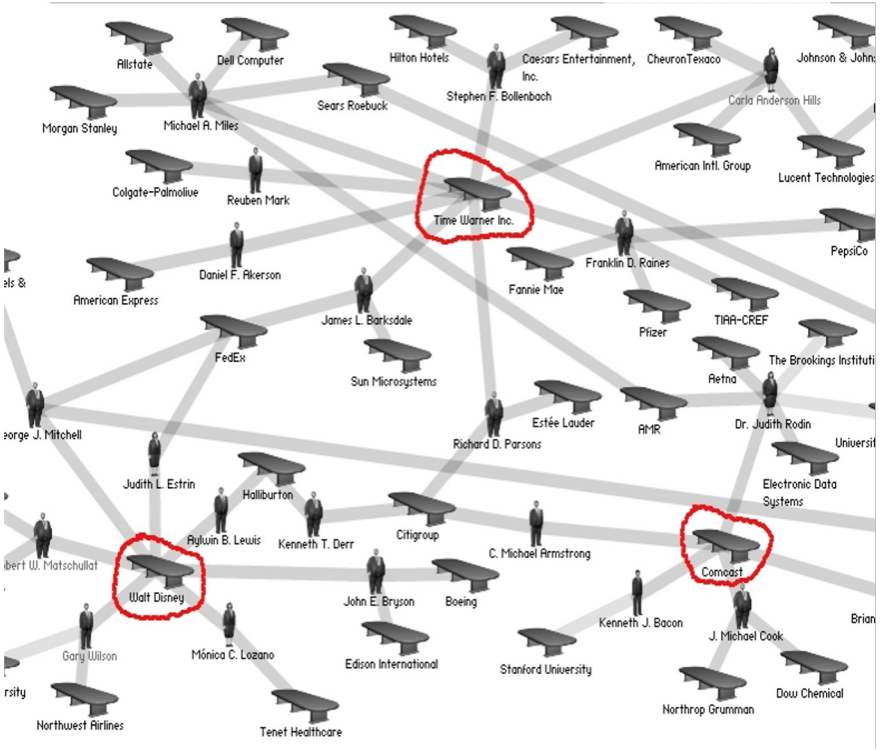
- A very common **TV trope** involves detectives looking at a wall where suspects are connected by red strings



https://tvtropes.org/pmwiki/pmwiki.php/Main/StringTheory

Fight organized crime





https://itnews.iu.edu/articles/2014/complex-networks-researcher-at-iu-fighting-crime-with-mobile-phone-data.php

https://en.wikipedia.org/wiki/File:Media_corporation_interlocks_-_2004.jpg

Understand political corruption

37 corruption cases in Spain in 1989-2018 involving 2,753 people having 27,545 connections

There are 197 connected components, 58 isolated nodes, and a giant component of 40% of nodes and 53% of edges

*“empirical results and simulations indicate that **a few recidivist agents** typically play a prominent role in corruption activities. These agents act as **bridges** among minor corrupt groups and possibly engage and coordinate them to work in more extensive and often much more harmful corruption processes to society.” (emphasis added)*

https://www.nature.com/articles/s41598-022-10909-2 based on data from https://casos-aislados.com/

