

# Network theory

Introduction and basic concepts



**CENTAI**



**ISI  
Foundation**

**Complexity in Social Systems**


**AA 2023/2024**

**Maxime Lucas**

**Lorenzo Dall'Amico**

# Course Organisation

- 48 hours :
  - 24 h about network theory and structure
  - 24 h about dynamical systems on networks + advanced topics
- Theory + practical code notebooks



Complexity in social systems

Search this book...

Coursebook for "Complessita' nei Sistemi Sociali"

**INTRODUCTION**

1. Python is easy :)
2. Basic network import and representation

**NETWORKX BASICS**

3. Introduction to NetworkX
4. How to fit a power law distribution
5. Basics of network analysis

**SPREADING MODELS**

6. Epidemic modeling, deterministic and stochastic models

Laurea Magistrale in Fisica Dei Sistemi Complessi A.A. 2021/22

Lecturers: Michele Tizzoni, Giovanni Petri

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Spreading models

- 6. Epidemic modeling, deterministic and stochastic models
- 7. Epidemics on networks
- 8. Epidemics on temporal networks

Community detection

- 9. Community detection

Next  
1. Python is easy :)

By G. Petri, M. Tizzoni  
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# Notebook 01

## Some info:

- the notebooks will be available throughout the course at: <https://maximelucas.github.io/complexity-book/>
- The source is at: <https://github.com/maximelucas/complexity-book>
  
- **course material:** <https://elearning.unito.it/scienzedellanatura/course/view.php?id=3440>
- **Other course page:** <https://fisica-sc.campusnet.unito.it/do/didattica.pl/Quest?corso=4ef1>
  
- Email contacts: maxime.lucas@centai.eu lorenzo.dallamico@isi.it (DO NOT WRITE TO @unito EMAILS please)

# Exam modality

Exam is divided in two parts:

A. Talk/Presentation

B. Questions on course material

Two options for **(A)**:

i. Talk (15mins) based on a chosen paper on networks and/or adjacent subjects

i.i. **Any paper** is fine, if in doubt, **ASK!**

i.ii. “**READ AROUND THE PAPER**”: expect questions not just on the paper, but on related ideas/concepts

ii. Presentation (15min) on small data analysis project on networks

ii.i. Again, **any project** is fine, but do ask to check data is appropriate/not too much time, etc.

ii.ii. Do present slides, not just code.

Be smart about **(B)**: it's likely we will ask questions on topics: 1.related to talk (**READ AROUND**)  
2.**AND** to something completely different (**STUDY EVERYTHING!**)

# Complex

[adj., v. kuh m-pleks, kom-pleks; n. kom-pleks]

–adjective

1.

composed of many interconnected parts; compound; composite: a complex highway system.

2.

characterized by a very complicated or involved arrangement of parts, units, etc.: complex machinery.

3.


so complicated or intricate as to be hard to understand or deal with: a complex problem.

*Source: Dictionary.com*

Complexity, a **scientific theory** which asserts that some systems display behavioral phenomena that are completely inexplicable by any conventional analysis of the systems' constituent parts. These phenomena, commonly referred to as emergent behaviour, seem to occur in many complex systems involving living organisms, such as a stock market or the human brain.

*Source: John L. Casti, Encyclopædia Britannica*

# Complexity

A network diagram in the top right corner showing interconnected nodes and edges, with some nodes highlighted in blue and others in white.

Behind each complex system  
there is a **network\***  
that defines the interactions  
between the components

See also: <https://complexityexplained.github.io/> and <https://www.complexity-explorables.org/>

