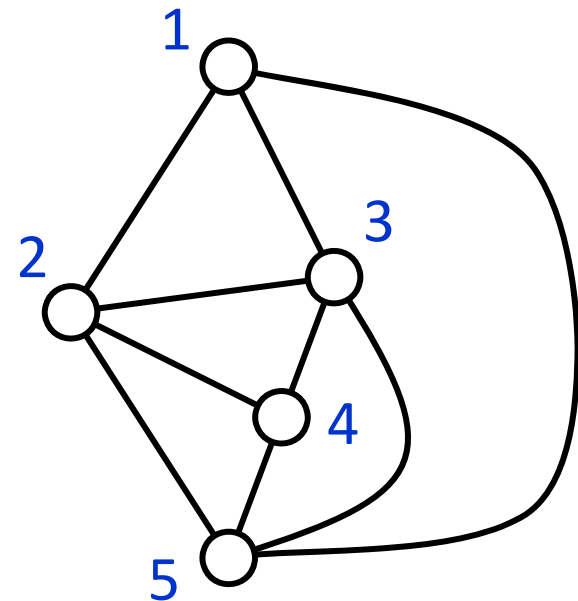


Network Thinking: Some Examples

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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.*



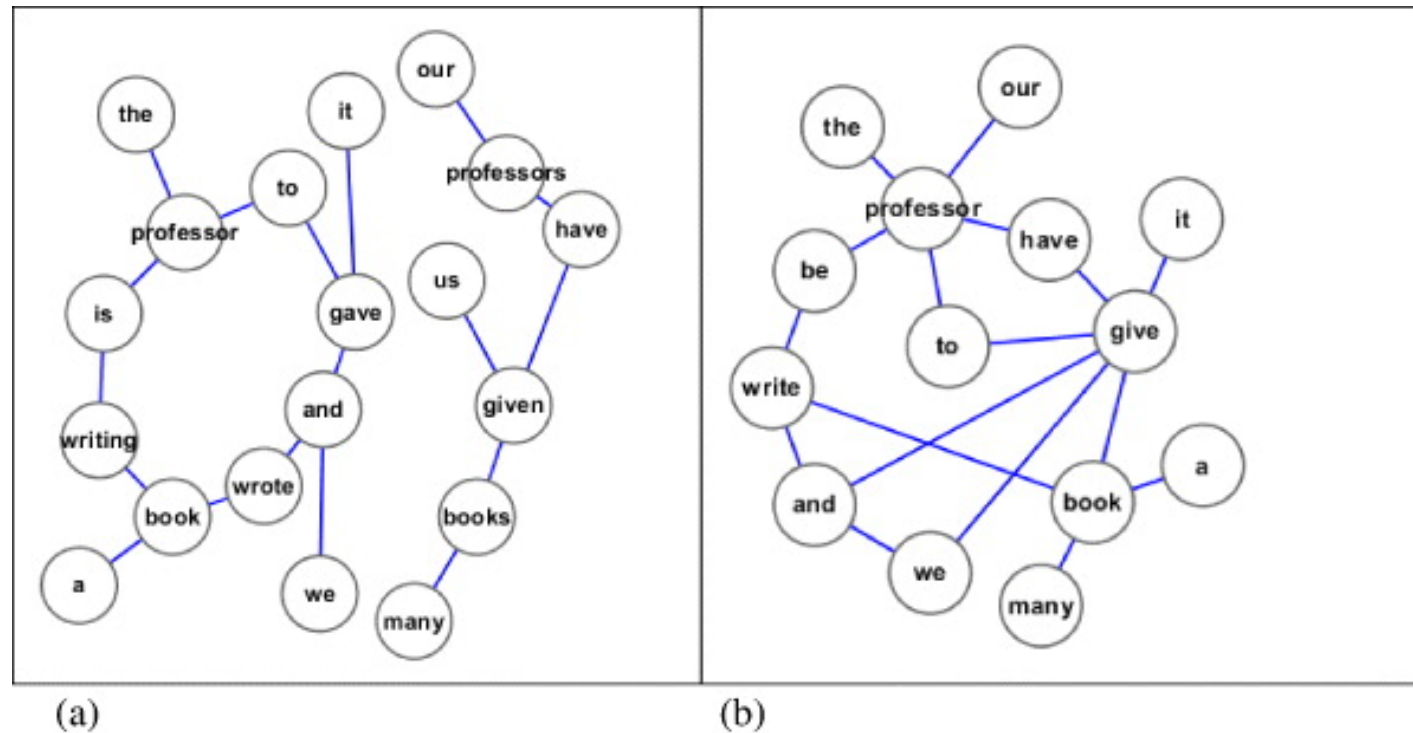
Astonishing Facts

- 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)



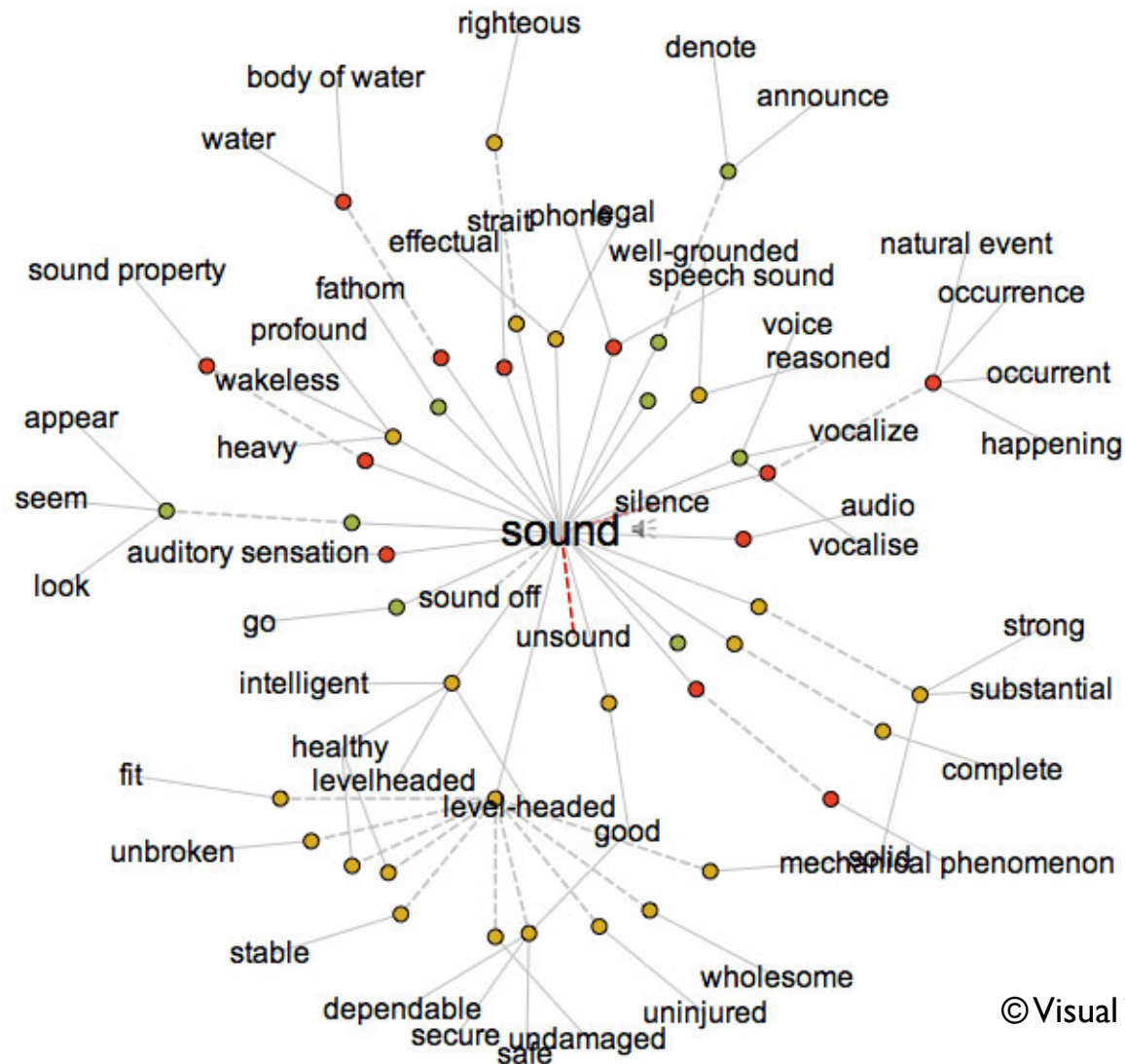
From Liu & Xu 2011; networks were generated from the following three sentences:

This professor is writing a book.

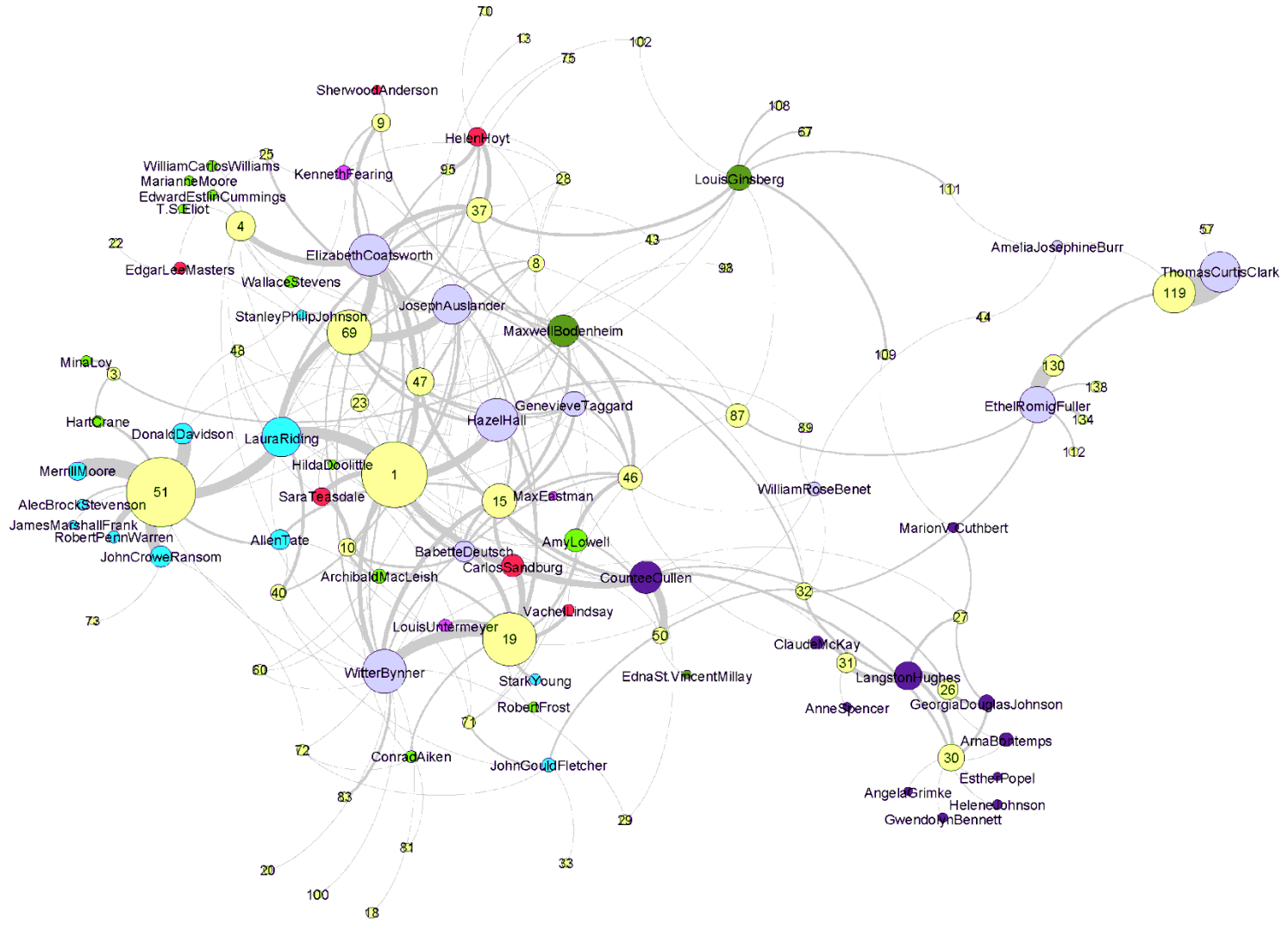
Our professors have given us many books.

We wrote a book and gave it to the professor.

Network of Words (Semantic)

