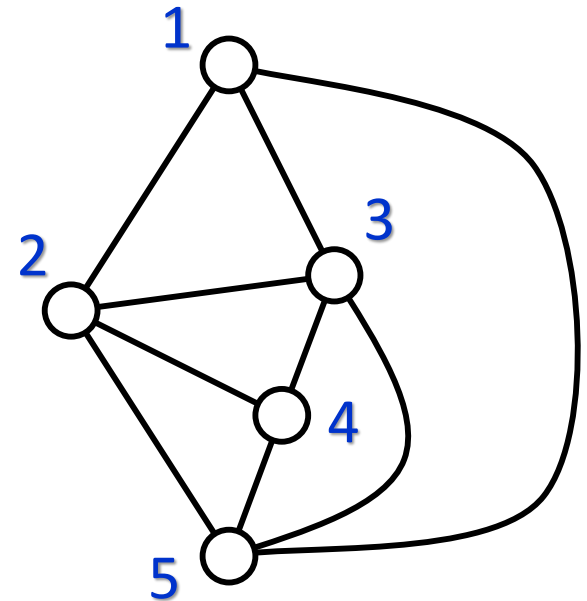


Network Thinking: Some Examples

Hiroki Sayama, D.Sc.

Binghamton University

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What Is Network Science?

- **Data-driven science** that focuses on “*how things are related*”, rather than what things are in isolation
- **Interdisciplinary science** that draws upon concepts and methods taken from *mathematics, computer science, physics, social sciences, humanities, etc.*

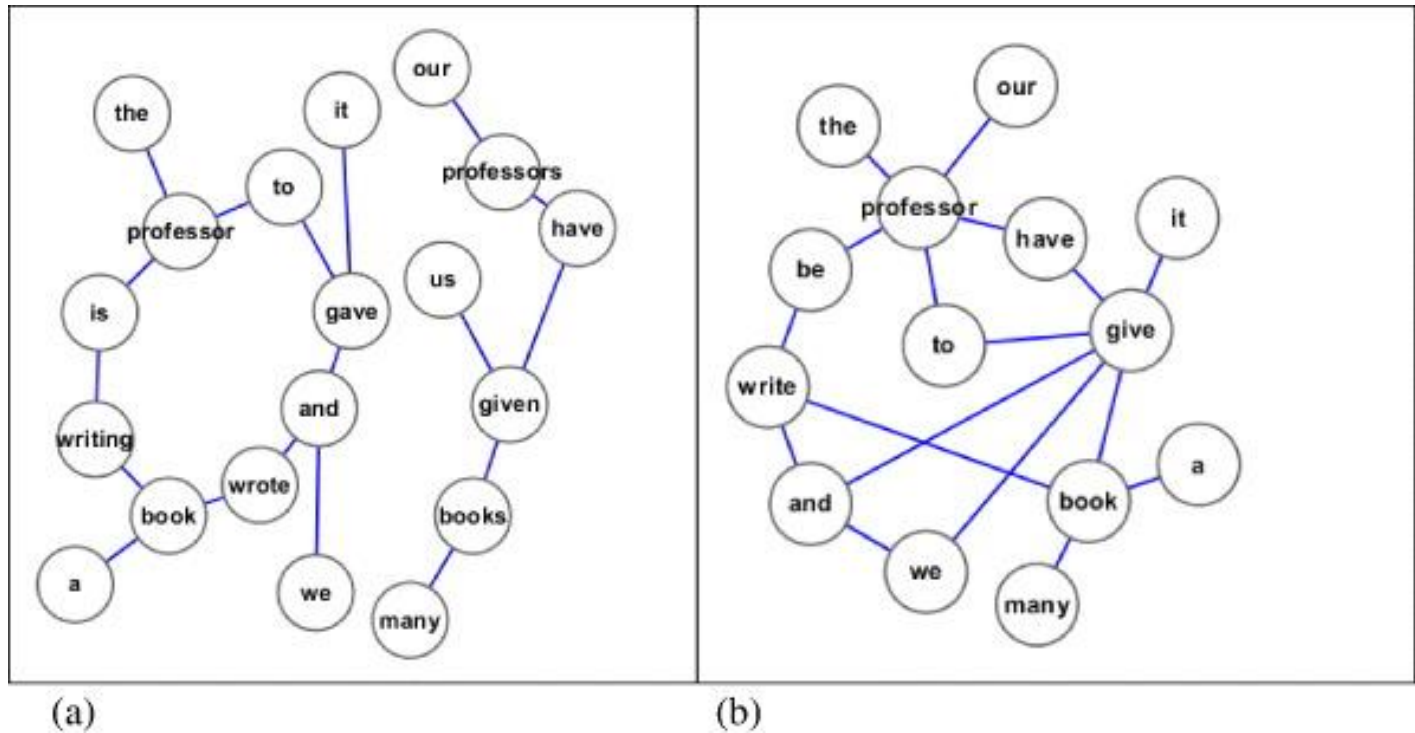
Astonishing Facts

- Various complex networks share a number of common features, despite their completely different origins
- Most real-world networks are huge, complex and heterogeneous, yet very “small” and “efficient”
 - “Six degrees of separation”



Networks in English

Network of Words (Syntactic)



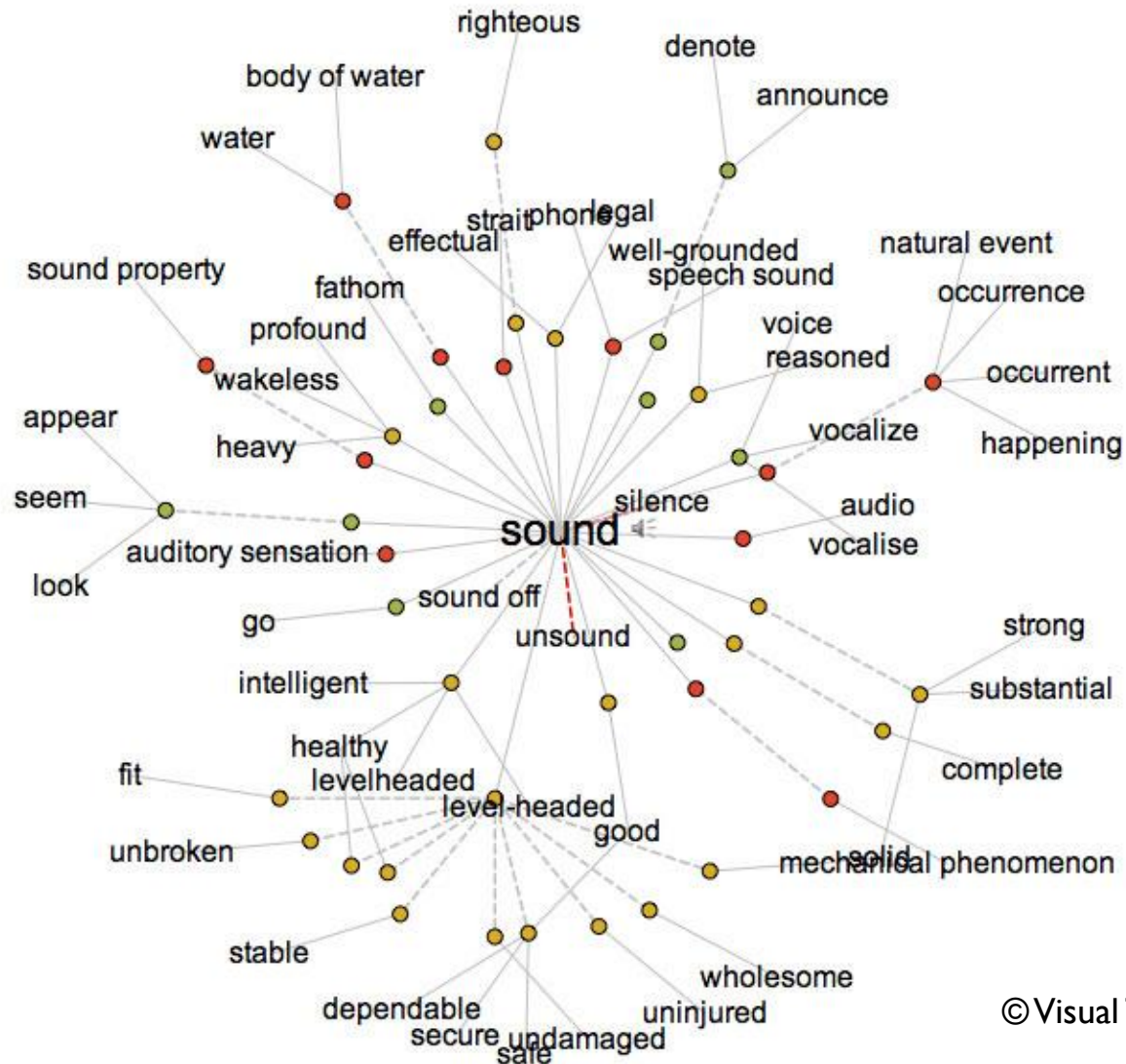
From Liu & Xu 2011; networks were generated from the following three sentences:

This professor is writing a book.

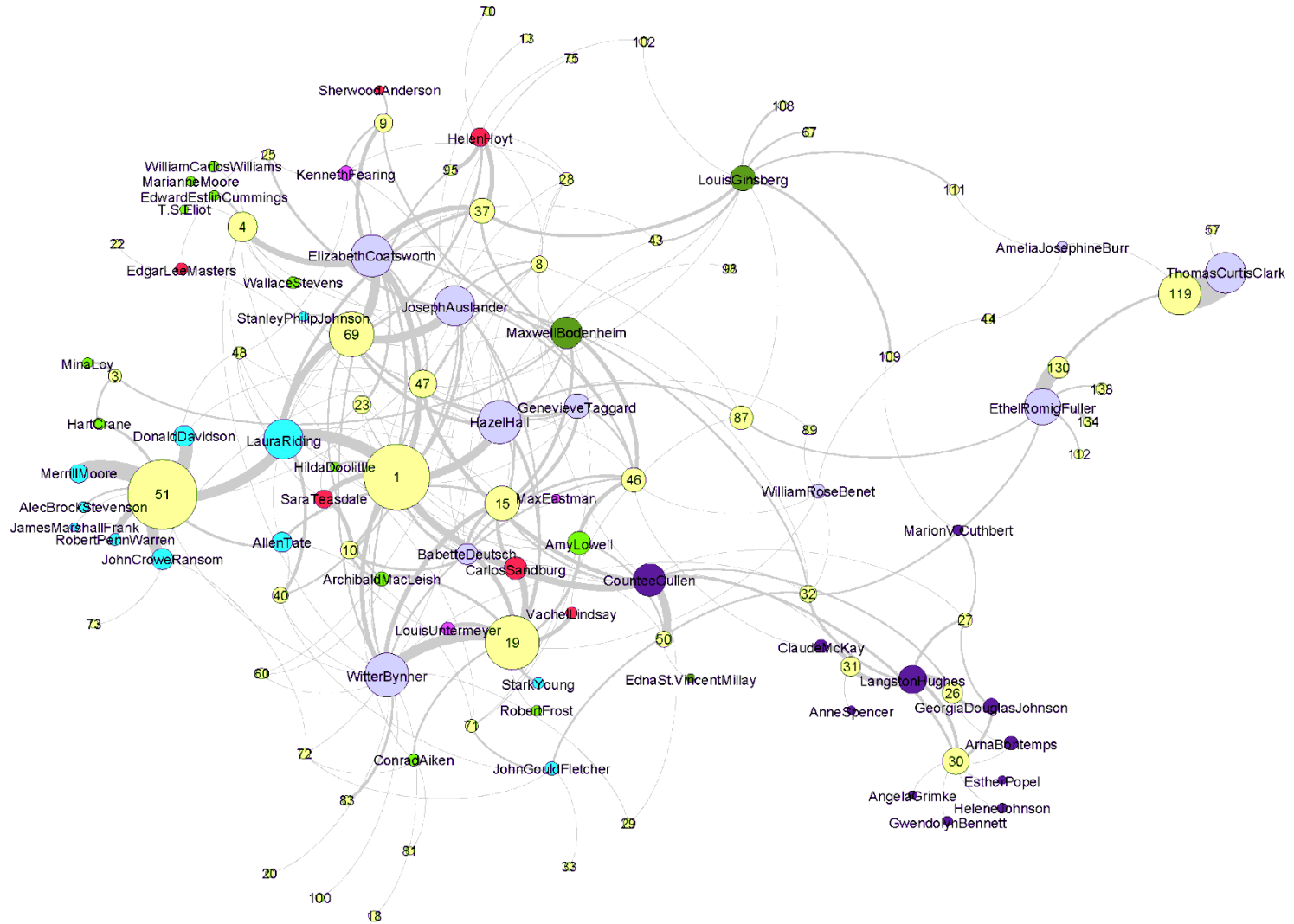
Our professors have given us many books.