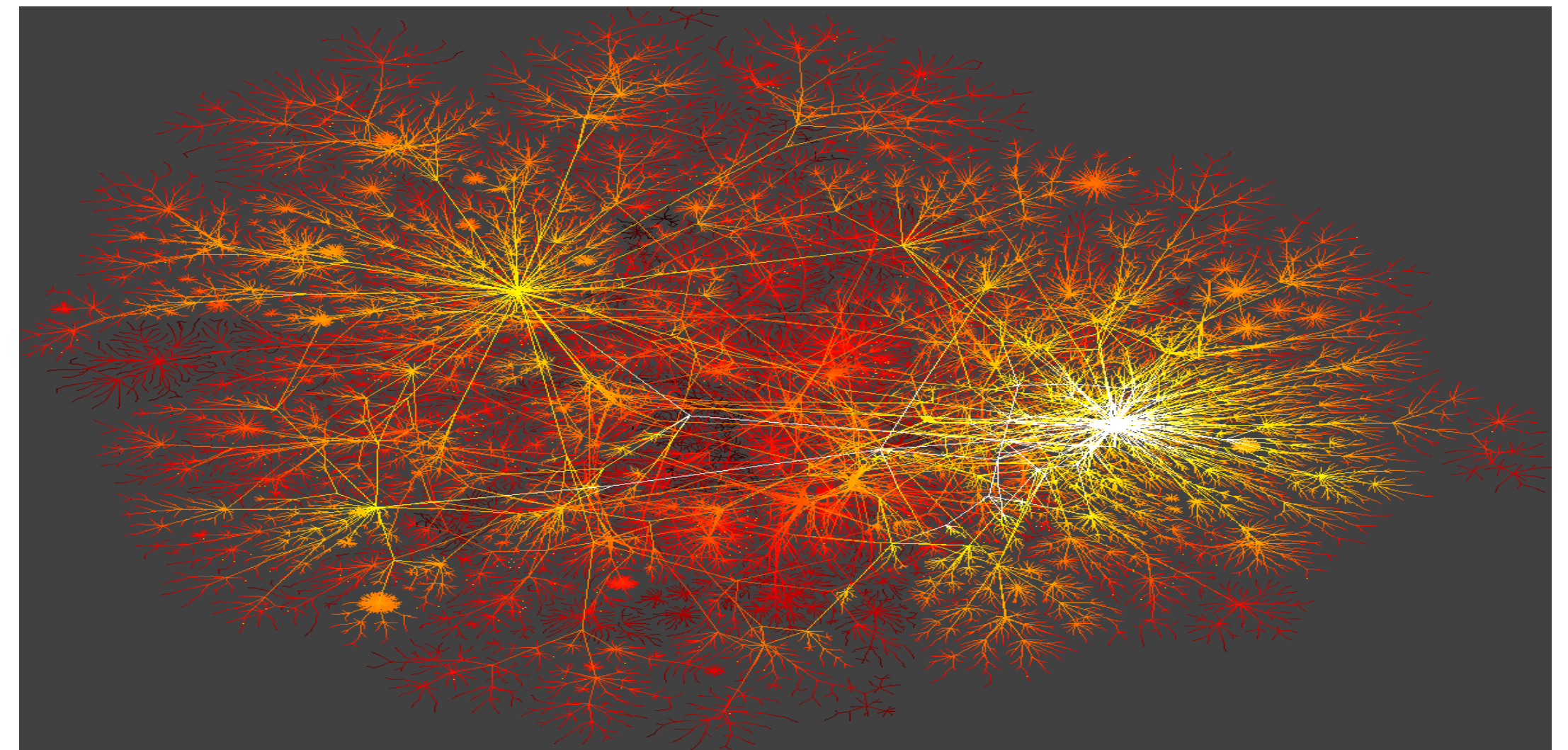
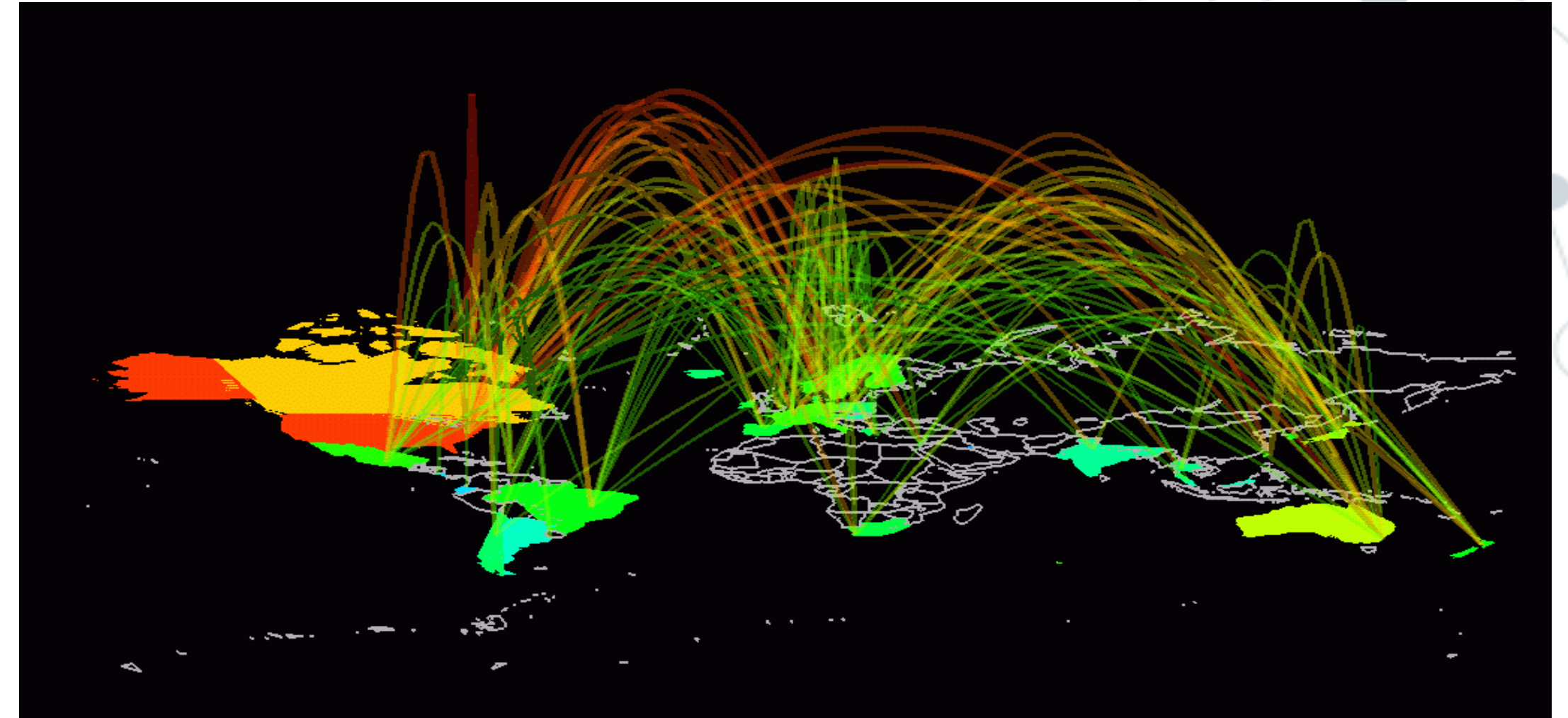
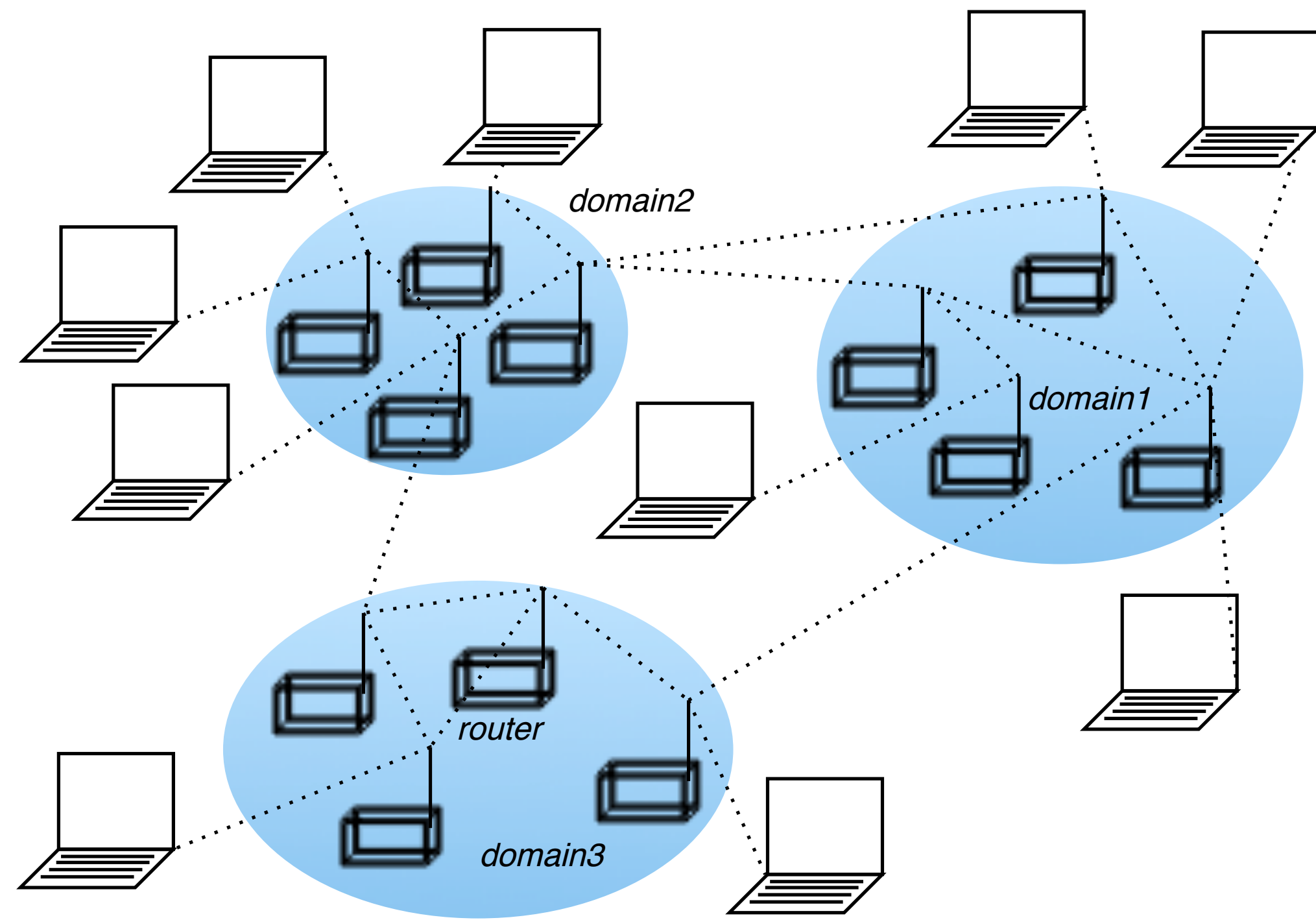
A network diagram in the bottom left corner showing interconnected nodes and edges, with some nodes highlighted in blue and others in white.