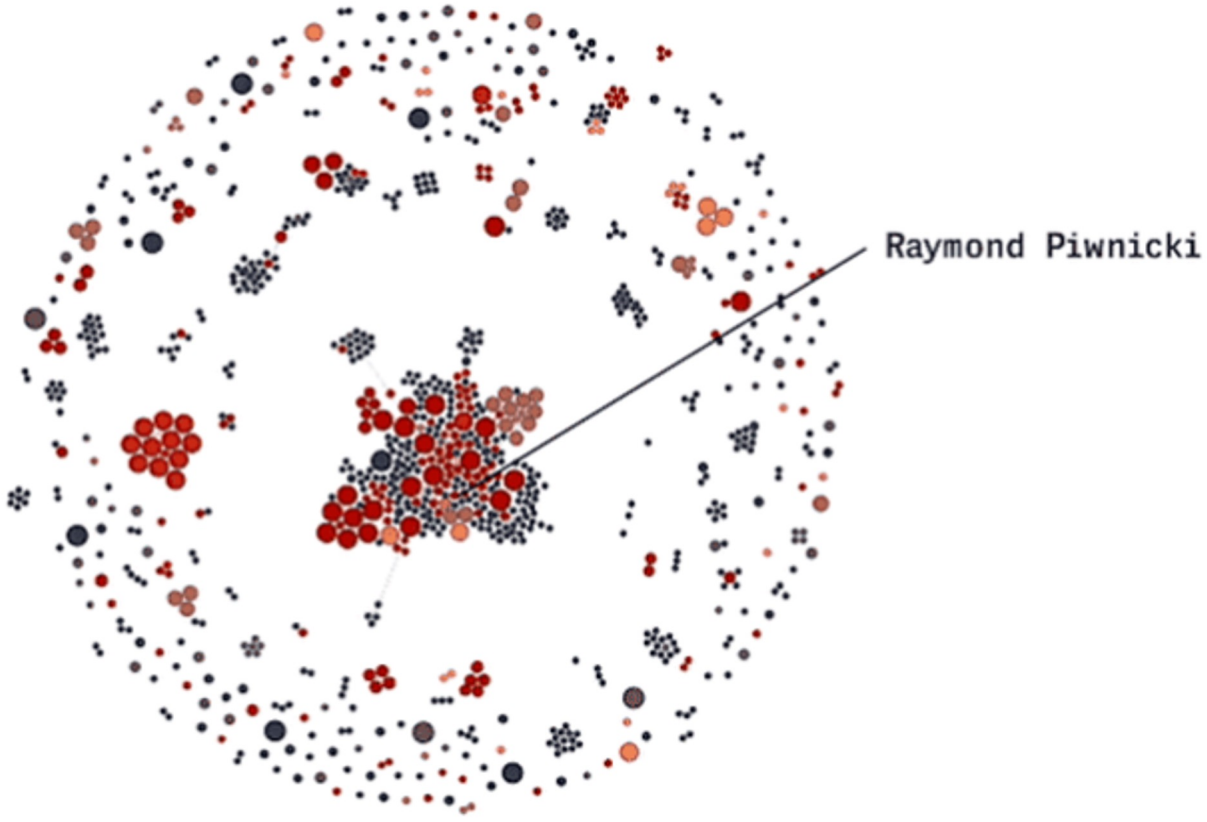
Fight police corruption

The Intercept_

BAD CHICAGO COPS SPREAD THEIR MISCONDUCT LIKE A DISEASE

Rob Arthur

August 16 2018, 3:03 p.m.