We wrote a book and gave it to the professor.

Network of Words (Semantic)

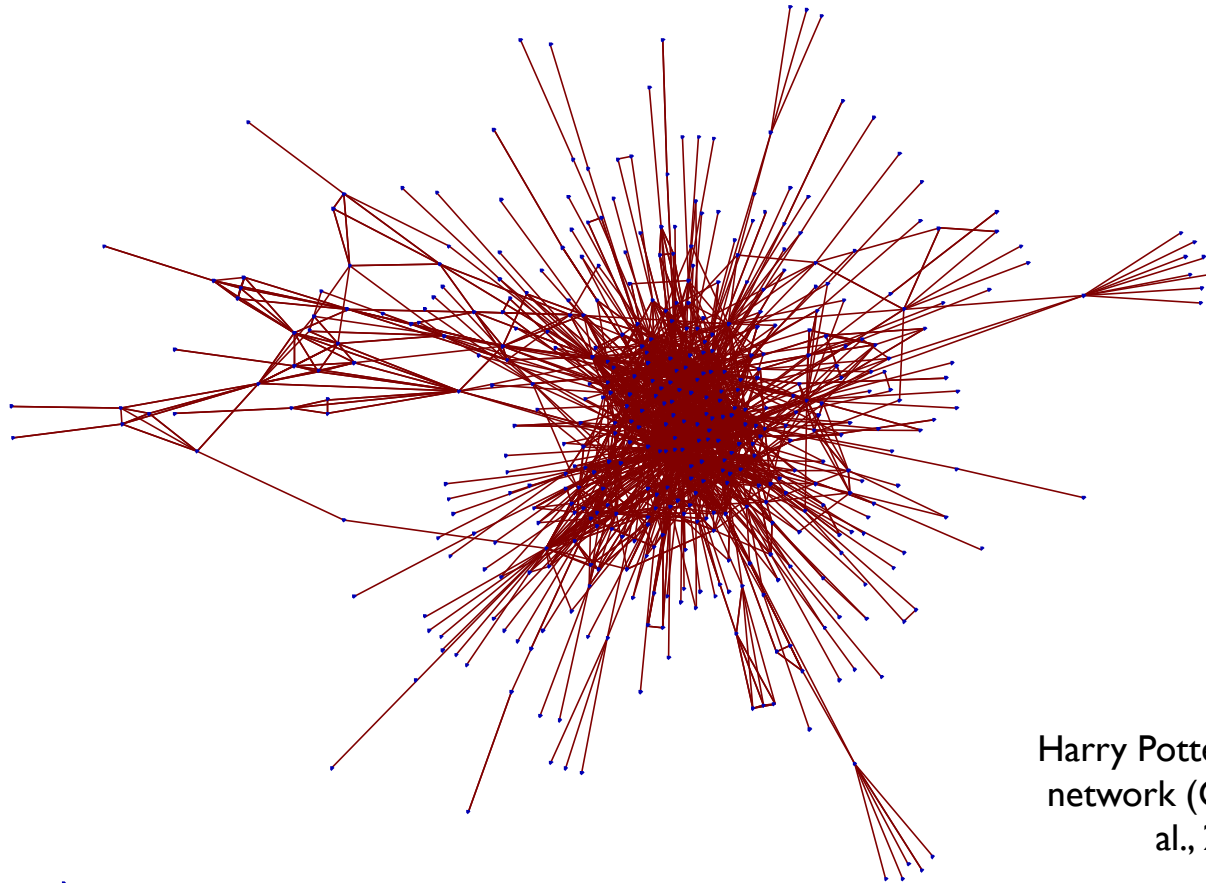


Network of U.S. Poets (1924-25)

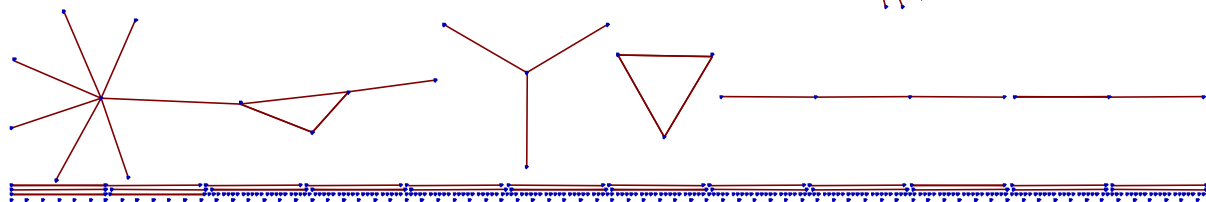


Hoyt Long: Literary Networks. <http://lucian.uchicago.edu/blogs/literarynetworks/>

Network of Fictional Characters



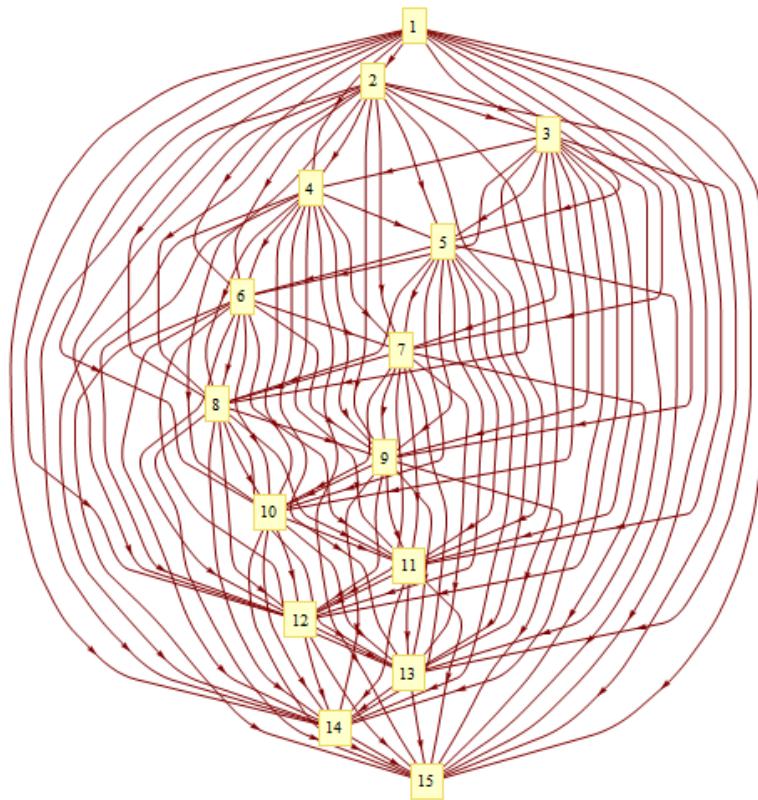
Harry Potter's character network (Calderone et al., 2011)



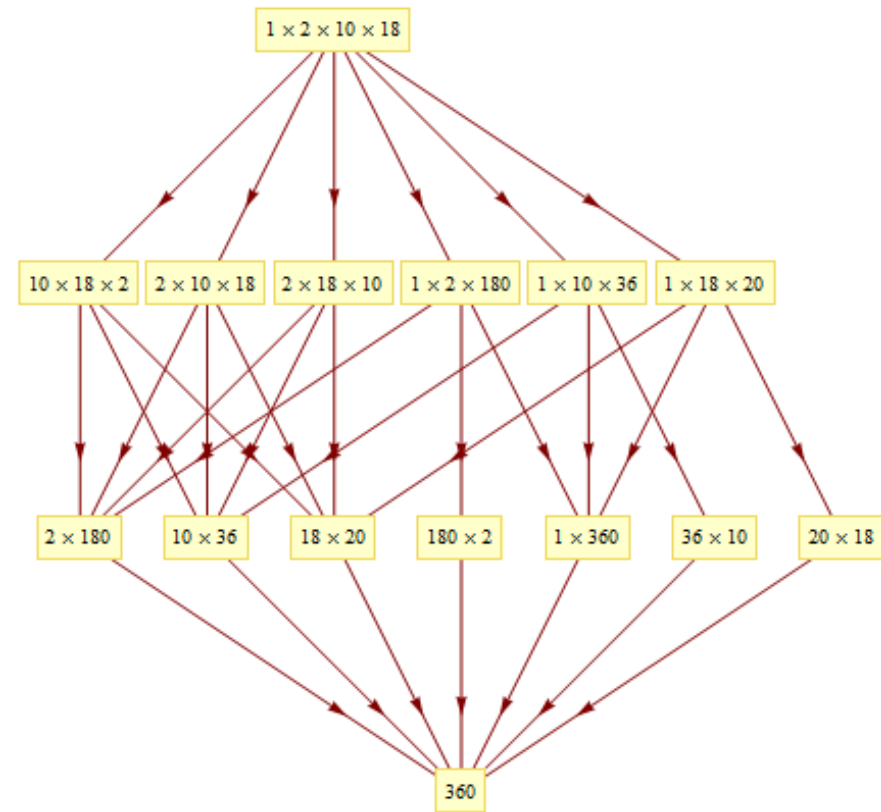


Networks in Math

Networks of Numbers (I)

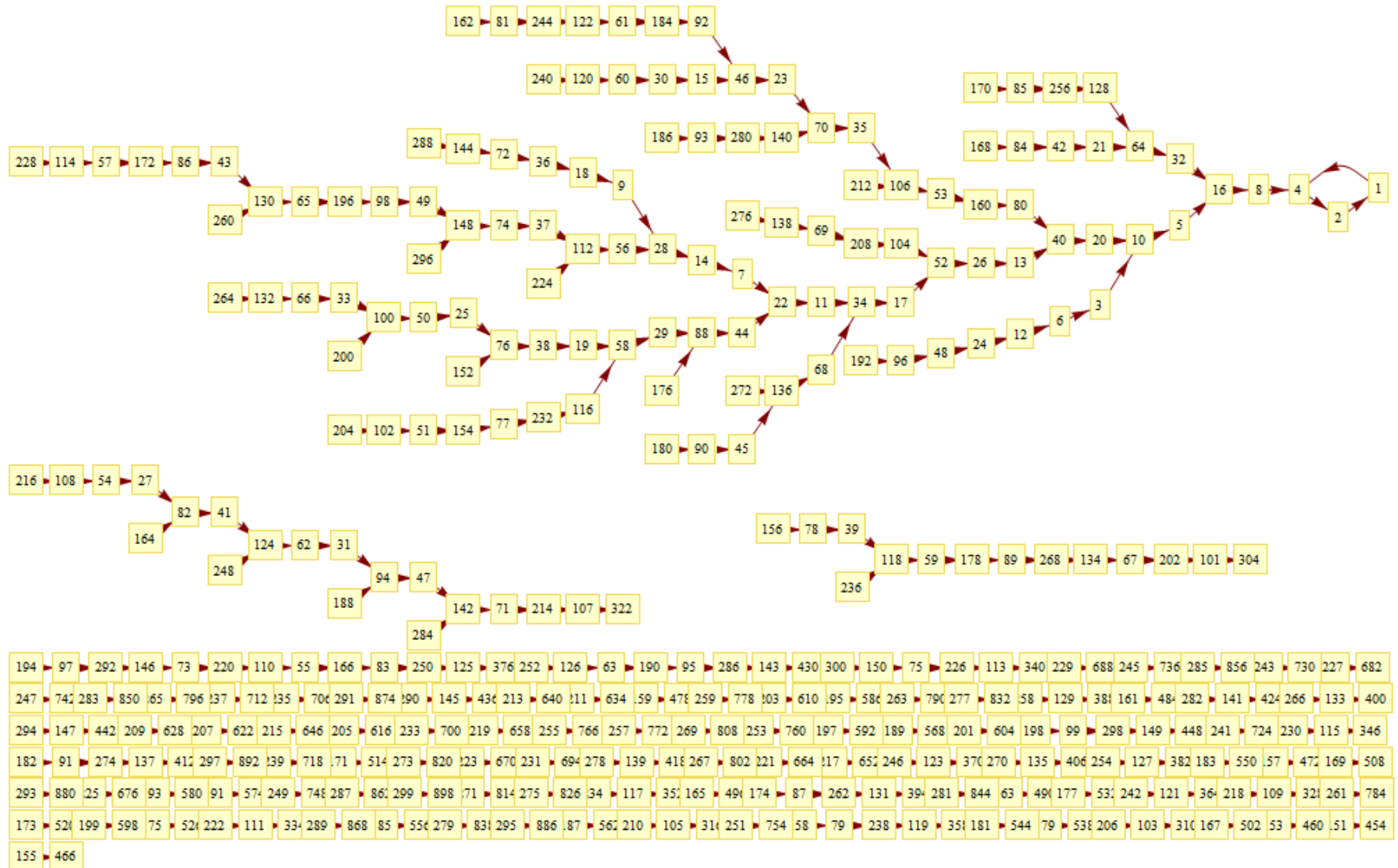


Transitivity network ($i \rightarrow j$ if and only if $i < j$)