# data mining and relational data

- Big Data not natively in structured format
- “The value of data explodes when it can be linked”
- “at the end of the 90s a new analytical trend joined data mining and machine learning: the emergence of **network science**”

*Amato, G., et al. (2018). How Data Mining and Machine Learning Evolved from Relational Data Base to Data Science. Springer*

# internet

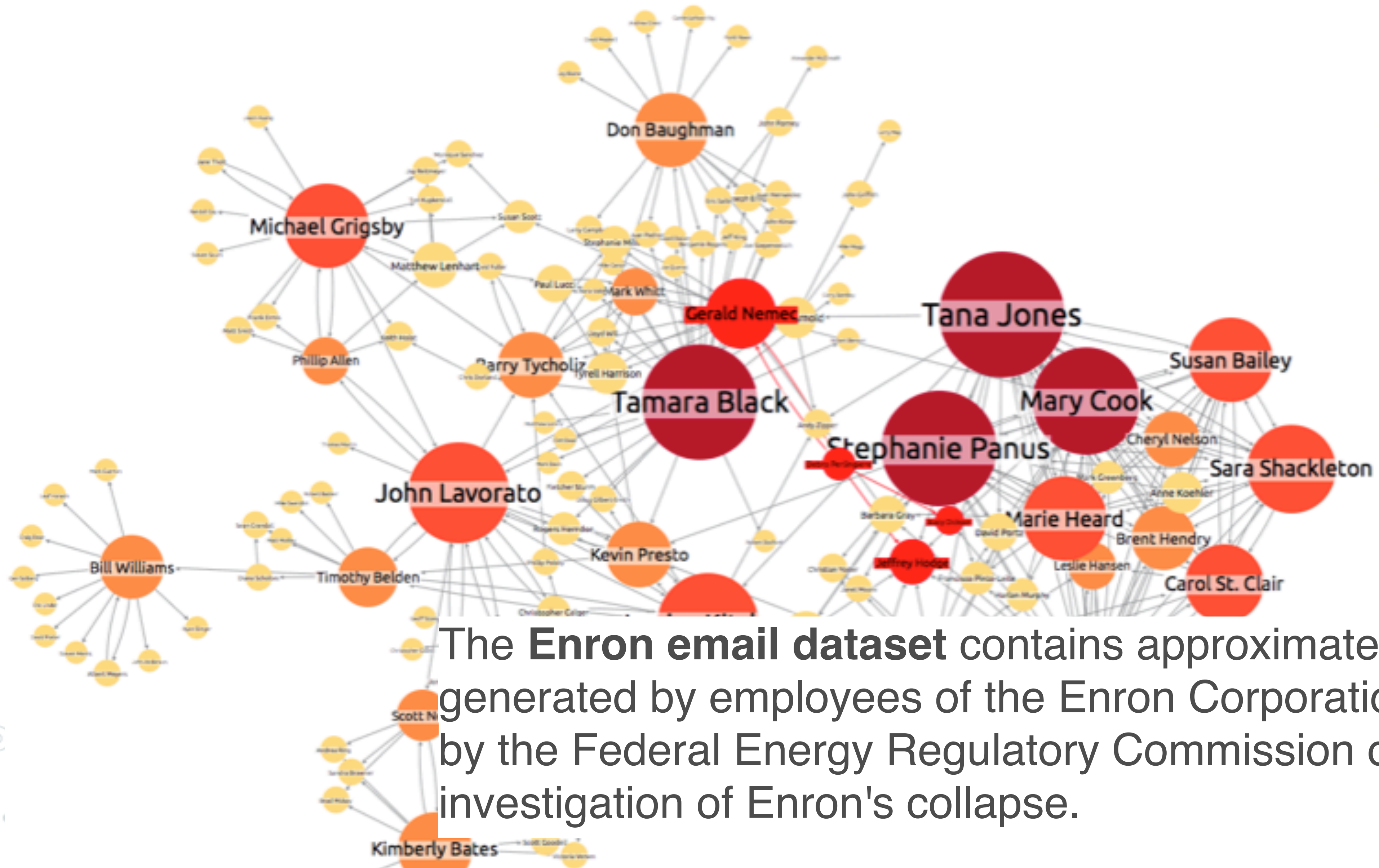




# online interactions

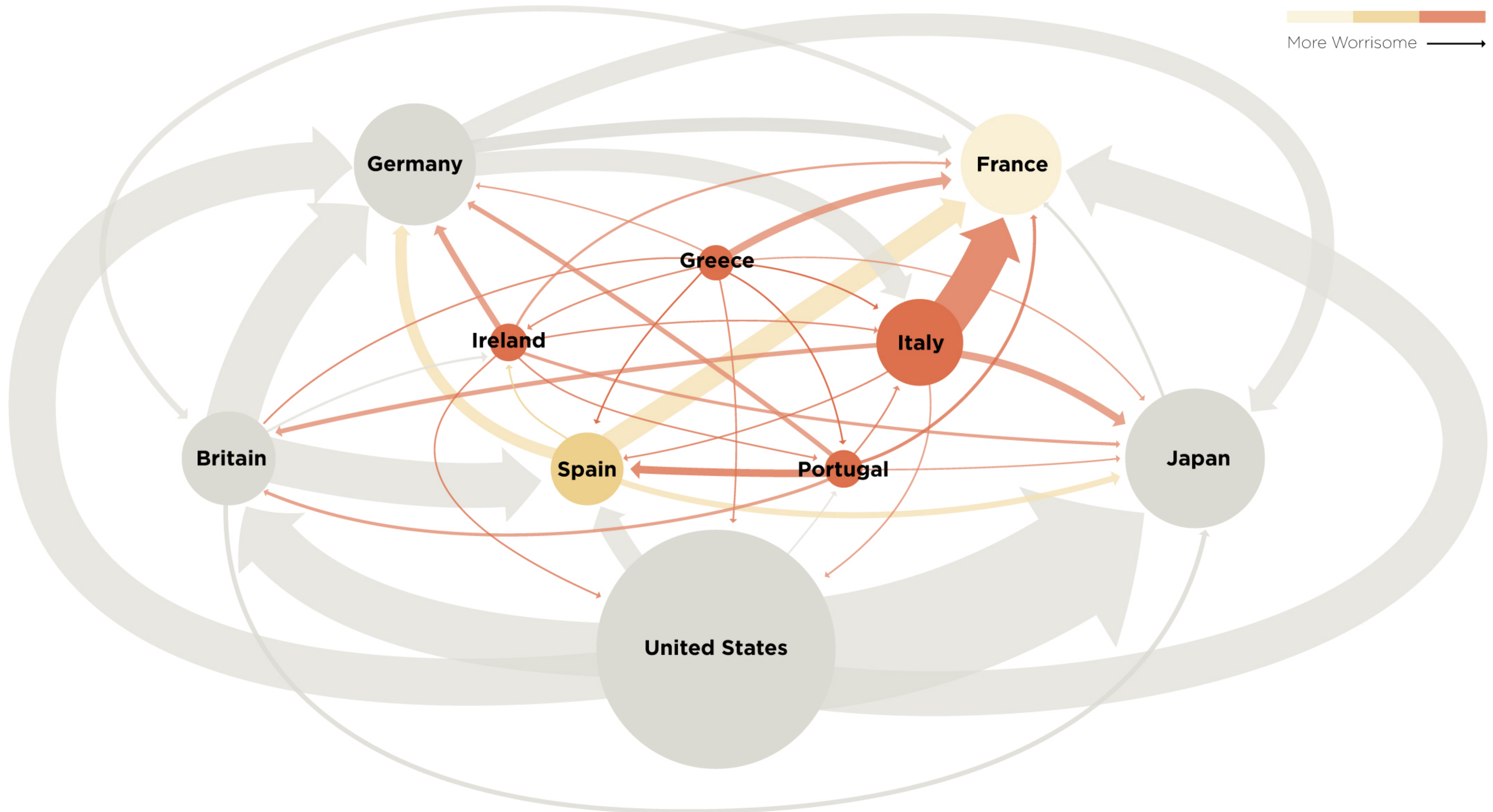


# email communication

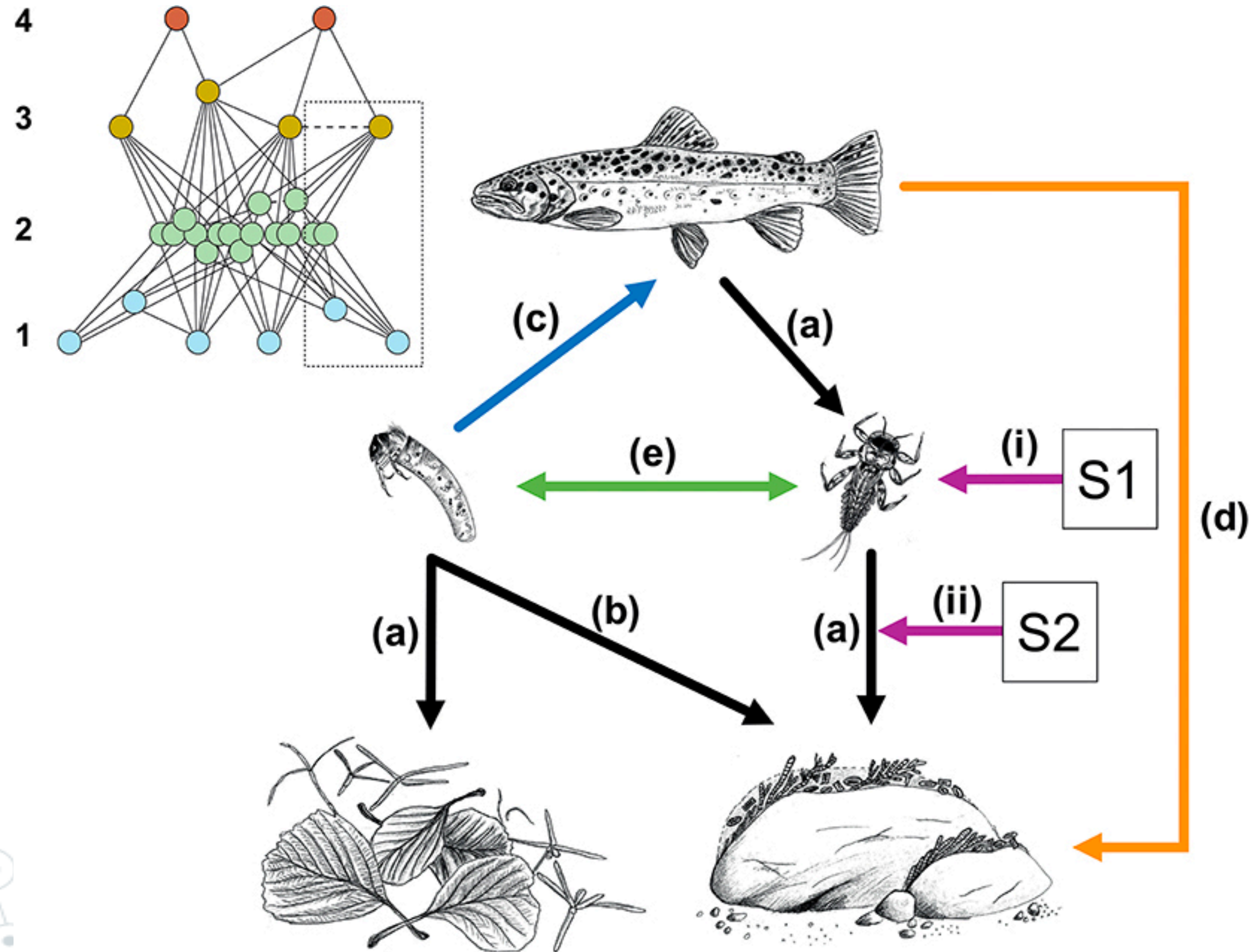


The **Enron email dataset** contains approximately 500,000 emails generated by employees of the Enron Corporation. It was obtained by the Federal Energy Regulatory Commission during its investigation of Enron's collapse.