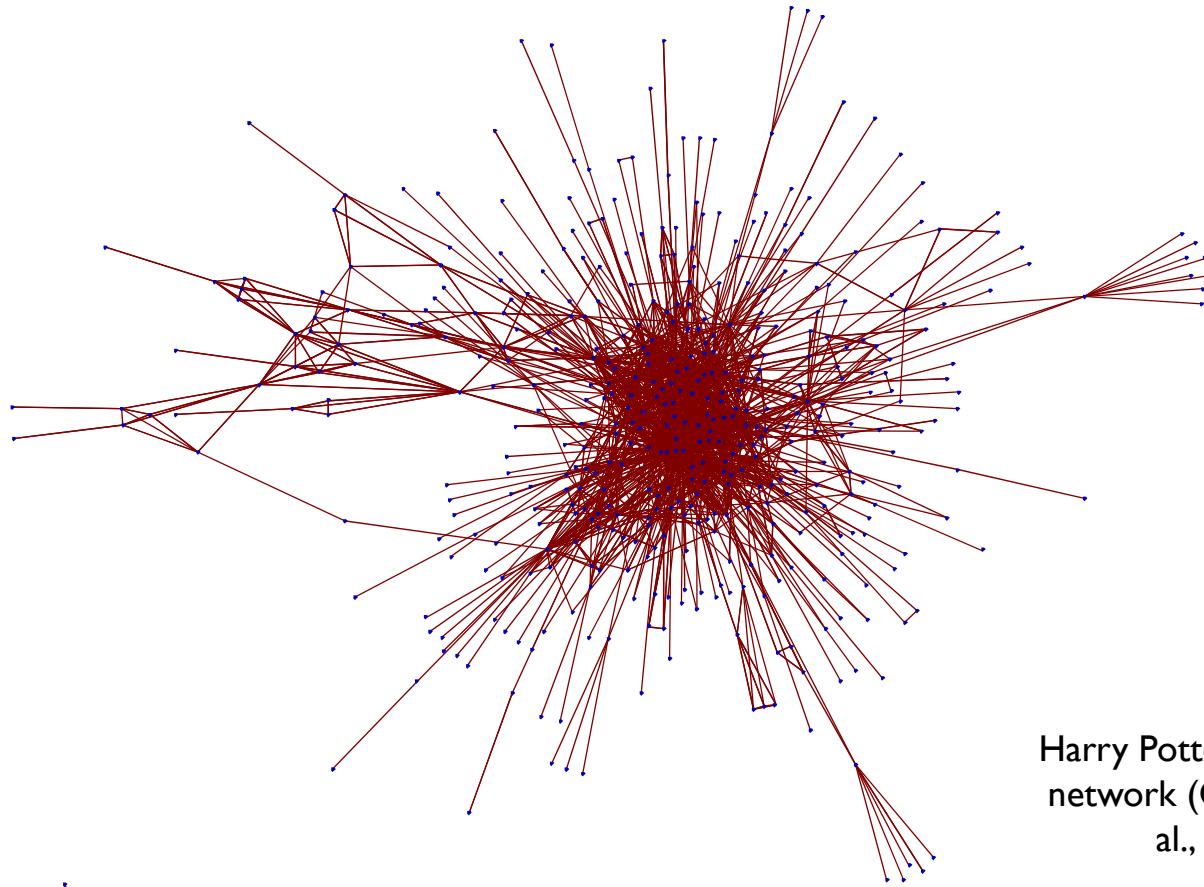


Network of U.S. Poets (1924-25)

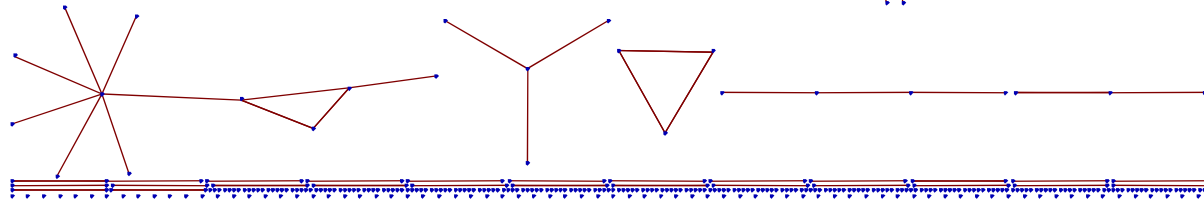


Hoyt Long: Literary Networks. <http://lucian.uchicago.edu/blogs/literarynetworks/>

Network of Fictional Characters



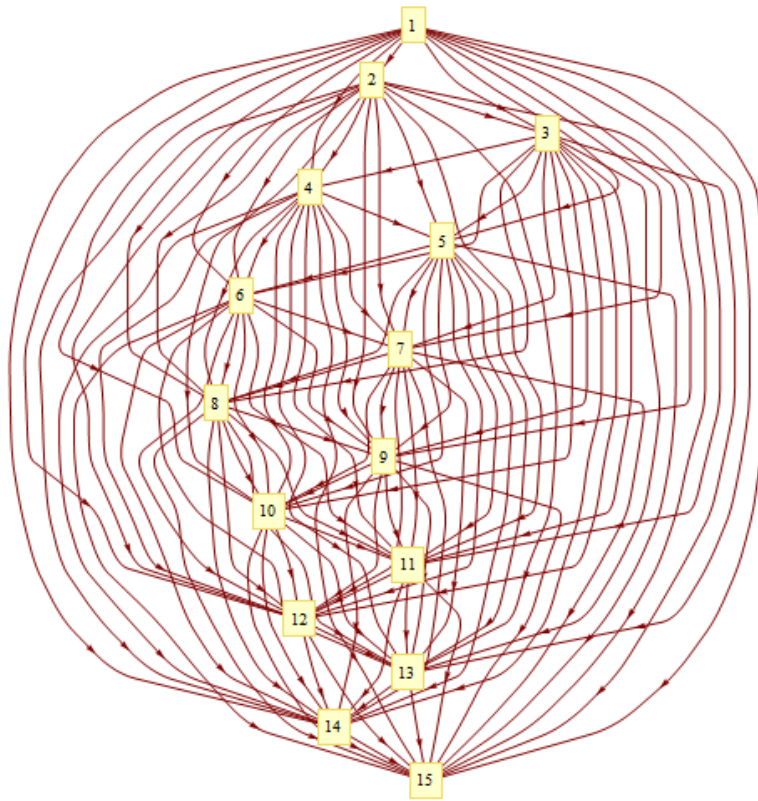
Harry Potter's character network (Calderone et al., 2011)



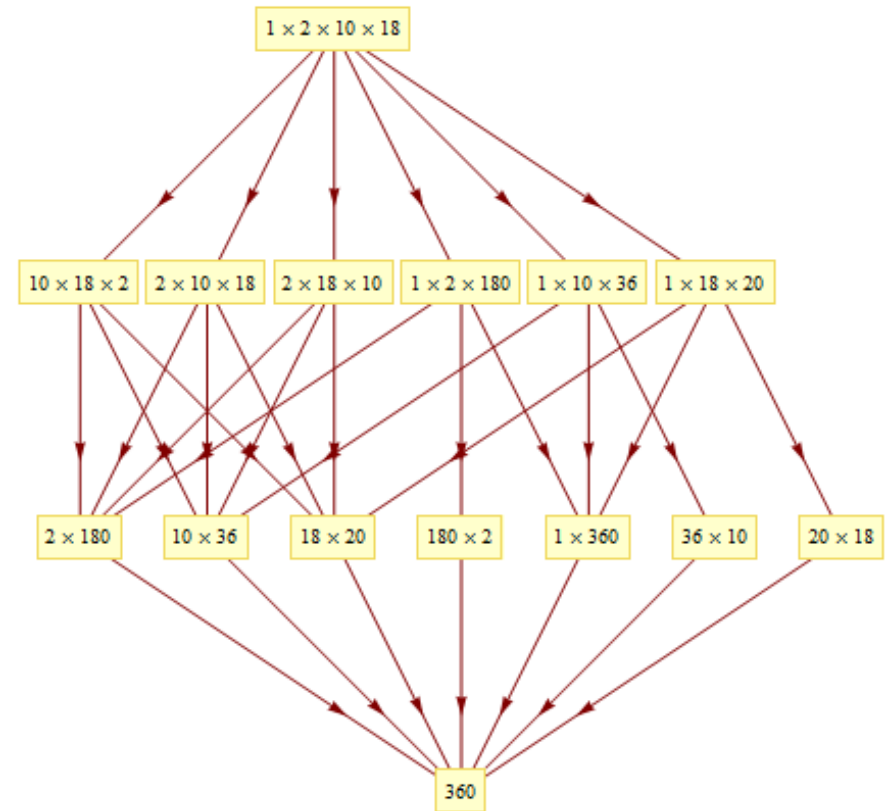


Networks in Math

Networks of Numbers (I)