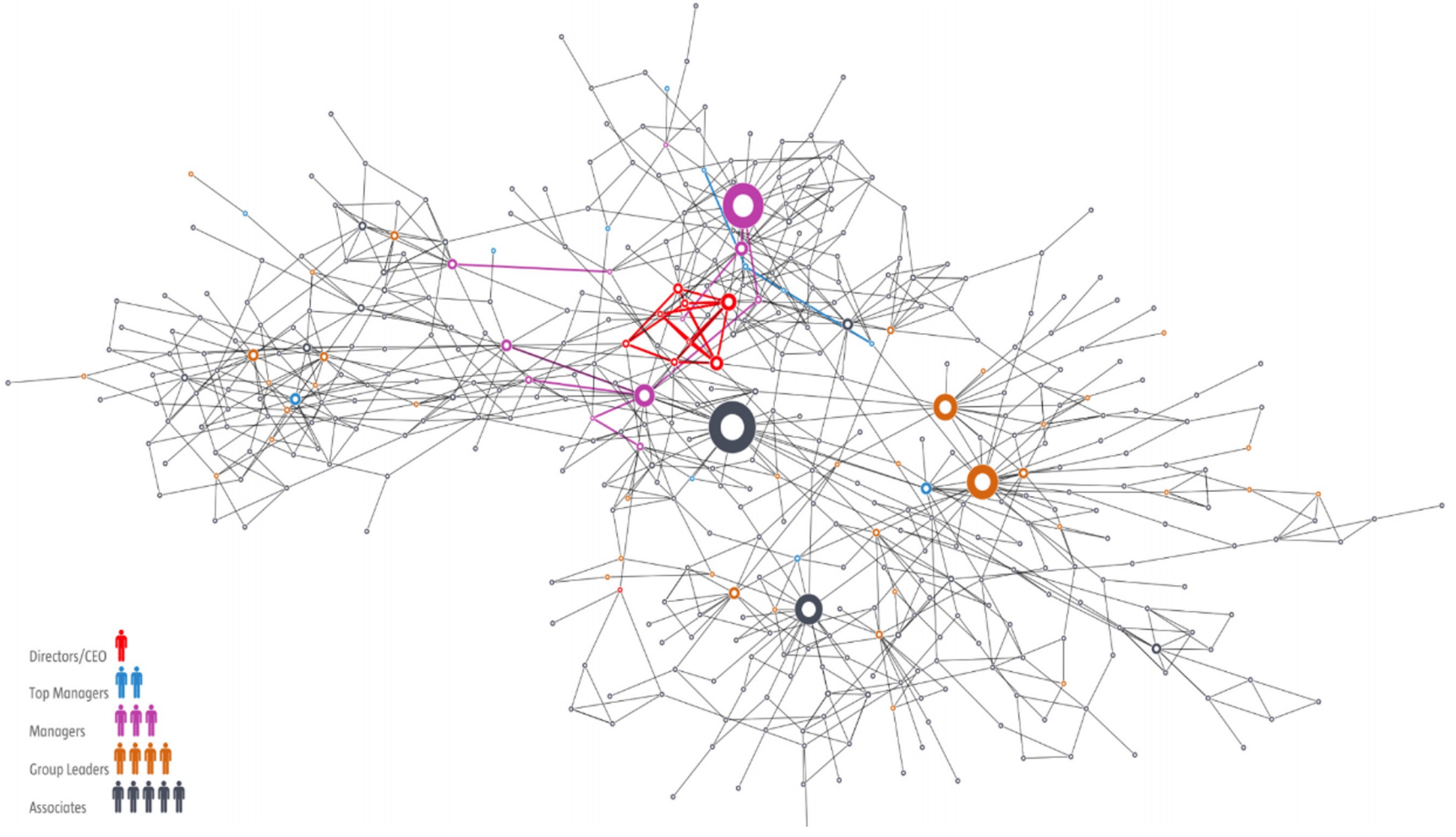


https://theintercept.com/2018/08/16/chicago-police-misconduct-social-network/

Forecast epidemics

https://www.youtube.com/watch?v=mm2u9RKwgsY

Understand organization structures



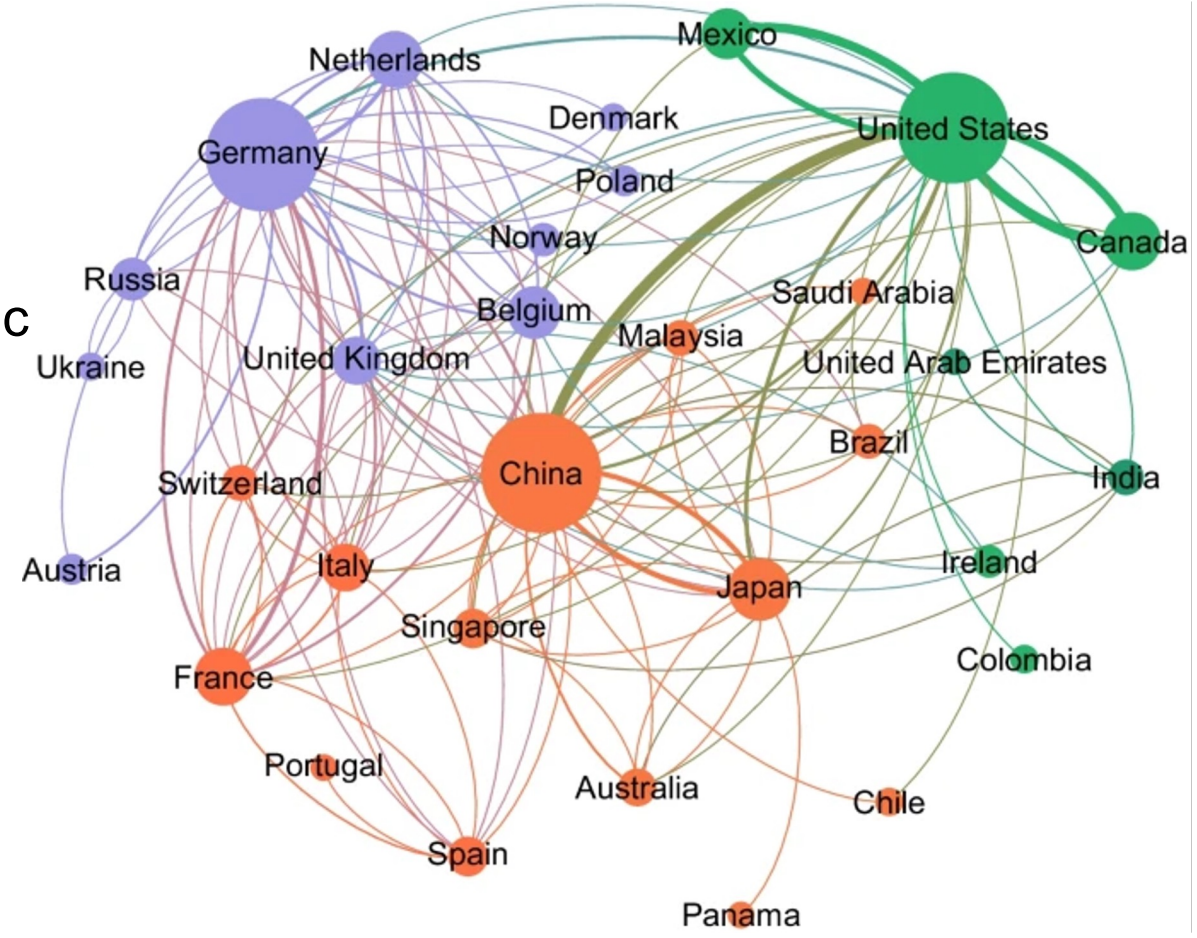
Improve communication

- About 3M e-mails sent or received by an EU research organization address
- Nodes are e-mail addresses (~1K internal, ~250K external)
- Edges are e-mails