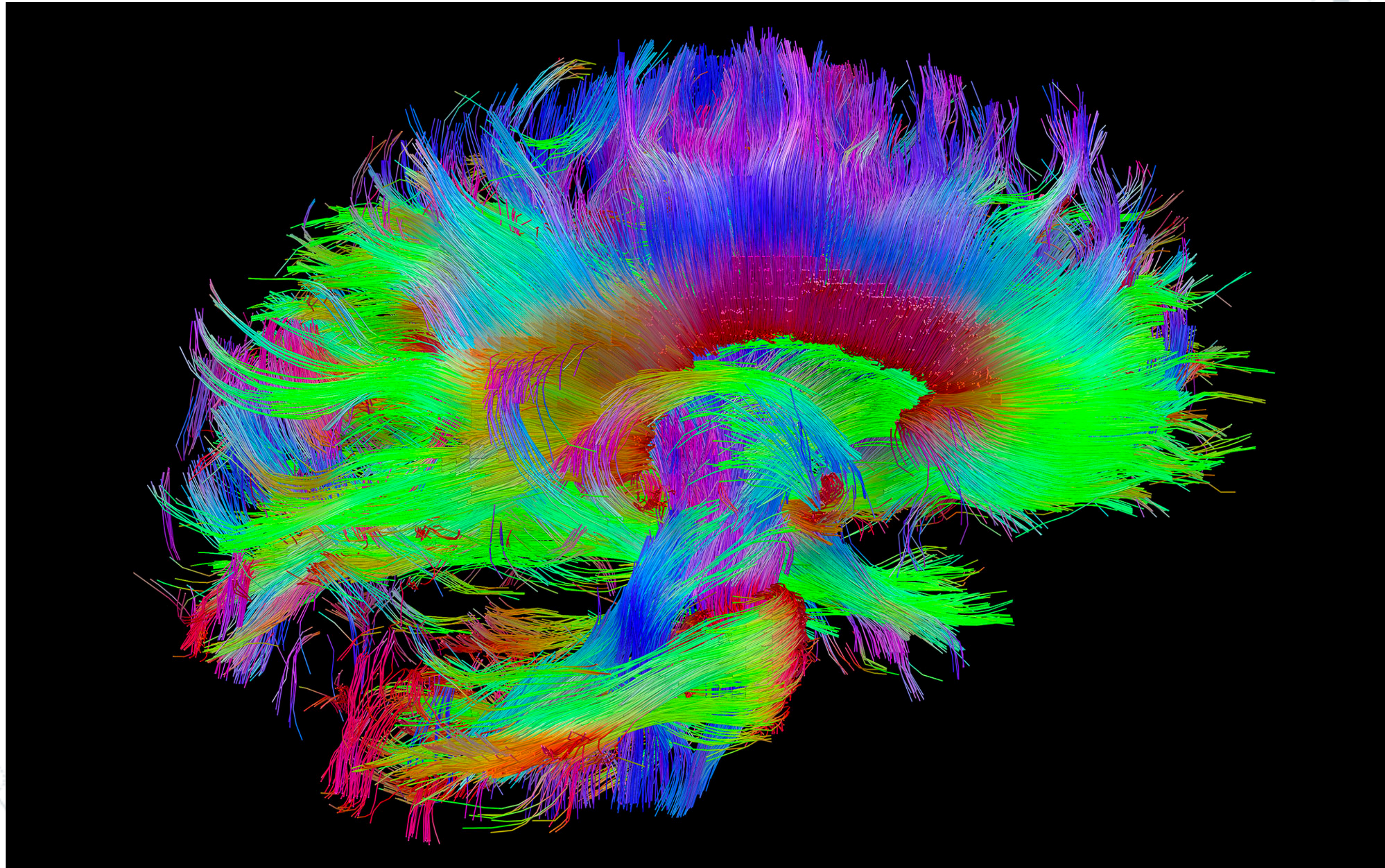
# financial networks



# Ecological networks




# Brain networks





many more...

- ▶ **biological** (protein-protein)
  - ▶ **infrastructure/transport** (air travel, road networks)
  - ▶ **mobility networks** (human movements)
  - ▶ **word co-occurrence**
  - ▶ **off-line interactions** (proximity, friendship)
  - ▶ **scientific collaborations** (co-authorship, citations)
- 

# network datasets

<http://snap.stanford.edu>

STANFORD  
UNIVERSITY

By Jure Leskovec



- SNAP for C++ ▶
- SNAP for Python ▶
- SNAP Datasets ▶
- BIOSNAP Datasets
- What's new
- People
- Papers
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## Stanford Large Network Dataset Collection

- **Social networks** : online social networks, edges represent interactions between people
- **Networks with ground-truth communities** : ground-truth network communities in social and information networks
- **Communication networks** : email communication networks with edges representing communication
- **Citation networks** : nodes represent papers, edges represent citations
- **Collaboration networks** : nodes represent scientists, edges represent collaborations (co-authoring a paper)
- **Web graphs** : nodes represent webpages and edges are hyperlinks
- **Amazon networks** : nodes represent products and edges link commonly co-purchased products
- **Internet networks** : nodes represent computers and edges communication
- **Road networks** : nodes represent intersections and edges roads connecting the intersections
- **Autonomous systems** : graphs of the internet
- **Signed networks** : networks with positive and negative edges (friend/foe, trust/distrust)
- **Location-based online social networks** : Social networks with geographic check-ins
- **Wikipedia networks, articles, and metadata** : Talk, editing, voting, and article data from Wikipedia
- **Temporal networks** : networks where edges have timestamps
- **Twitter and Memetracker** : Memetracker phrases, links and 467 million Tweets
- **Online communities** : Data from online communities such as Reddit and Flickr
- **Online reviews** : Data from online review systems such as BeerAdvocate and Amazon

SNAP networks are also available from [SuiteSparse Matrix Collection](#) by [Tim Davis](#).

# tools

- ▶ network visualization

- ▶ Gephi

- ▶ D3

- ▶ igraph

- ▶ Python libraries

- ▶ NetworkX

- ▶ Graph-tool

- ▶ SNAP

 graph-tool

 Gephi

  
NetworkX



# approaches

A decorative background featuring a network graph with nodes and edges. The nodes are represented by circles of varying sizes and colors (light blue, dark blue, and grey), connected by thin lines. The graph is distributed across the top and bottom of the slide.

- ▶ **Physics of complex systems**

- ▶ microscopic modeling
- ▶ statistical physics tools (mean-field)
- ▶ universal features

- ▶ **Computer science**

- ▶ machine learning
- ▶ link prediction
- ▶ classification
- ▶ clustering

# ranking



network science



Tutti Immagini Notizie Libri Video Altro Impostazioni Strumenti

Circa 2.790.000.000 risultati (0,53 secondi)

Suggerimento: Cerca risultati solo in **italiano**. Puoi specificare la lingua di ricerca in **Preferenze**.

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**Network science** is an academic field which studies complex **networks** such as telecommunication **networks**, computer **networks**, biological **networks**, cognitive and semantic **networks**, and social **networks**, considering distinct elements or actors represented by nodes (or vertices) and the connections between the elements or ...

## Network science - Wikipedia

[https://en.wikipedia.org/wiki/Network\\_science](https://en.wikipedia.org/wiki/Network_science)

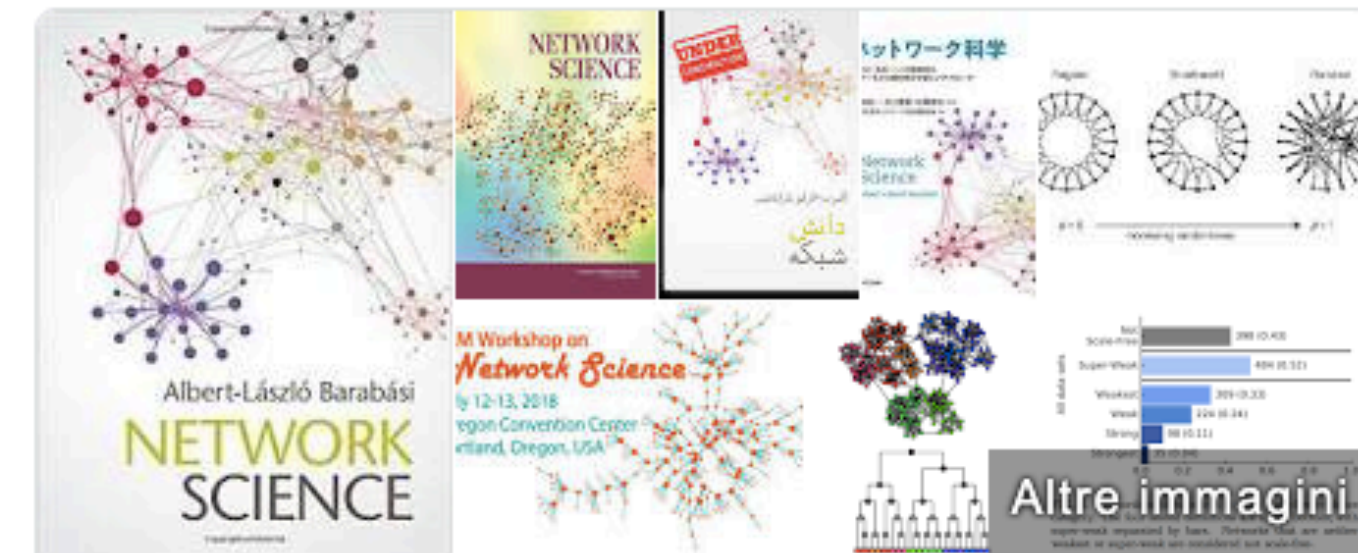


Informazioni su questo risultato Feedback

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## Network science

Campo di studi

Tradotto dall'inglese - La scienza di rete è un campo accademico che studia reti complesse come reti di telecomunicazione, reti di computer, reti biologiche, reti cognitive e semantiche e reti sociali, considerando i diversi elementi o attori rappresentati dai nodi e le connessioni tra gli elementi o gli attori come collegamenti. [Wikipedia \(inglese\)](#)