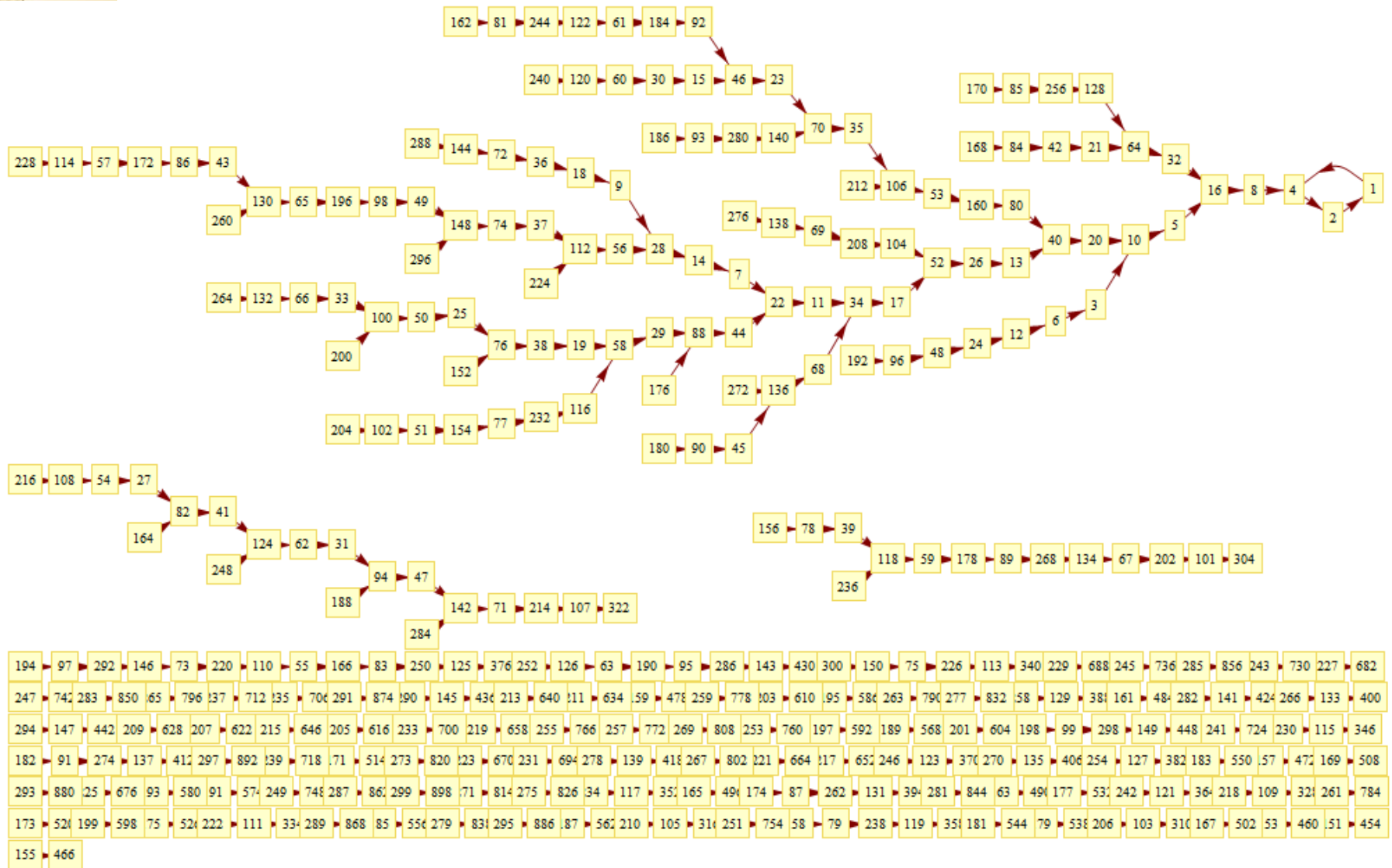


Transitivity network ($i \rightarrow j$ if and only if $i < j$)



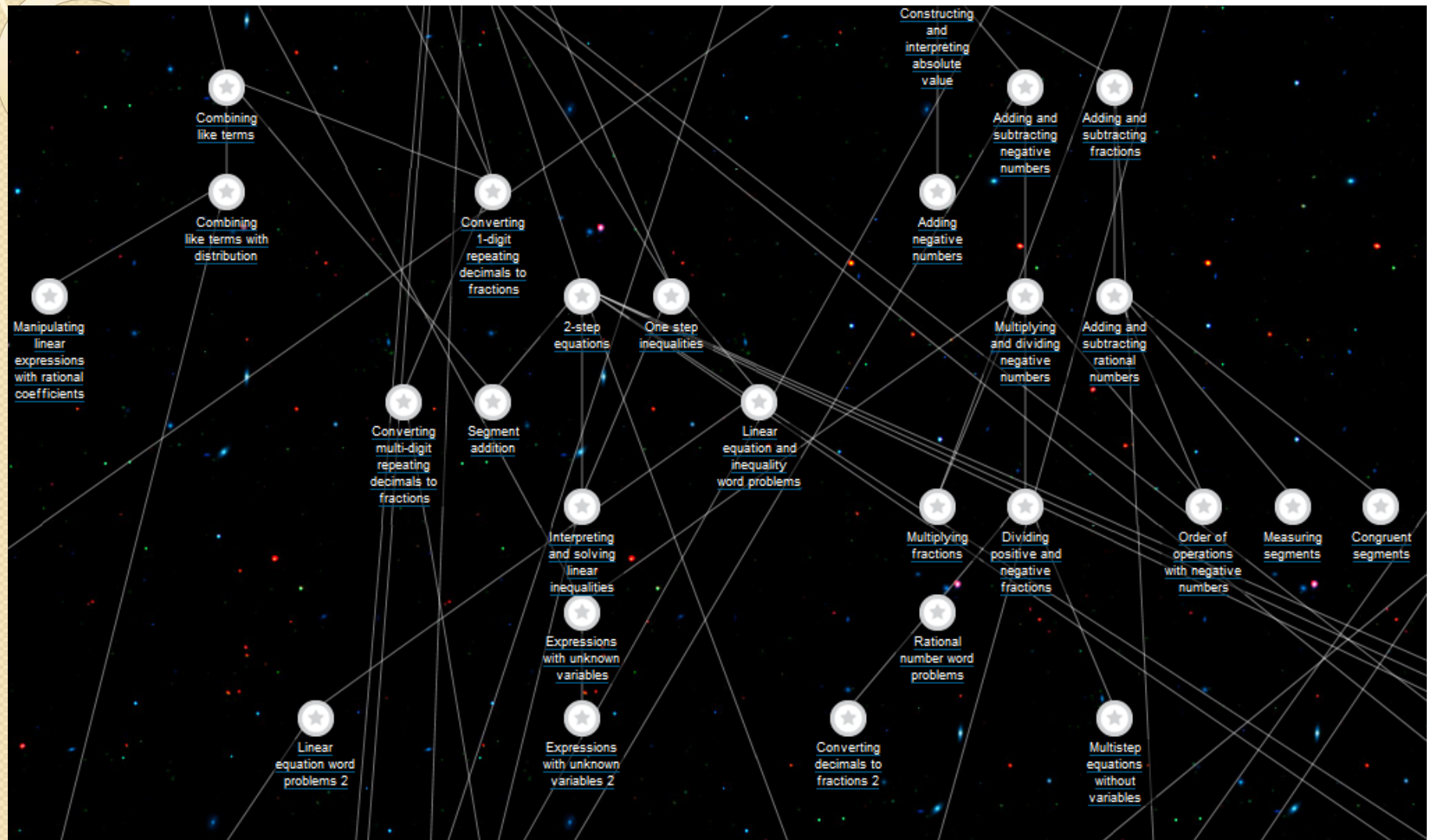
Associativity network (about multiplication)

Networks of Numbers (2)