https://www.youtube.com/watch?v=4JS-30dglqg

Understand international trade

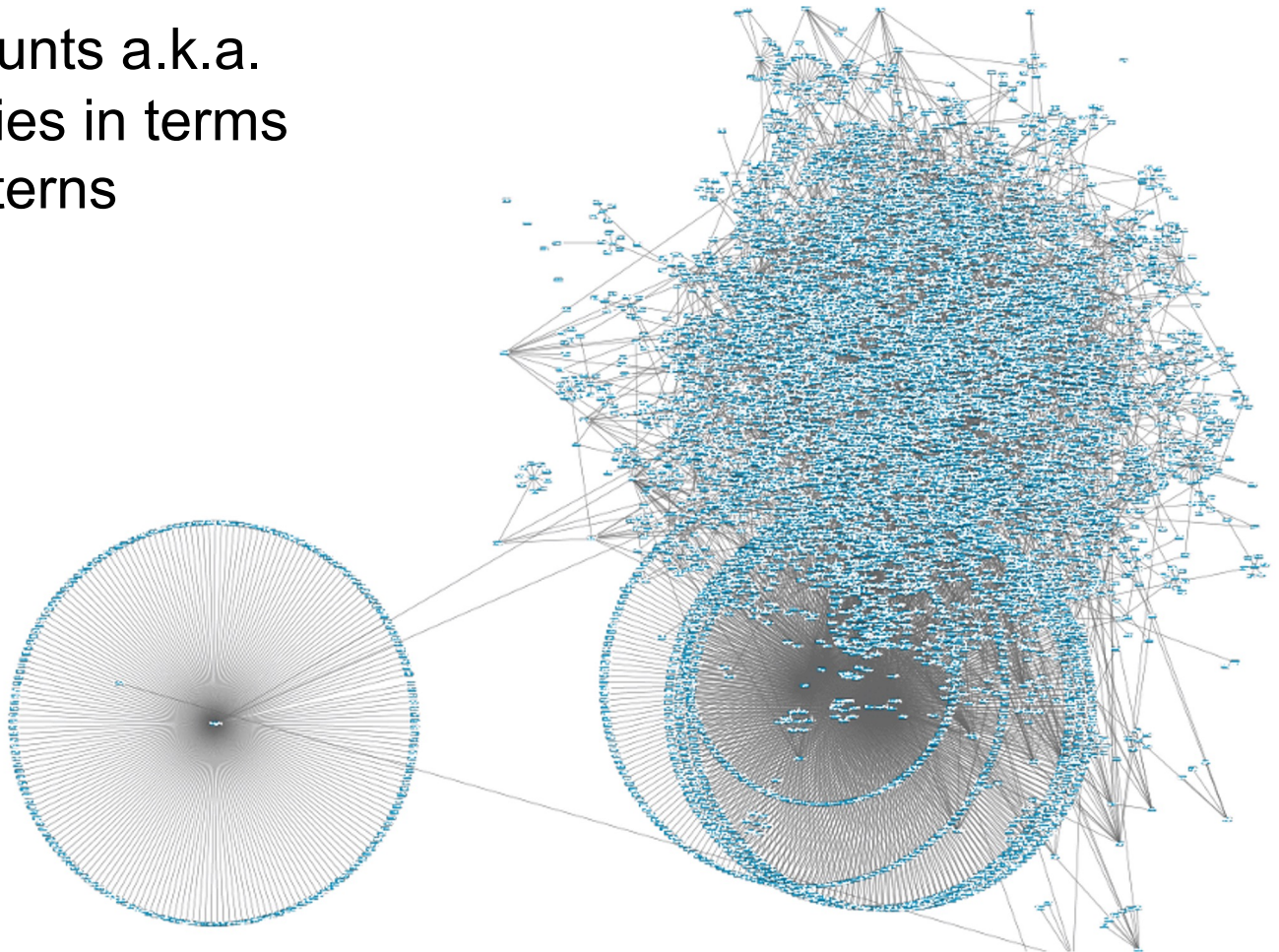
- Multiple structural, economic, geographical, and political factors affect the global trade network structure.
- Economic complexity: economic power comes from the relation between a country and its exports (bipartite networks)
- Shock propagation: financial shocks (eg 2008 crisis) can spread through trade relations