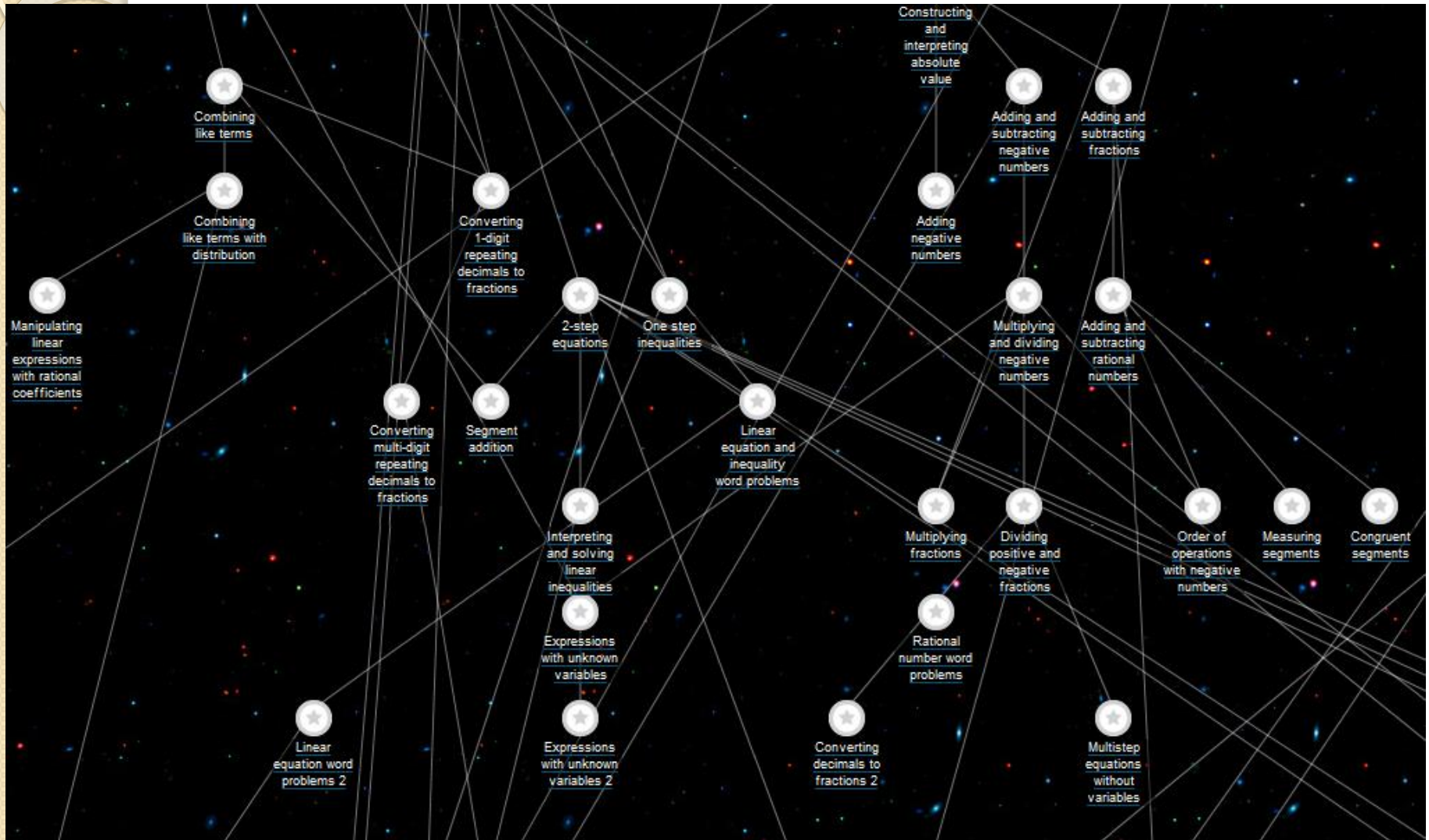
Associativity network (about multiplication)

Networks of Numbers (2)



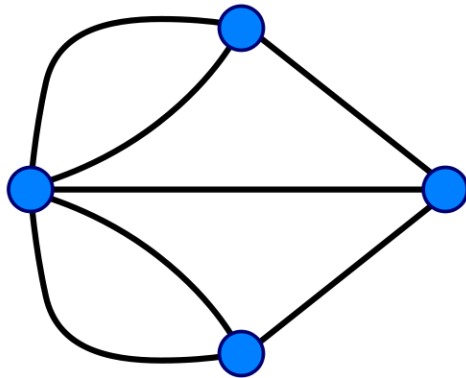
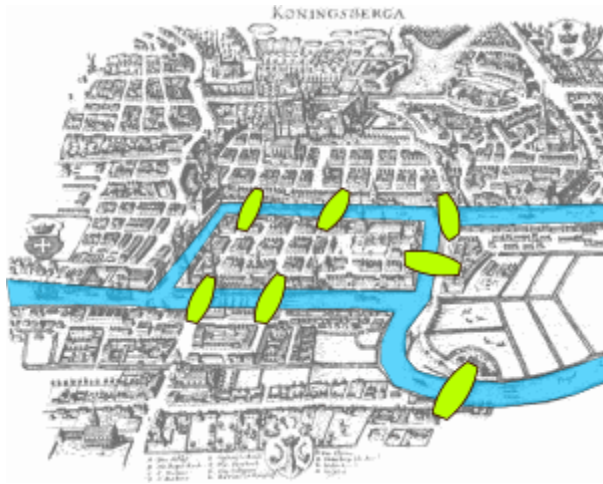
Collatz sequence ($x \rightarrow y$; $y = x/2$ if x is even, or $3x+1$ otherwise)

Network of Concepts



Knowledge Map (from Khan Academy)

Networks in Math Puzzles



Seven bridges of Königsberg
(images from Wikipedia)

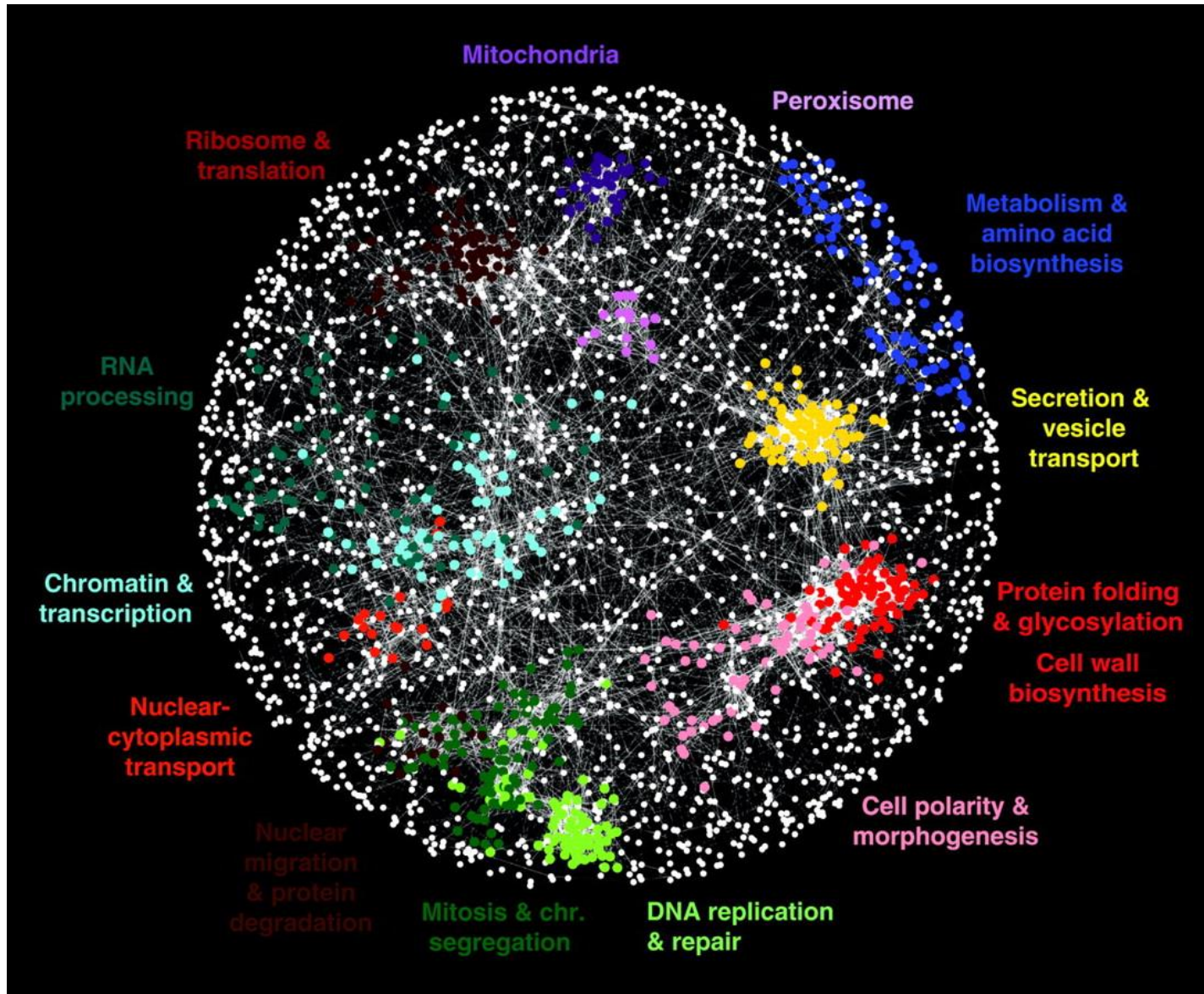


42 bridges in Bristol, UK
(images from Bristol Post / Dr. Thilo Gross)