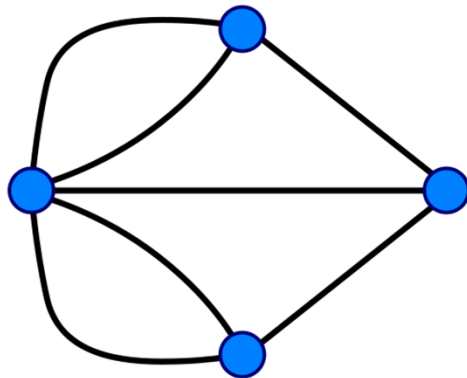
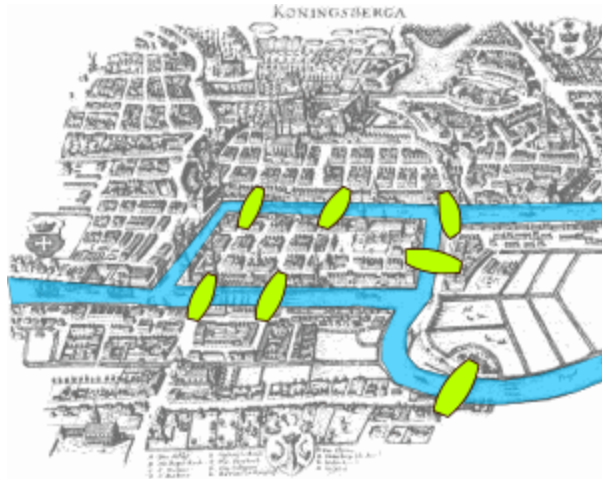
Collatz sequence ($x \rightarrow y$; $y = x/2$ if x is even, or $3x+1$ otherwise)

Network of Concepts



Knowledge Map (from Khan Academy)

Networks in Math Puzzles



Seven bridges of Königsberg
(images from Wikipedia)

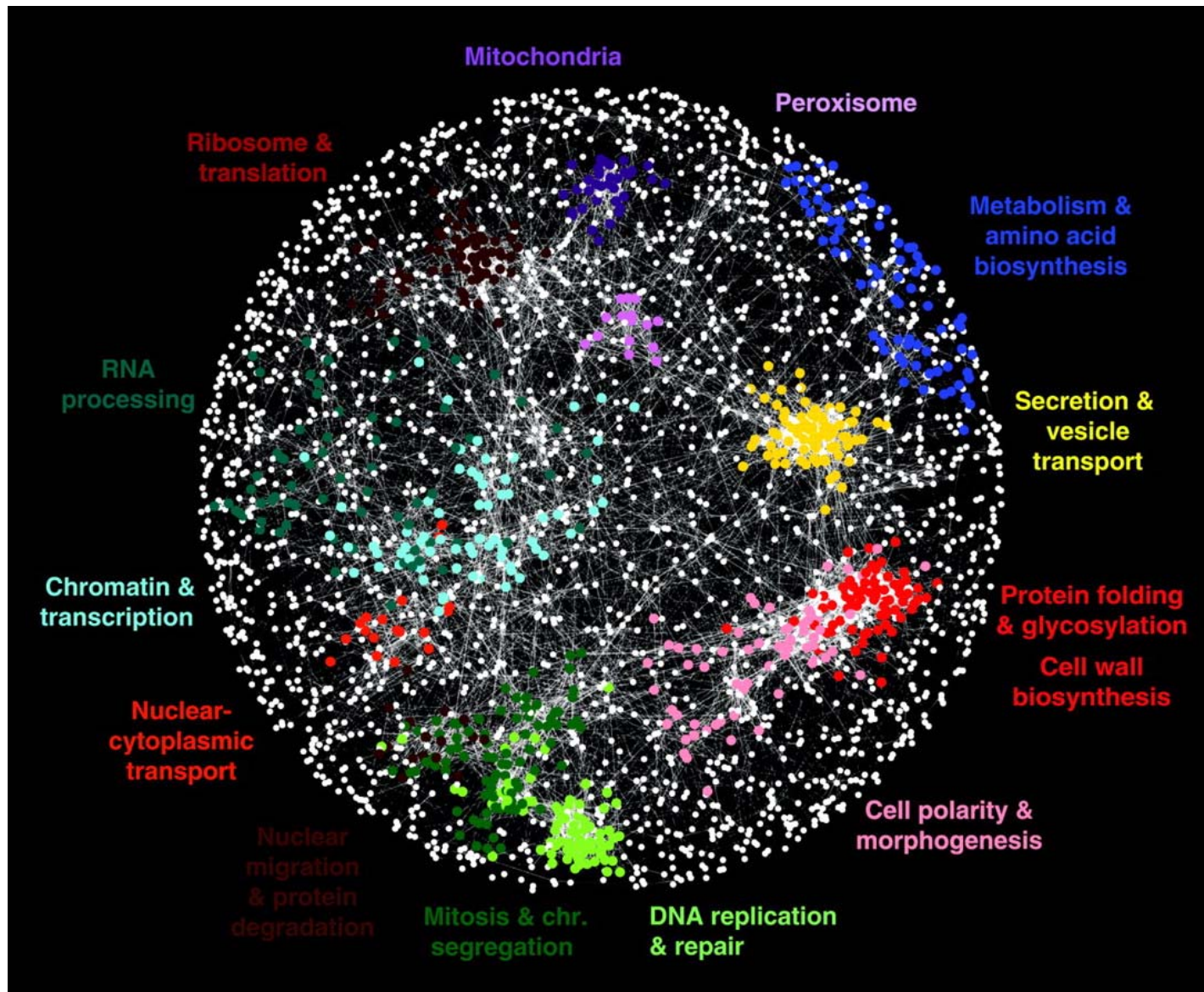


42 bridges in Bristol, UK
(images from Bristol Post / Dr. Thilo Gross)