https://doi.org/10.1007/s41109-022-00479-7

Fight misinformation and hate online

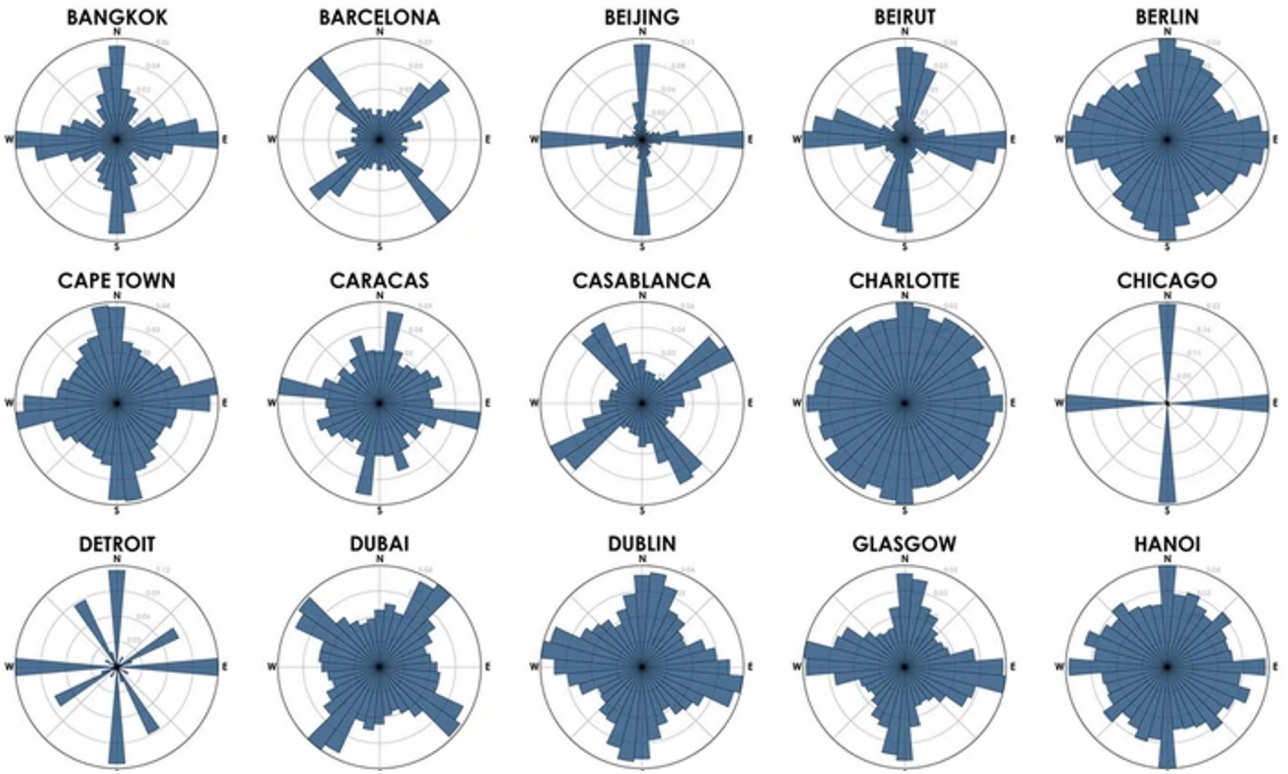
- Inauthetentic accounts a.k.a. "**bots**" are anomalies in terms of connectivity patterns