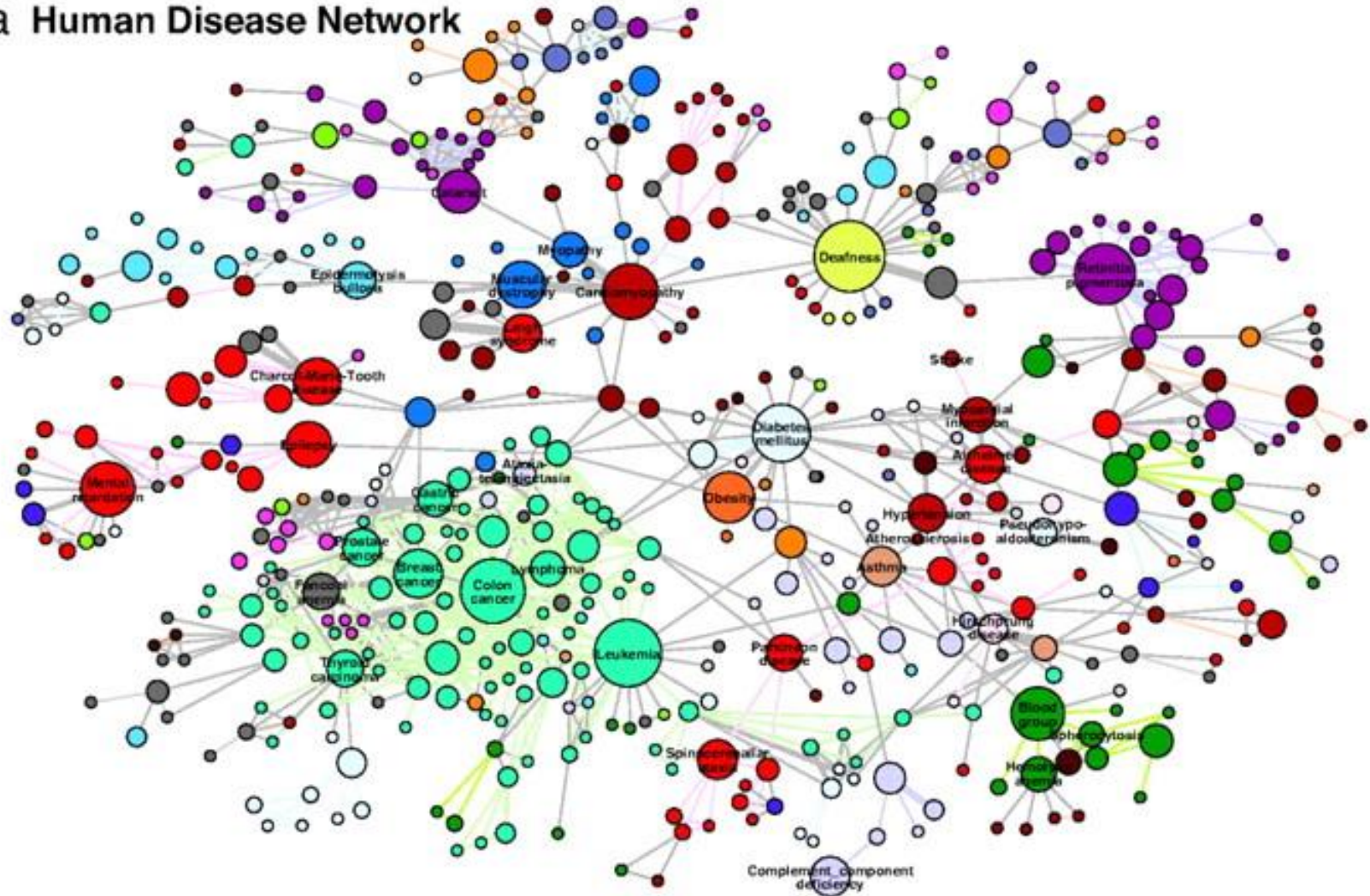
Networks in Science

Network of Genes

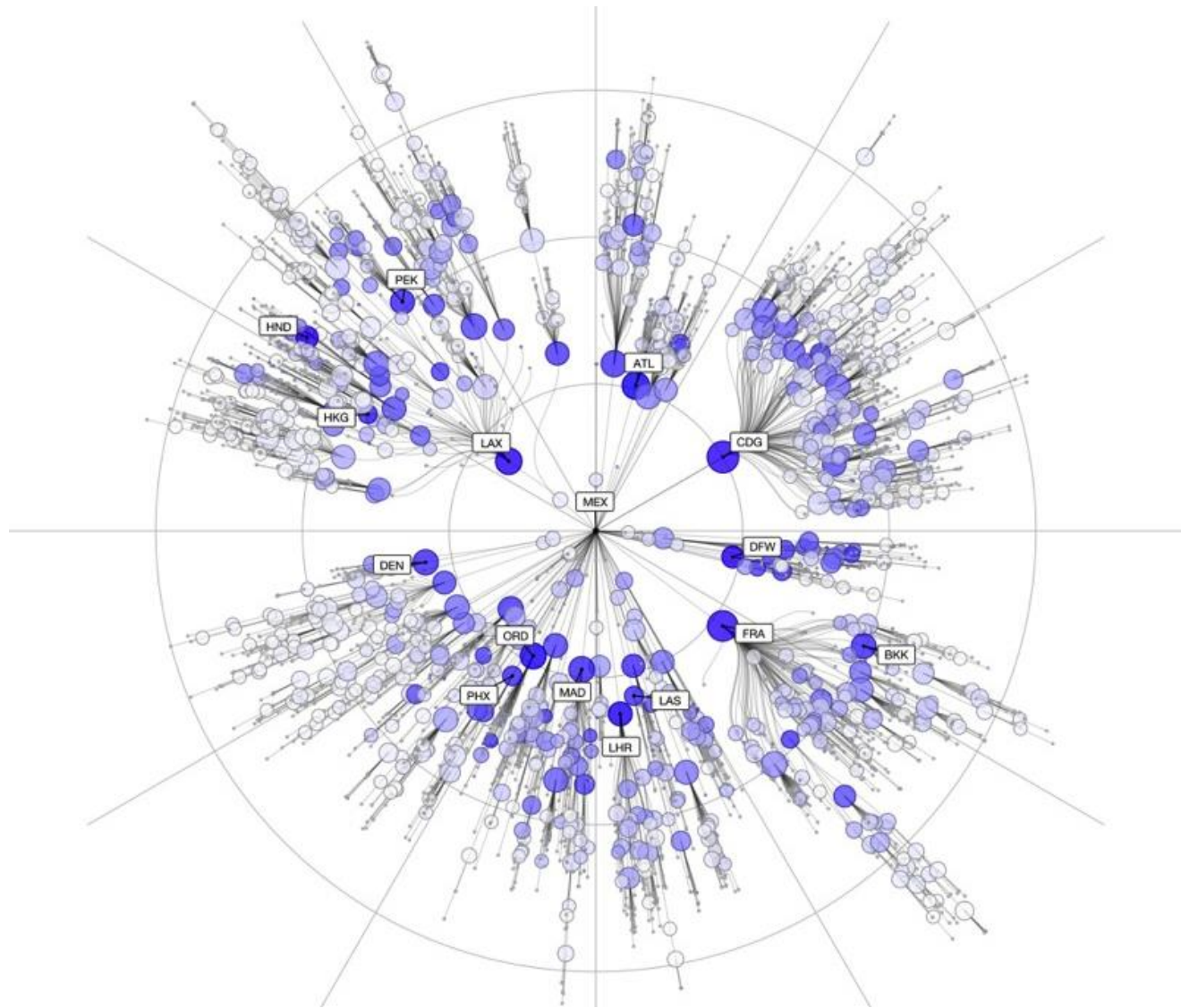


Network of Diseases

a Human Disease Network

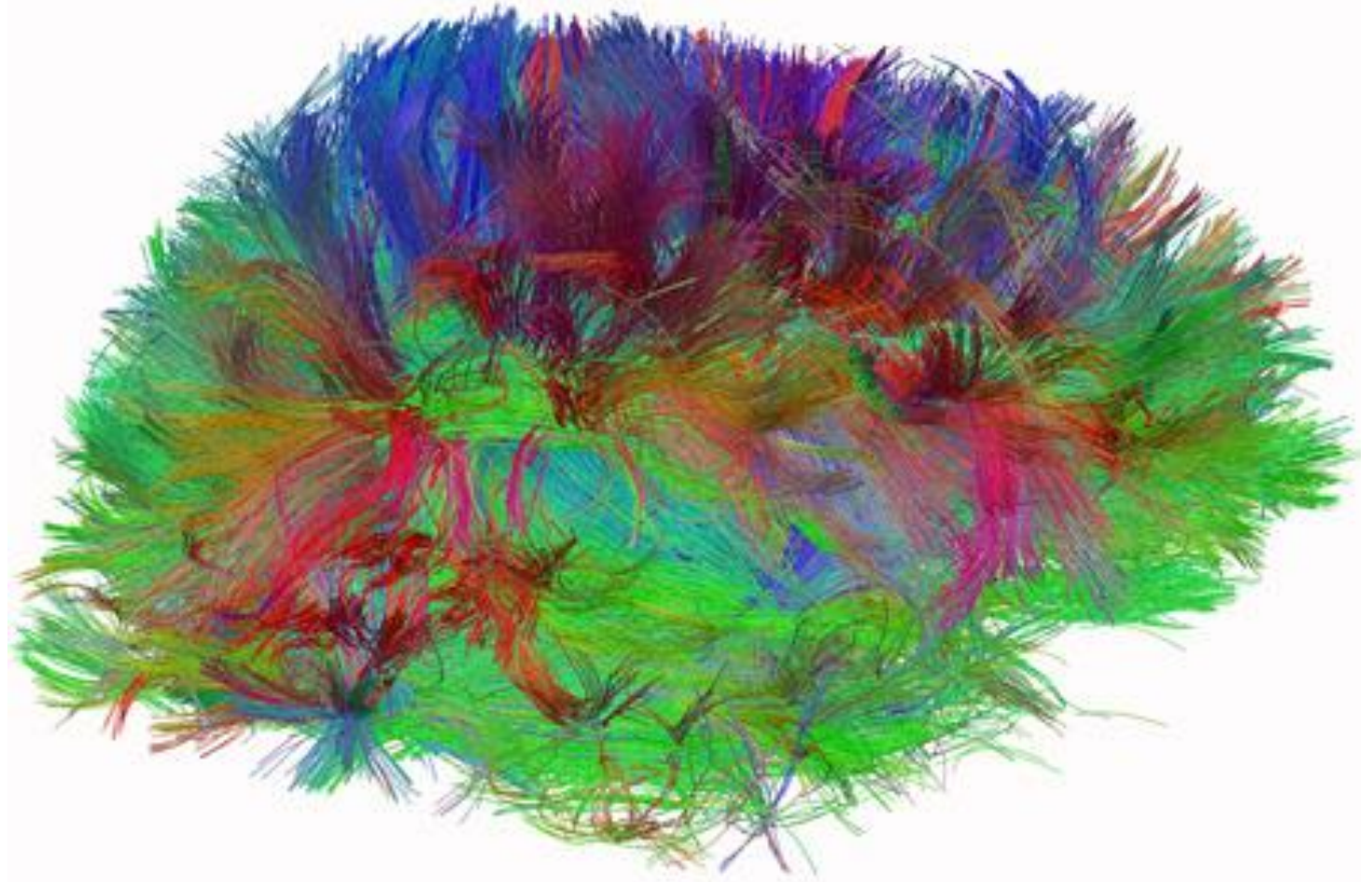


Network of Disease Propagation



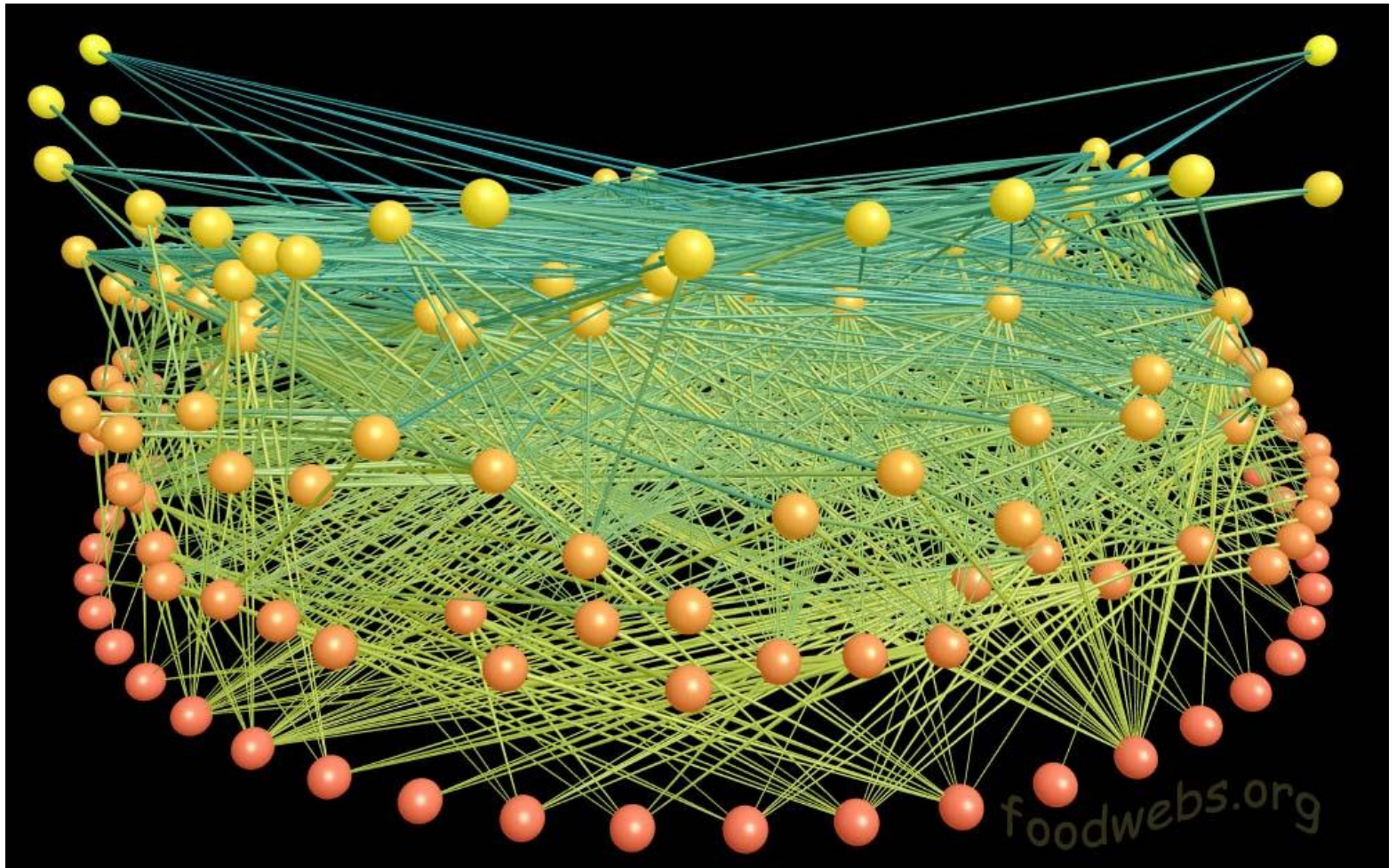
H1N1 activities illustrated according to distance from MEX airport (Brockmann, 2013)