Networks in Science

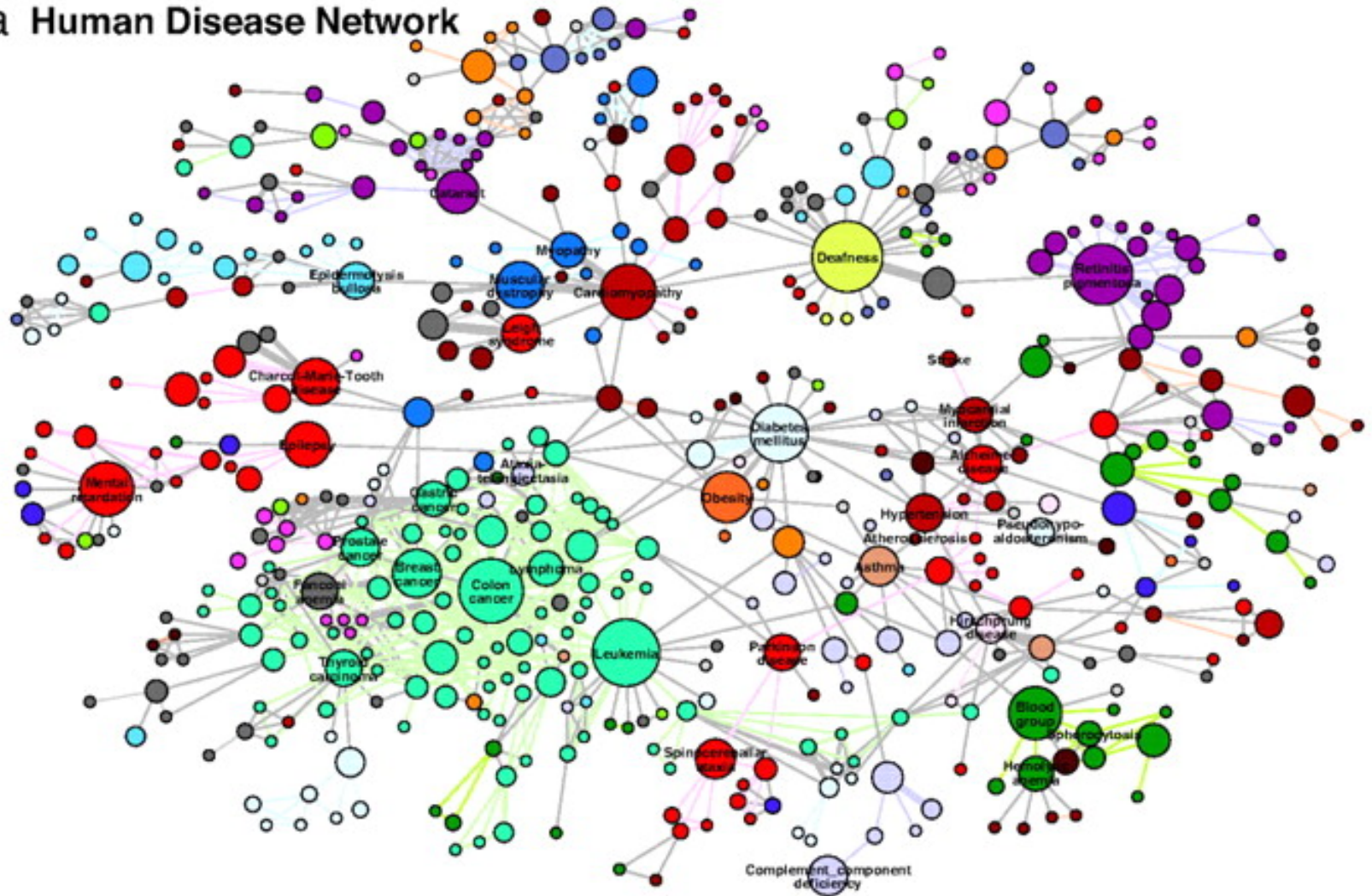
Network of Genes



Costanzo
et al., 2010

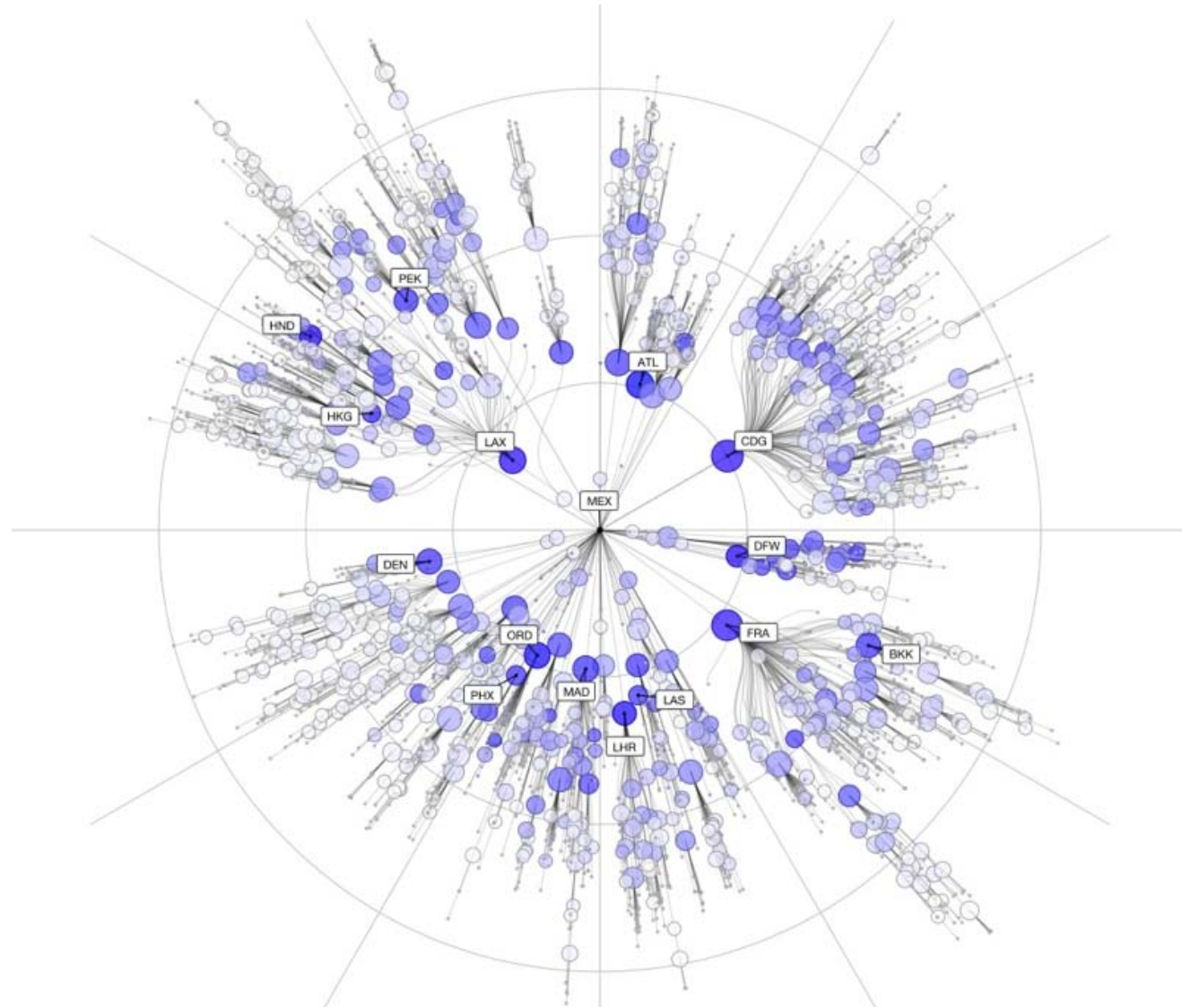
Network of Diseases

a Human Disease Network