Vedi la descrizione originale

## Ricerche correlate

Visualizza altri 10 elementi



Algoritmo



Apprendi... automatico



Rete di computer



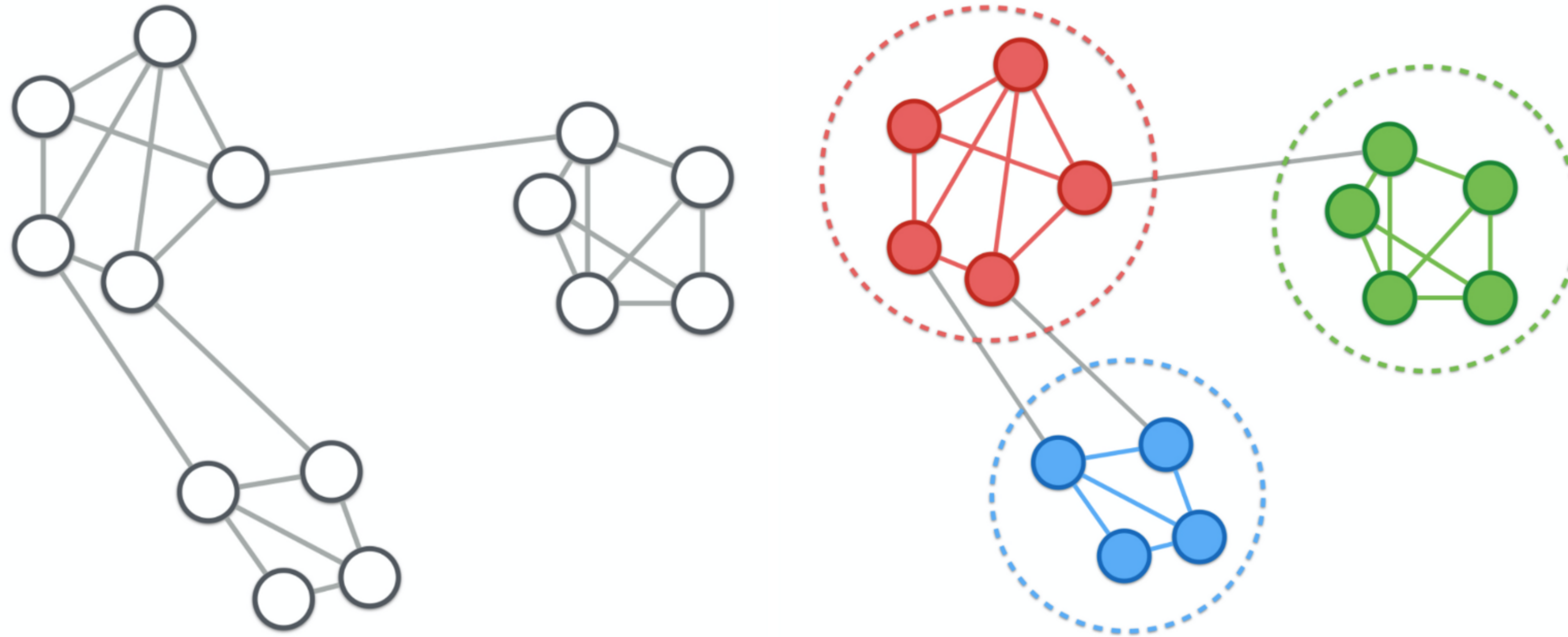
Ottimizza...



Ricerca scientifica

Feedback

# community detection




*application: identify similar customers based on their purchases*

# recommendation


**NETFLIX ORIGINAL**  
**STRANGER THINGS**  
95% Match 2016 1 Season 4K Ultra HD 5.1

When a young boy vanishes, a small town uncovers a mystery involving secret experiments, terrifying supernatural forces and one strange little girl.


Winona Ryder, David Harbour, Matthew Modine  
TV Shows, TV Sci-Fi & Fantasy, Teen TV Shows