Network of the Brain



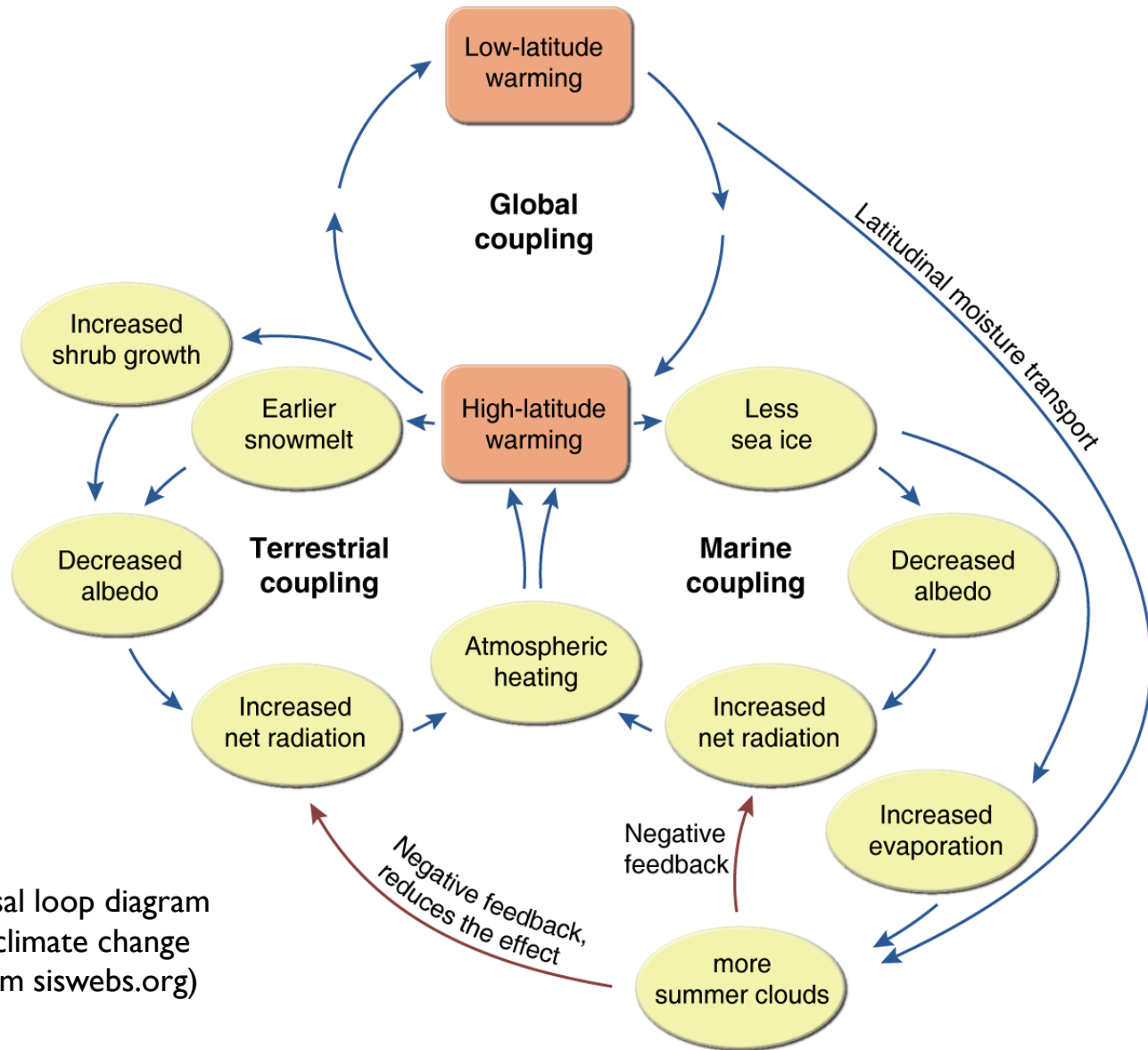
Van J. Wedeen, M.D., MGH/Harvard U.

Food Webs



Food web in El Verde Rainforest, Puerto Rico by J. Dunne (from foodwebs.org)

Causal Loop Diagram

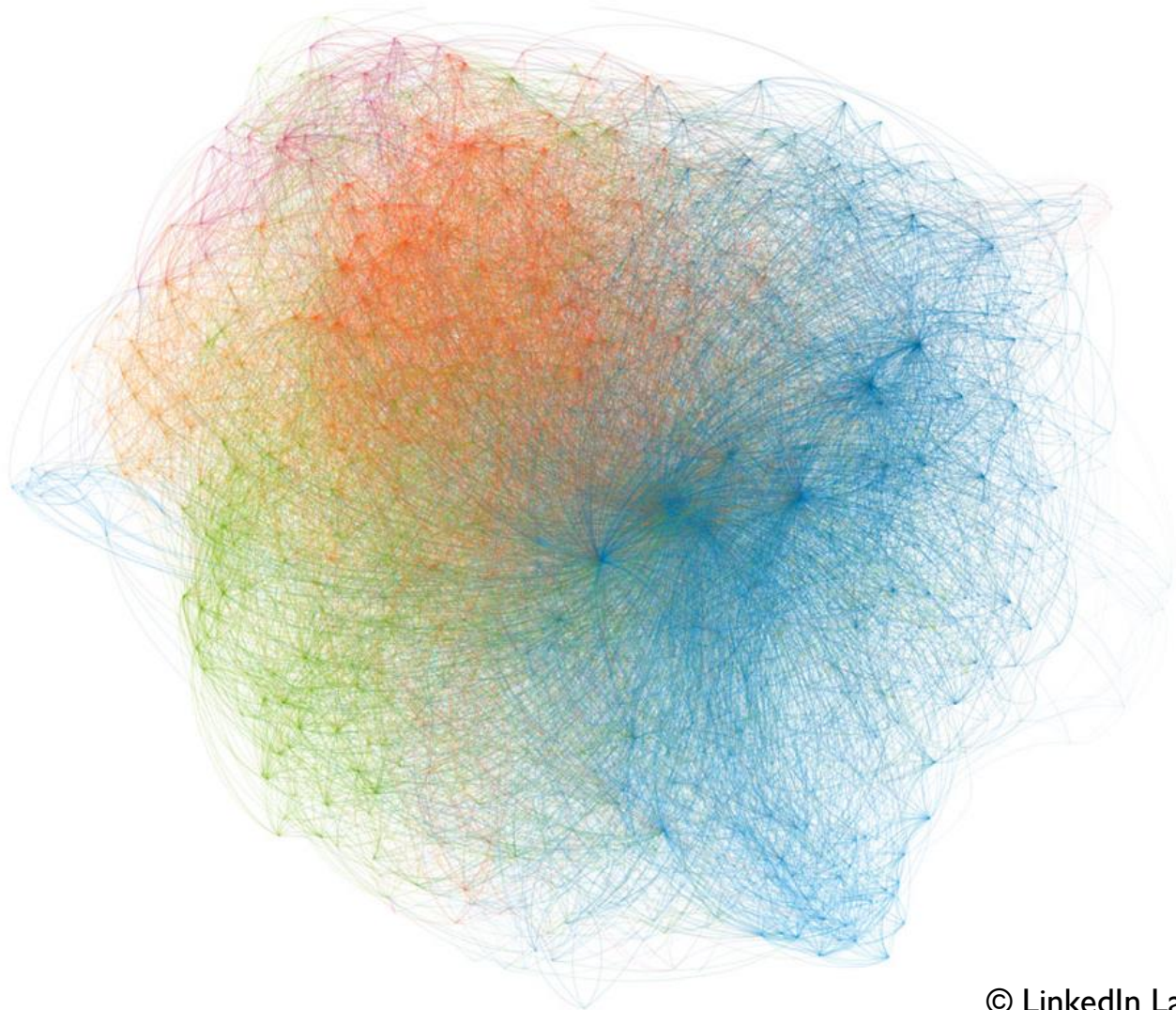


Causal loop diagram
of climate change
(from siswebs.org)