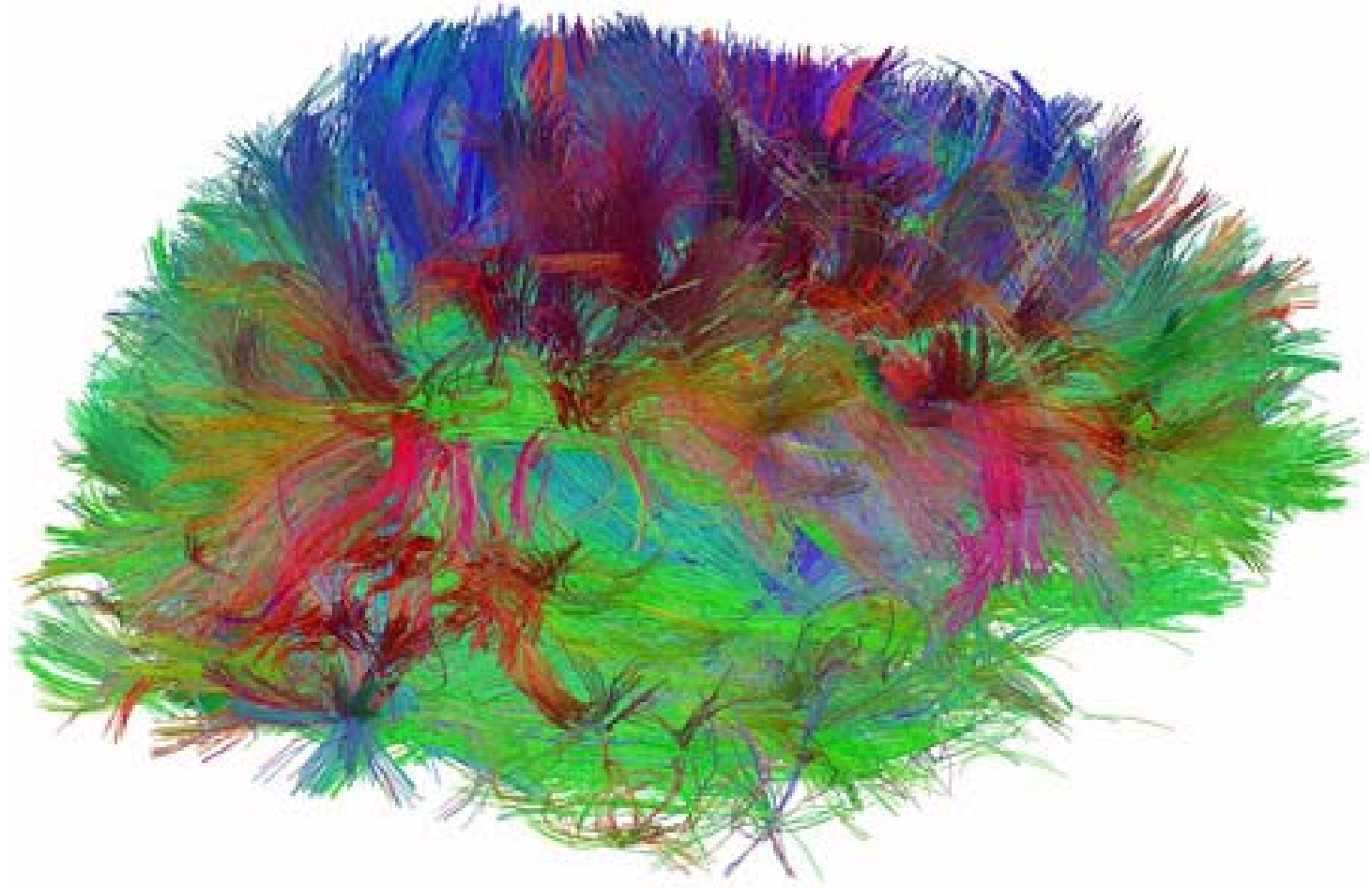
Goh et al., 2007

Network of Disease Propagation



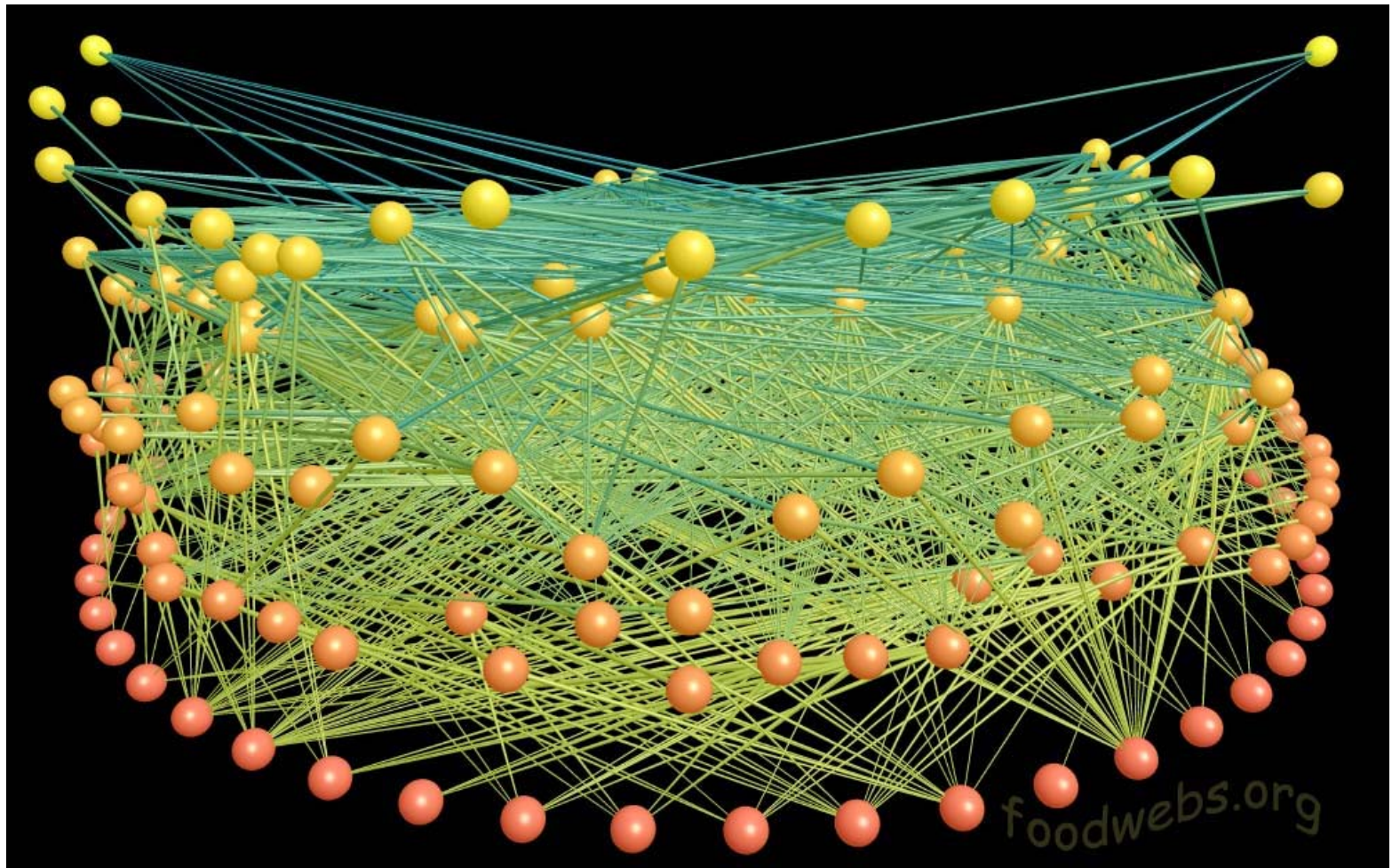
H1N1 activities illustrated according to distance from MEX airport (Brockmann, 2013)