https://gigazine.net/gsc_news/en/20150310-graph-8000-fake-twitter-account/

Improve mobility within cities

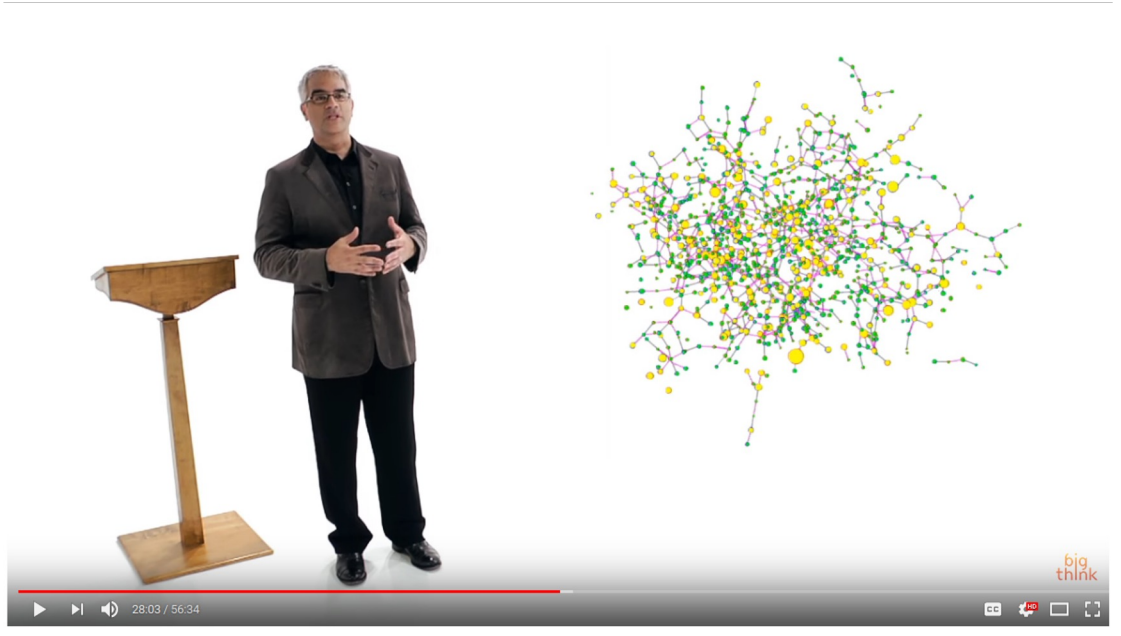
- City grids have polarities that can be seen through networks analysis.



https://doi.org/10.1007/s41109-019-0189-1

Understand diseases
Design new treatments

Must watch:
Nicholas Christakis (1 hour)



https://www.youtube.com/watch?v=wadBvDPeE4E

Things to remember

- Definitions
  - complex system, complex network, emergent property
- Examples of complex networks
- Applications of networks analysis

How Studying Networks Science

- **Interdisciplinary**: problems from disciplines other than physics
- **Empirical** and data-driven
- **Quantitative**, mathematical, computational

What we will learn

- Describe networks in **formal terms**
- **Load, manipulate, export, visualize networks**, using different tools and languages
- Quantify networks' **structural components and properties**
- **Demonstrate networks algorithms**, eg search engines to crawl and rank Web pages
- Find important nodes and **communities**
- **Describe dynamic processes** on networks, such as the spread of diseases and rumors

How we will learn

https://github.com/chatox/networks-science-course/

- Theory sessions:
  - Help you find important nodes, communities, and track influence
  - Help you understand how to model complex networks
  - Do some simple (and not so simple) exercises to check that you understood correctly each concept, and to help you remember
- Practice sessions:
  - Help you work with complex networks
  - Manage and analyze graphs in Python

Challenges

- Network science is usually a **course for graduate students** (eg, master or even doctoral students)
- **Adapted** for 2° year ungraduated students
- Nonetheless, it heavily relies on **probability**: study it ☺
- Math (and network science) is **learned by doing**:
  - exercises (not evaluated) during lectures
  - exercise on your own
- A lot of material, but some is extra, and **less** than previous year ;)

Sources

- A. L. Barabási (2016). Network Science – Chapter 01 and Chapter 02
- F. Menczer, S. Fortunato, C. A. Davis (2020). A First Course in Network Science – Chapter 00
- URLs cited in the footer of specific slides