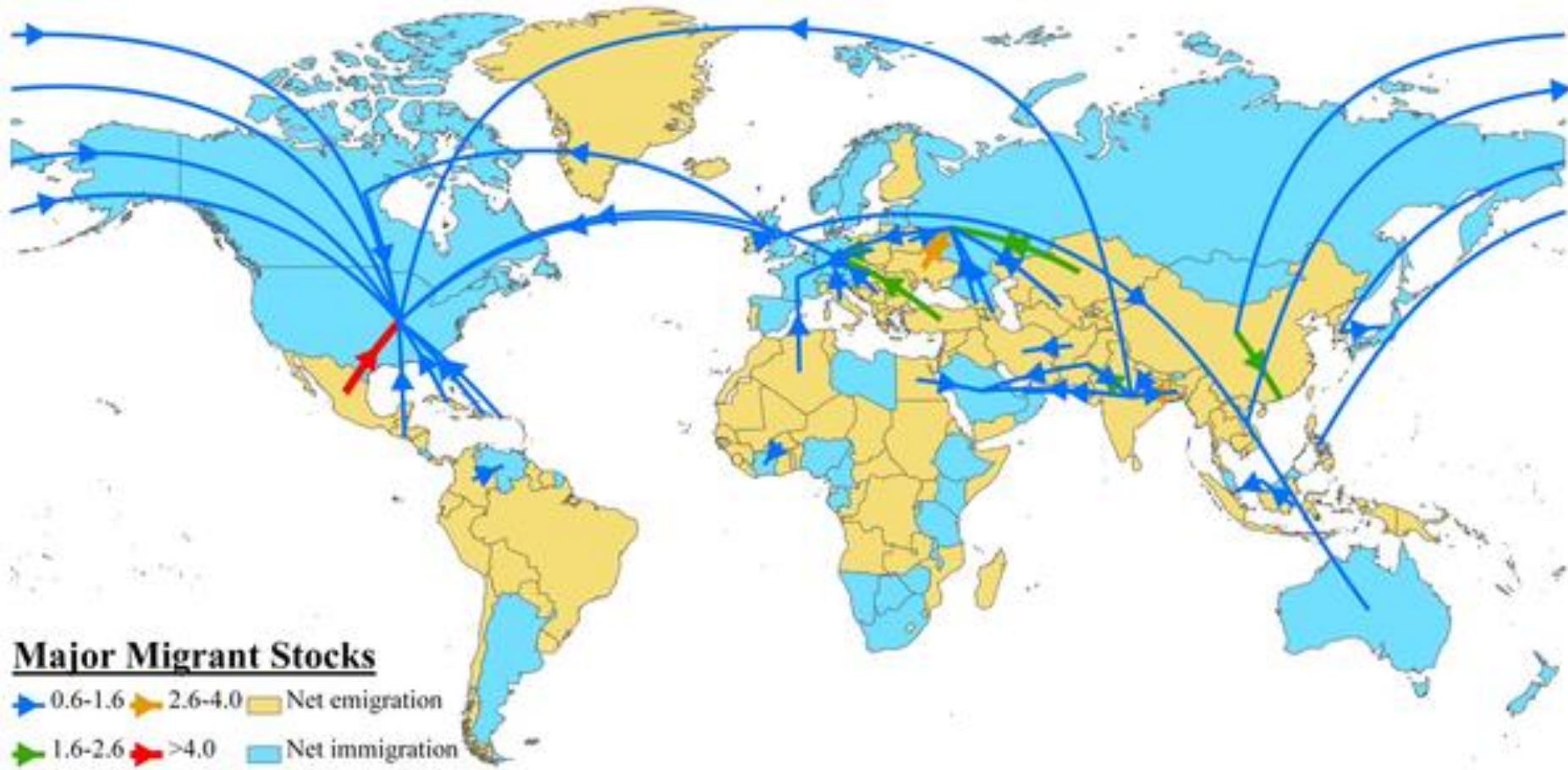


Networks in Social Studies

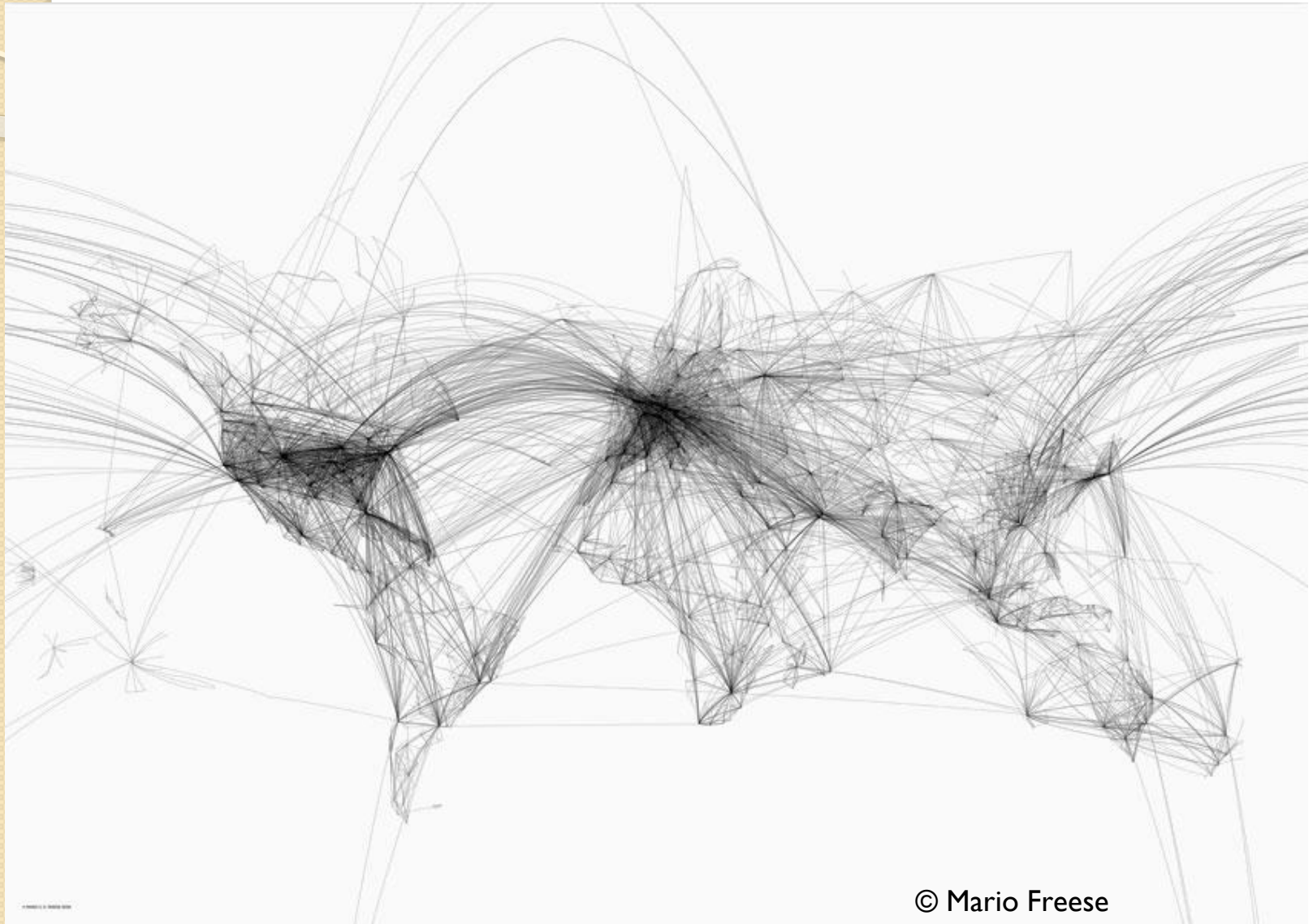
Network of People Around You



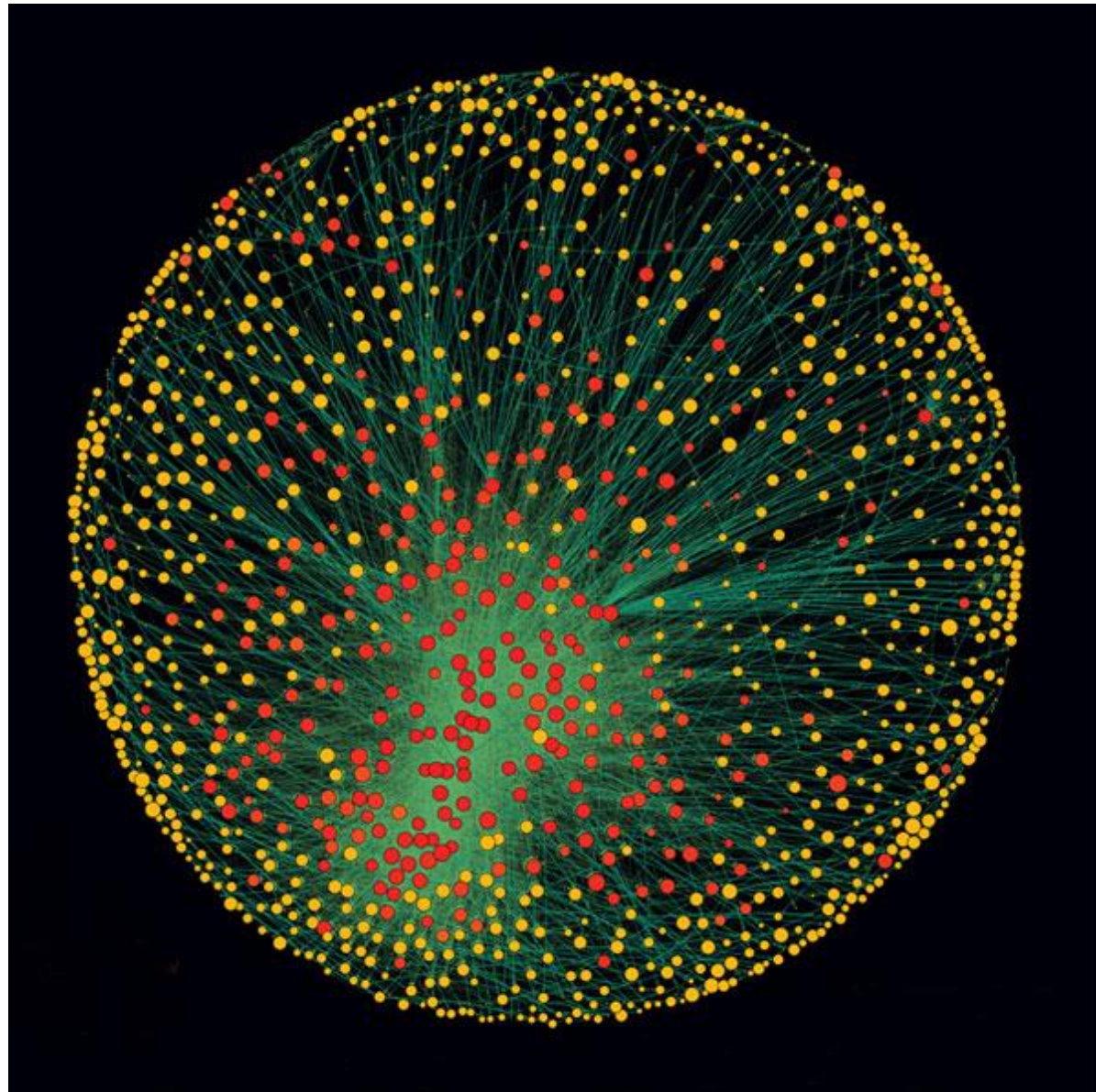
Network of Human Migration



Network of Transportations

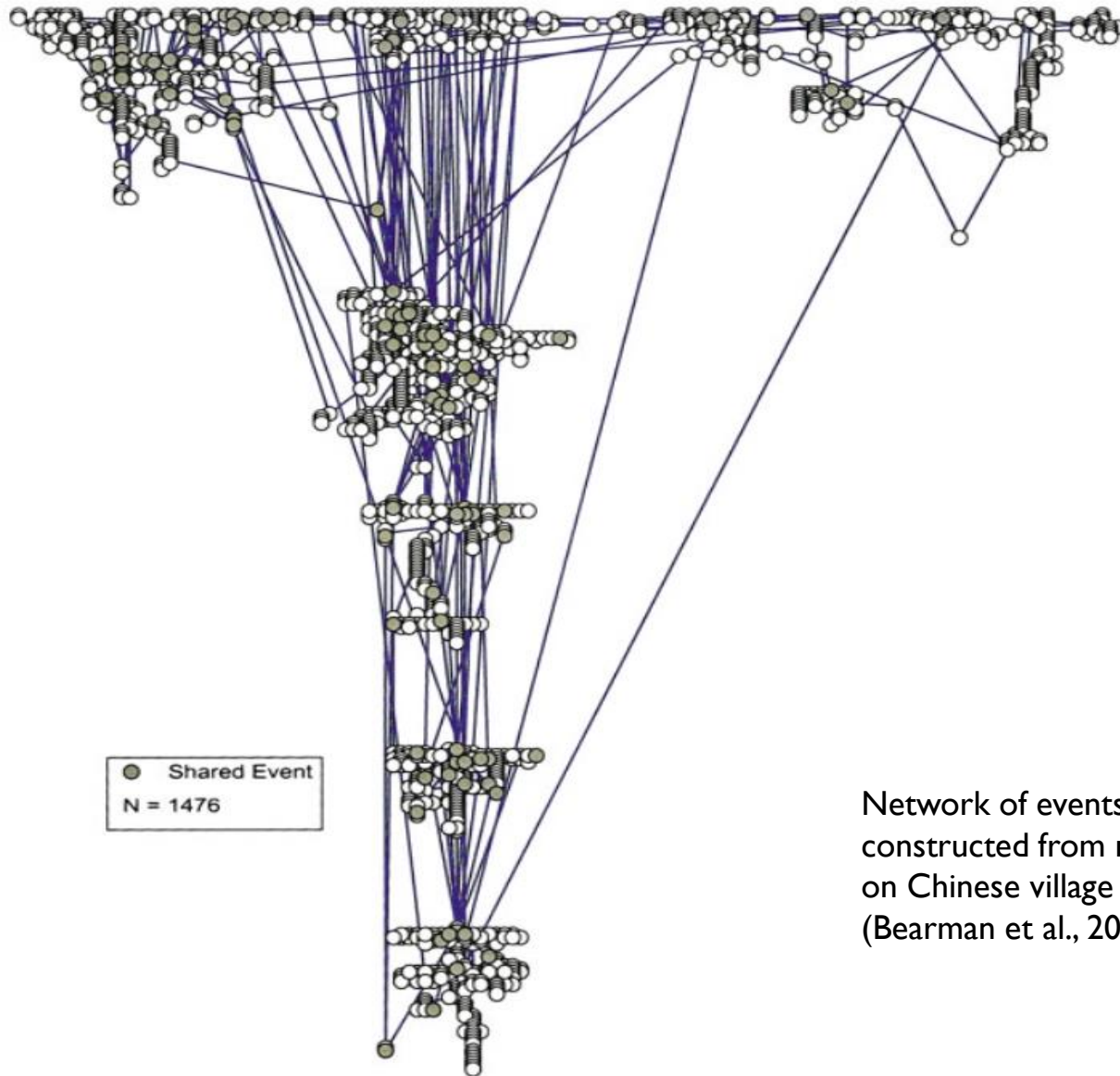


Network of Corporations



Vitali et al.,
2011

Network of Historical Events

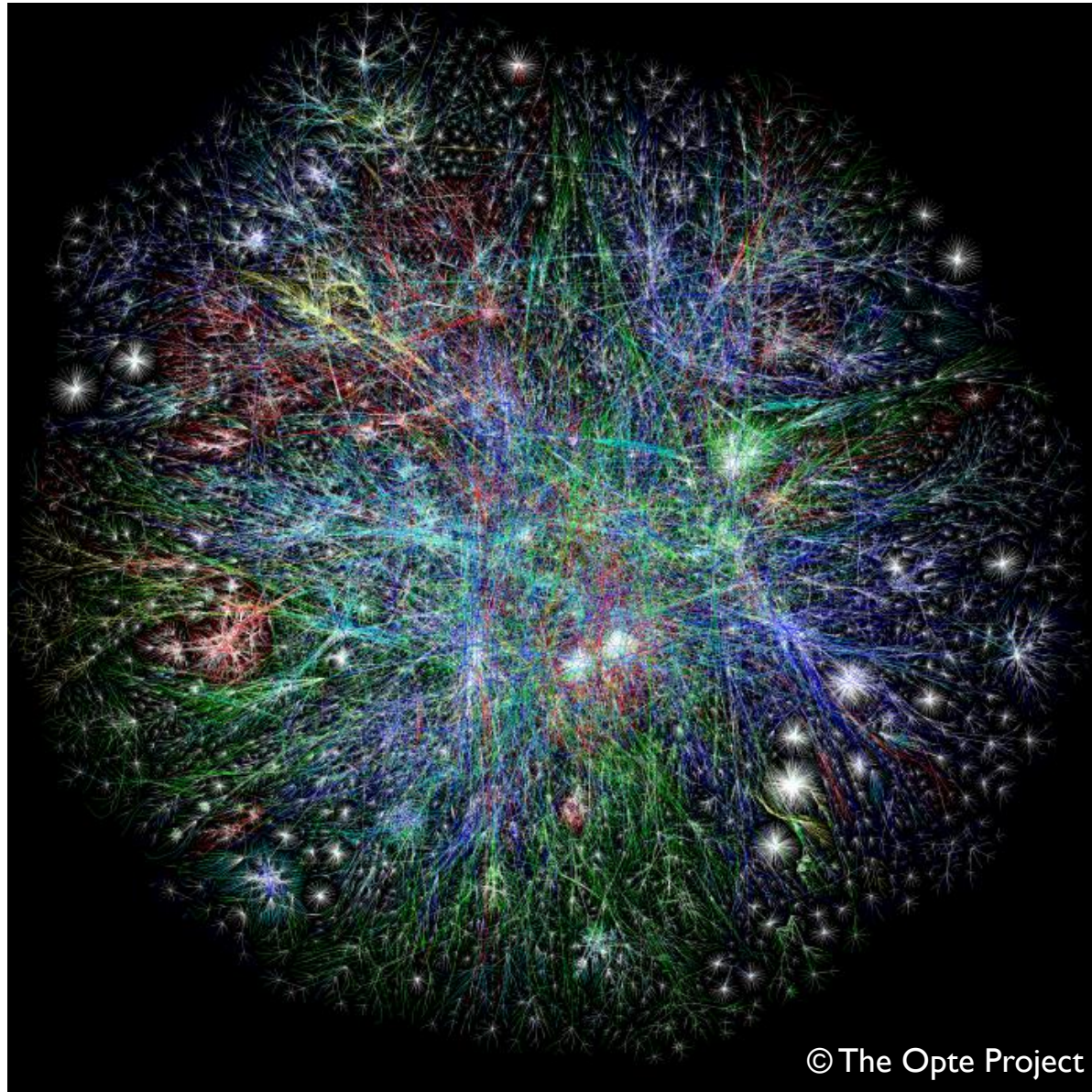


Network of events
constructed from narratives
on Chinese village Liu Ling
(Bearman et al., 2003)