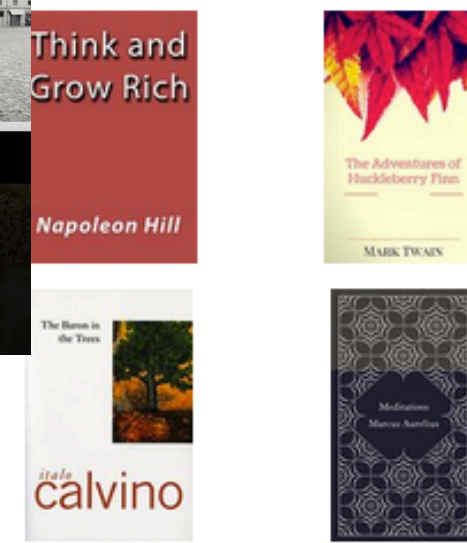
**Popular on Netflix**



**Recently Watched**



## Recommended for you, Thomas



Literature & Fiction  
62 ITEMS



Exercise & Fitness Equipment  
8 ITEMS



Health, Fitness & Dieting Books  
37 ITEMS



Tableware  
12 ITEMS



Prime Video – Unlimited Streaming for Prime Members  
12 ITEMS



Coffee, Tea & Espresso  
98 ITEMS



Biographies & Memoirs  
17 ITEMS



Engineering Books  
7 ITEMS

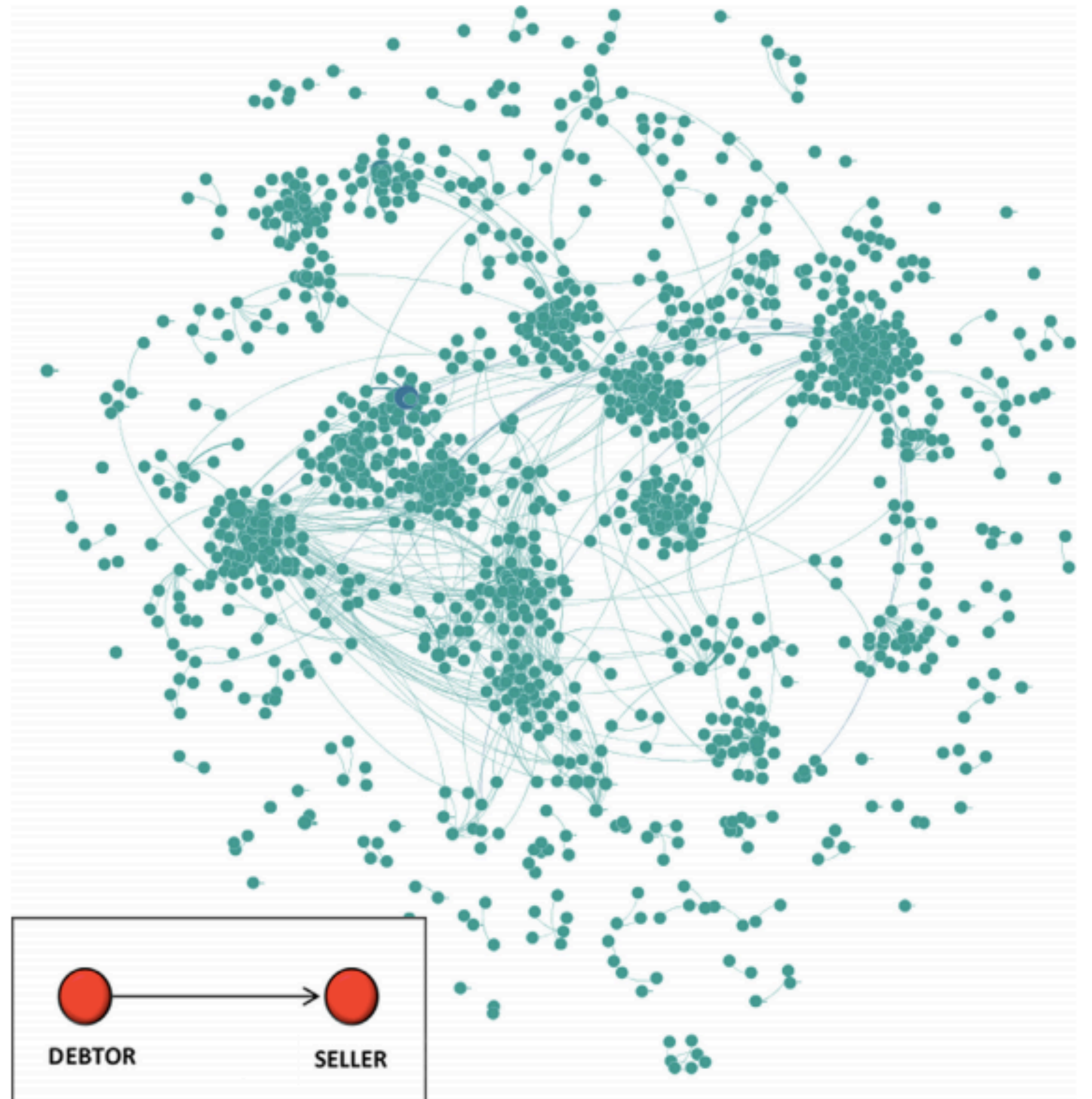
# fraud detection

Using social network analysis to prevent money laundering

Andrea Fronzetti Colladon\*, Elisa Remondi


University of Rome Tor Vergata, Department of Enterprise Engineering, Via del Politecnico, 1-00133 Rome, Italy

*identify nodes at higher risk of fraud based on their features and position in the transaction network*