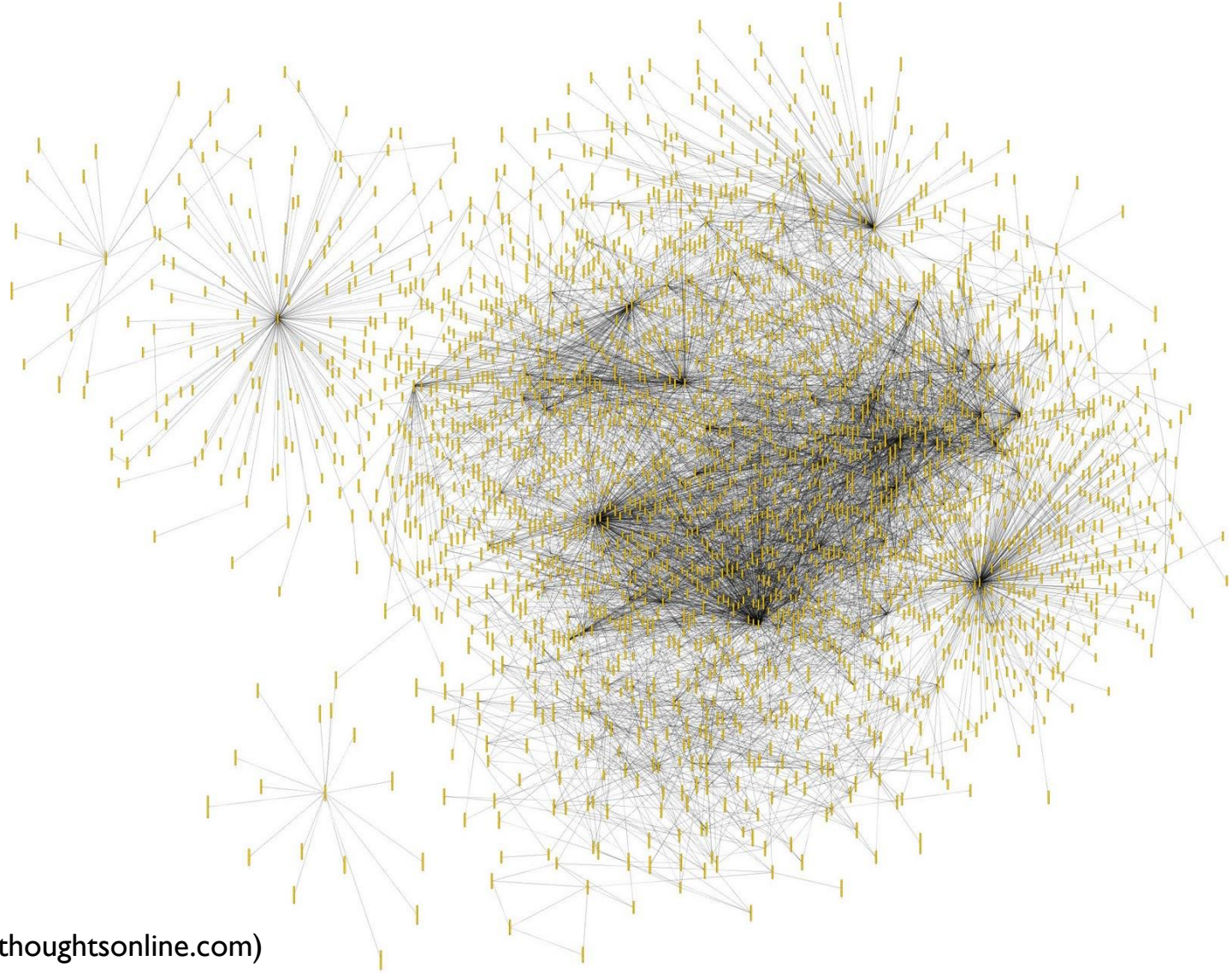


Networks in Technical Education

The Internet



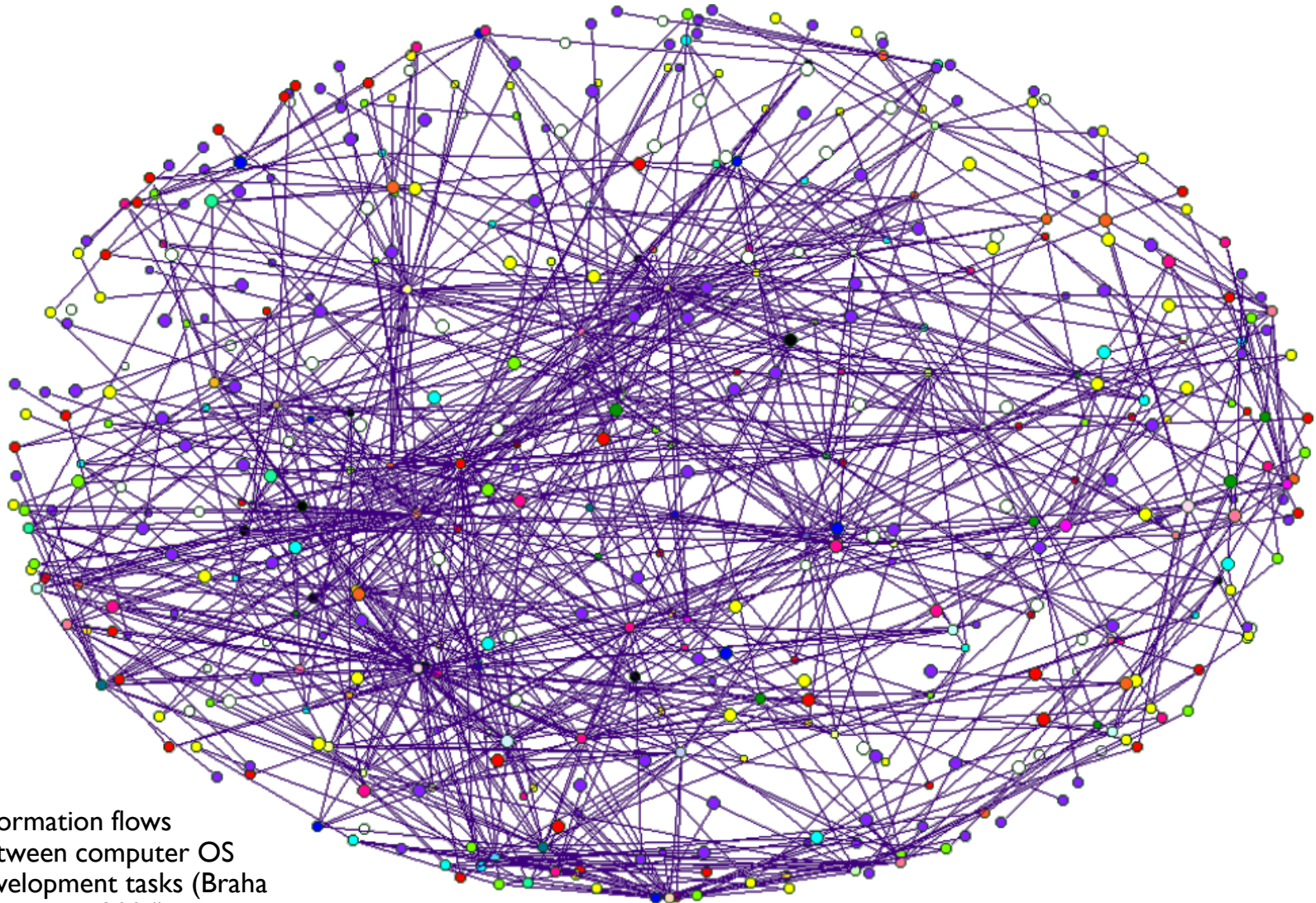
Network of Java Classes



Cavlin, 2012

(from simplethoughtsonline.com)

Network of Product Design



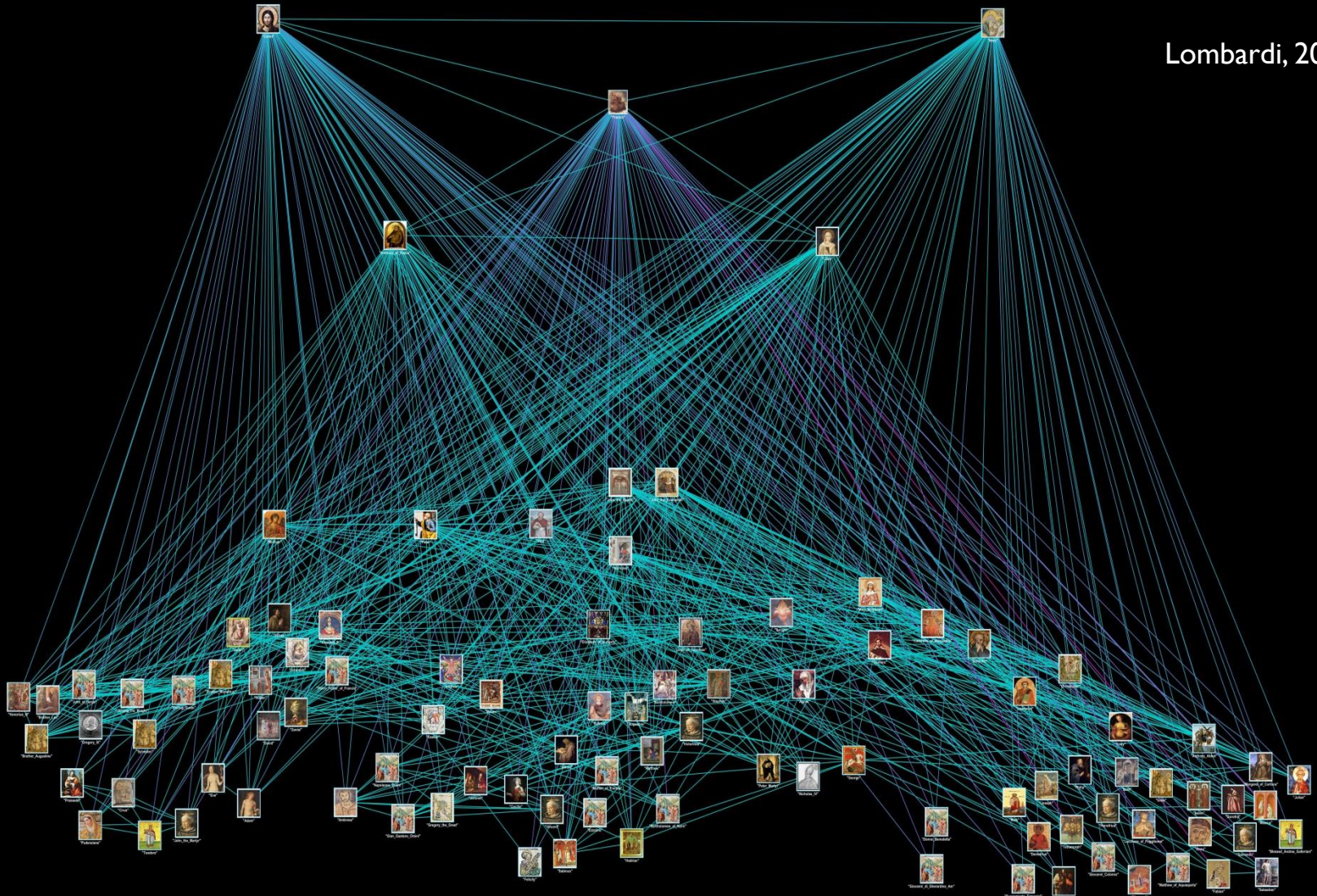
Information flows
between computer OS
development tasks (Braha
& Bar-Yam, 2004)



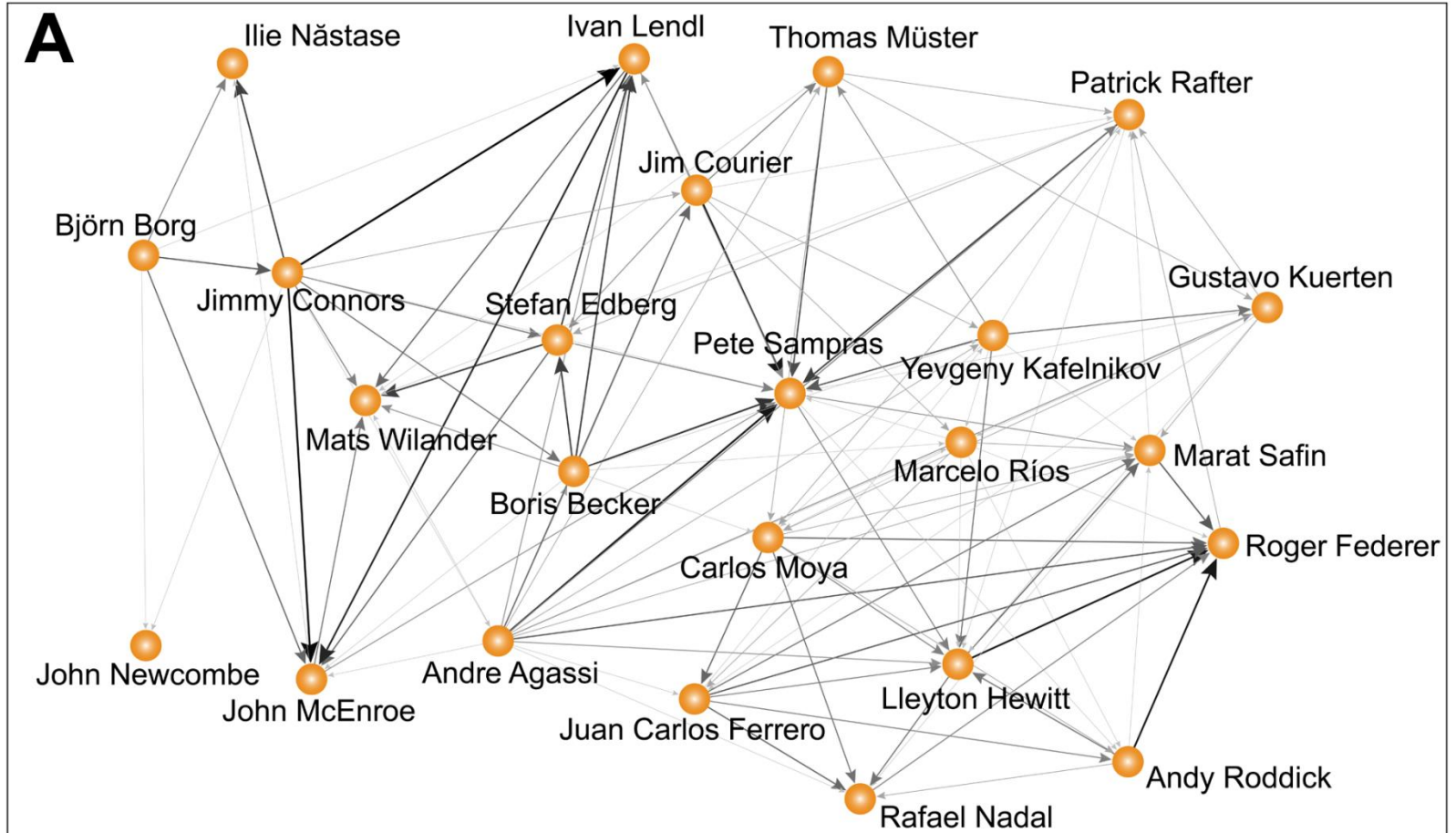
Networks in Other Subjects

Network of Saints in Iconography

Lombardi, 2013



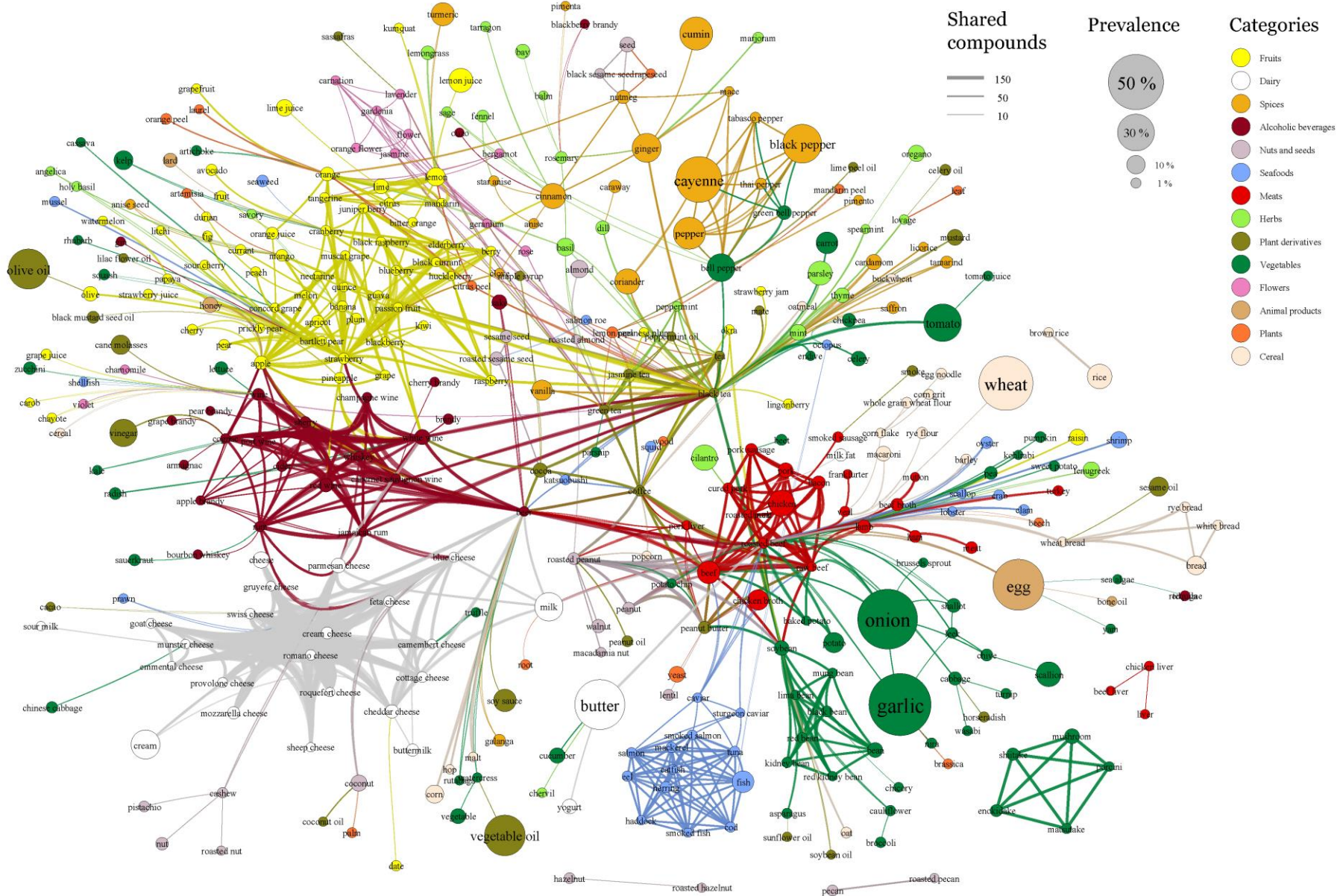
Network of Top Tennis Players



Flavor Network

Yong-Yeol Ahn, Sebastian Ahnert, James P. Bagrow, and A.-L. Barabási

"Flavor network and the principles of food pairing", *Scientific Reports* 1, 196 (2011)

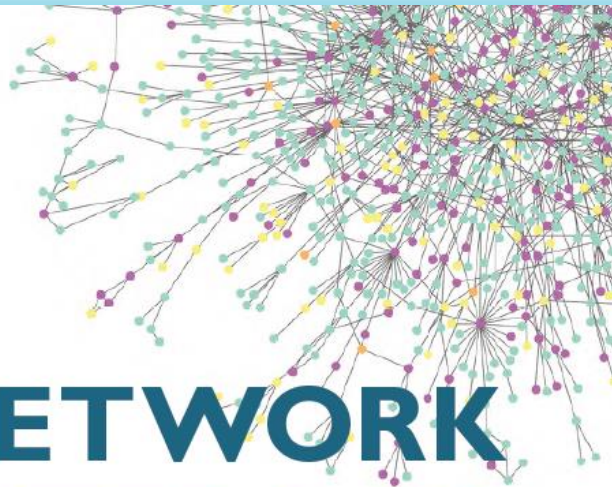


Flavor network. Culinary ingredients (circles) and their chemical relationship are illustrated. The color of each ingredient represents the food category that the ingredient belongs to, and the size of an ingredient is proportional to the usage frequency (collected from online recipe databases: epicurious.com, allrecipes.com, menuplan.com). Two culinary ingredients are connected if they share many flavor compounds. We extracted the list of flavor compounds in each ingredient from the book "Fenaroli's handbook of flavor ingredients (5th ed.)" and then applied a backbone extraction method by Serrano et al. (*PNAS* 106, 6483) to pick statistically significant links between ingredients. The thickness of an edge represents the number of shared flavor compounds. To reduce clutter, edges are bundled based on the algorithm by Danny Holten (<http://www.win.tue.nl/~dholten/>).

Take-Home Message

- Anything can be understood as a network if you pay attention to “**connections**” between things

“Network Literacy: Essential Concepts and Core Ideas”



NETWORK LITERACY

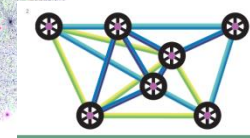
Essential Concepts and Core Ideas



NetSciEd

1 NETWORKS ARE EVERYWHERE

- The concept of networks (social and general) and of discrete low-frequency oscillations has been used in many aspects of life.
- There are networks that describe the physical structure of our world: transportation, the human electrical grid, the world wide web, etc.
- There are networks of people: e.g. family networks, computer networks, Facebook/Flickr networks, professional groups, etc.
- There are economic networks: e.g. a network of products, financial transactions, corporate or banking relationships, etc.
- There are biological and ecological networks: e.g. food webs, gene networks, neural networks, protein-protein interactions, ecological systems that are interacting, complex ecosystems, their dynamic states, people connected in events, etc.
- Networks exist at various scales across temporal scales.

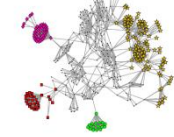


2 NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- There is a notion of connectivity for nodes/interactions. The global properties (like clustering or assortativity) are important to the system.
- Connections are called links, edges or interactions. They can be directed or undirected.
- Connections can be weighted (strength, frequency). They can be positive or negative.
- The number of connections of a node is called the degree of that node.
- Many networks have been found that are similar to each other: e.g. social networks, biological networks, financial networks, etc.
- Global network properties like clustering, assortativity, etc. are important to the system.
- Some networks have been found that are similar to each other: e.g. social networks, biological networks, financial networks, etc.

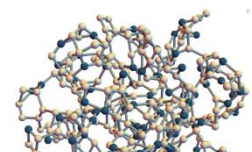
3 NETWORKS CAN HELP REVEAL PATTERNS

- In many networks you can find a small number of nodes that are highly connected to others. They are called hubs.
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4 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

- Networks can be visualized in many different ways.
- There are a variety of tools available for visualizing networks.
- Visualization of networks often helps to understand a network and its structure.
- There are many different tools available for visualizing networks.
- It is important to be careful when visualizing and interpreting networks.



7 THE STRUCTURE OF A NETWORK CAN INFLUENCE ITS STATE AND VICE VERSA

- Network structure can influence the state of a network.
- Network structure can influence the state of a network.
- Network structure can influence the state of a network.
- Network structure can influence the state of a network.

6 NETWORKS HELP YOU TO COMPARE A WIDE VARIETY OF SYSTEMS

- Networks help you to compare a wide variety of systems.
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5 TODAY'S COMPUTER TECHNOLOGY ALLOWS YOU TO STUDY REAL-WORLD NETWORKS

- Computer technology has dramatically advanced the ability to study real-world networks, and this is especially important for large and well-structured networks.
- There are many free software tools available for studying real-world networks.
- Computer allow you to simulate, visualize and analyze real-world networks. It is important to be careful when visualizing and interpreting networks.
- Learning computer science skills opens the door to many possibilities for a career. These include scientific data analysis, software engineering, data visualization, media creation, and many others.