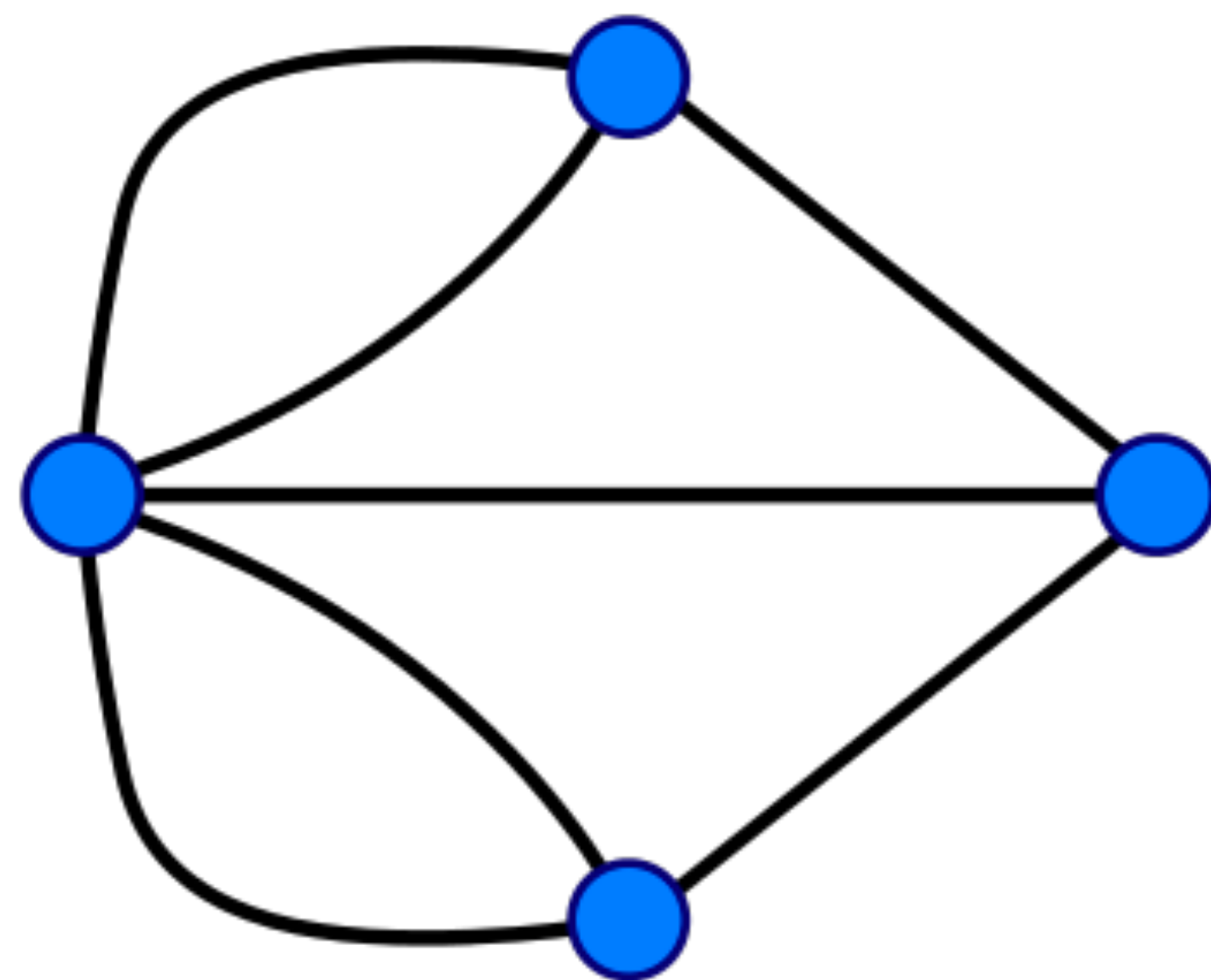
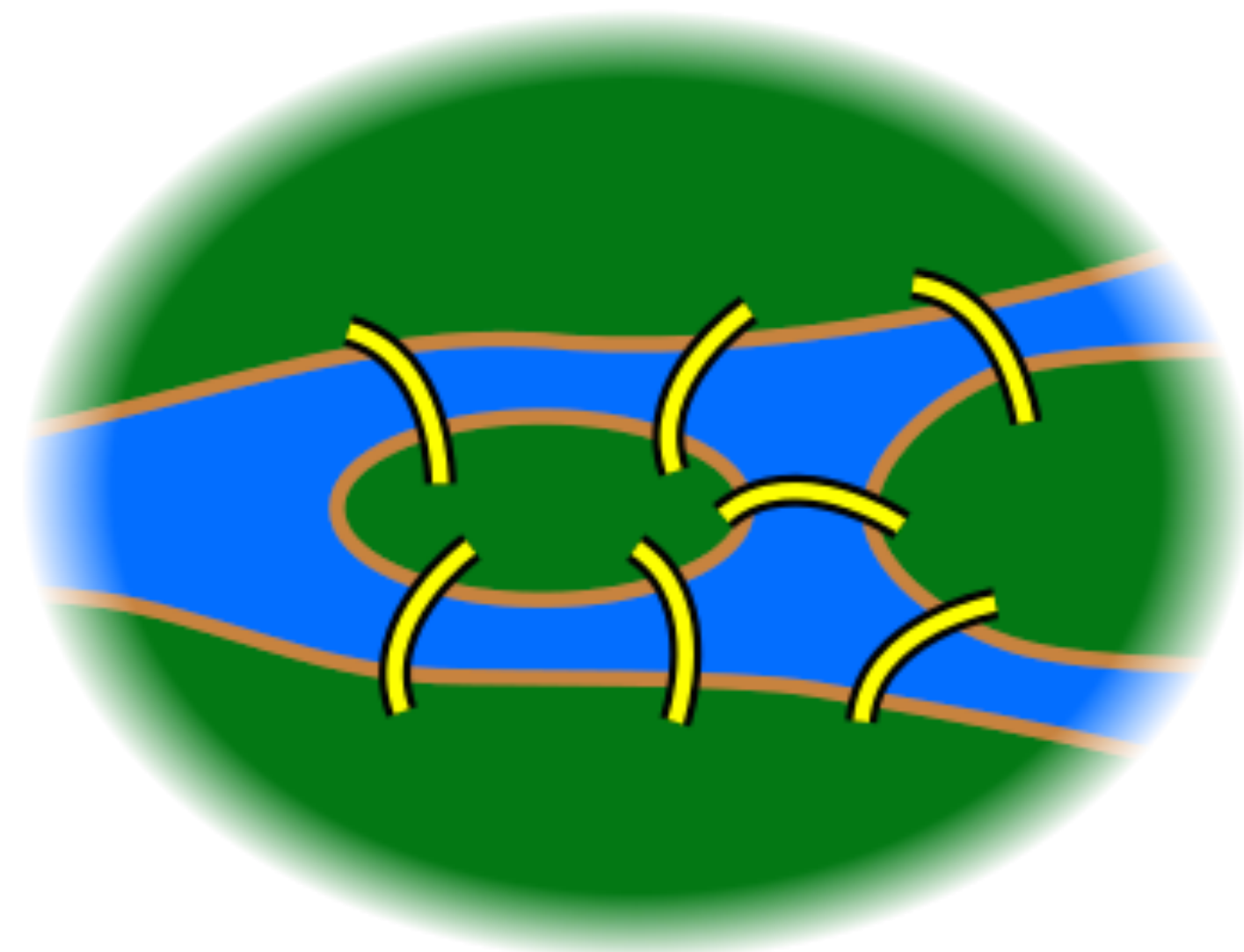
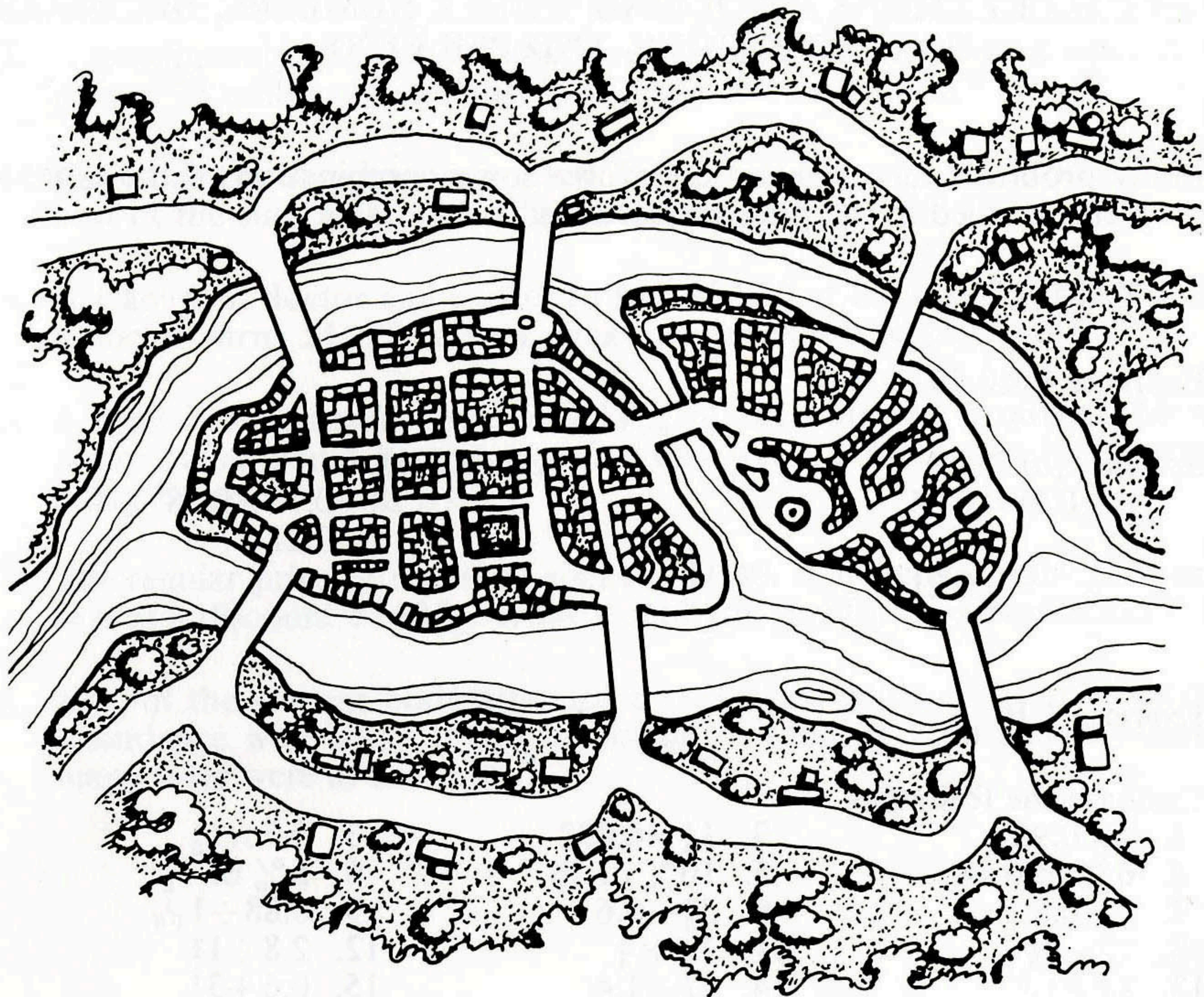


# references


- M. E. J. Newman, “Networks: an introduction” Oxford University Press
  - Albert-László Barabási, “Network Science” <http://networksciencebook.com/>
- 



# THE BRIDGES OF KONIGSBERG







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- Email contacts: maxime.lucas@centai.eu lorenzo.dallamico@isi.it (DO NOT WRITE TO @unito EMAILS please)