Network of the Brain



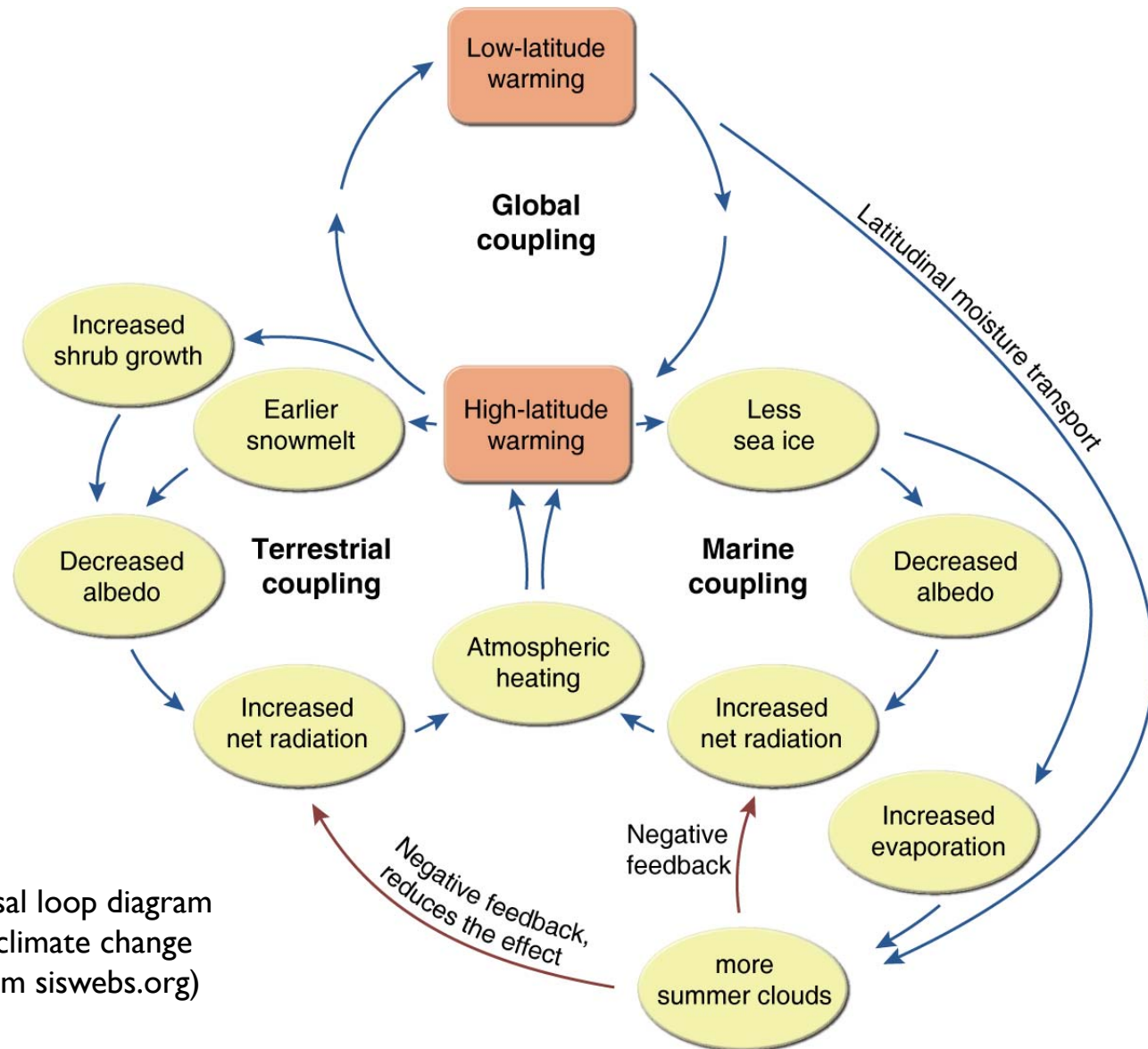
Van J. Wedeen, M.D., MGH/Harvard U.

Food Webs



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

Causal Loop Diagram

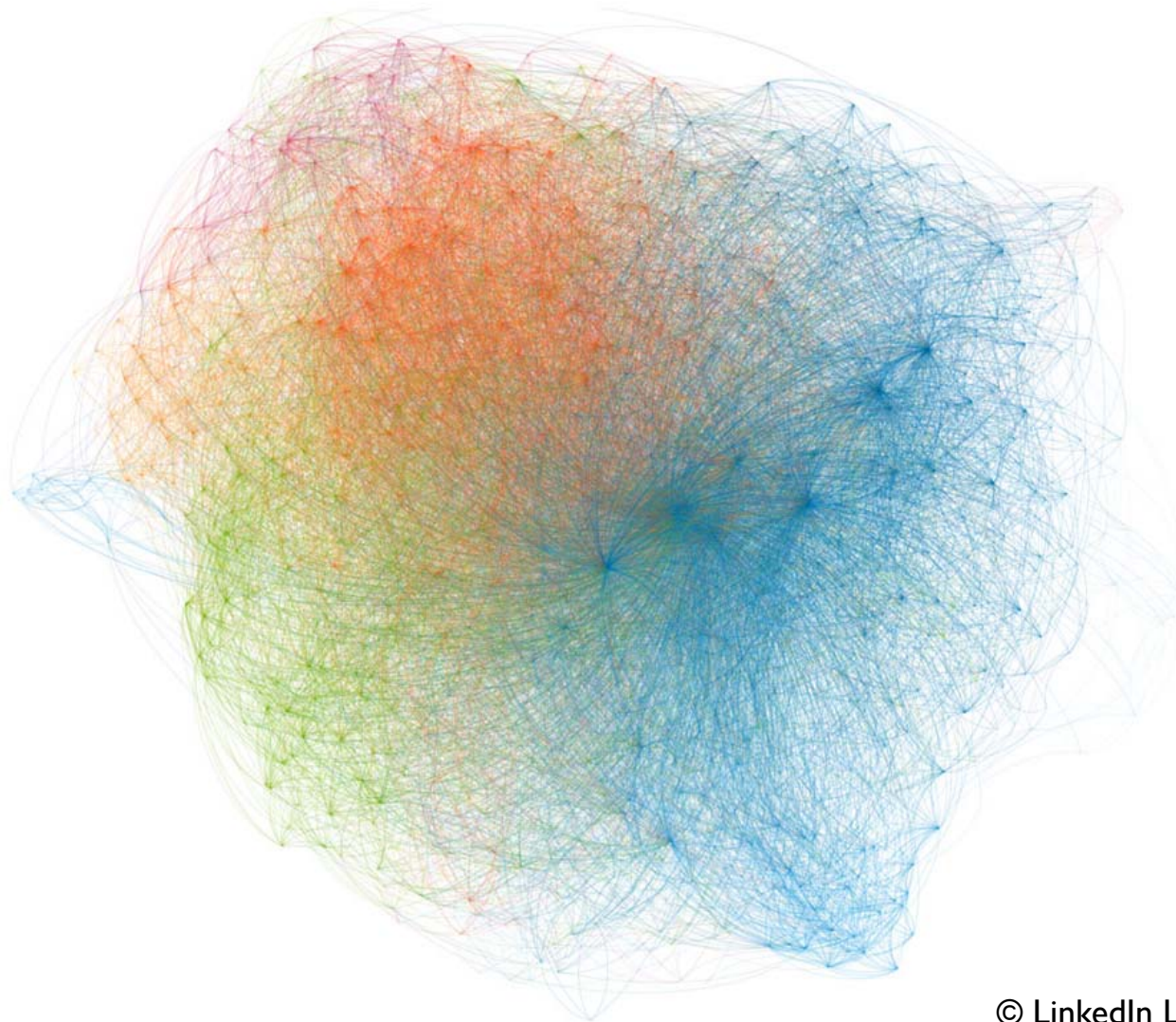


Causal loop diagram of climate change (from siswebs.org)



Networks in Social Studies

Network of People Around You

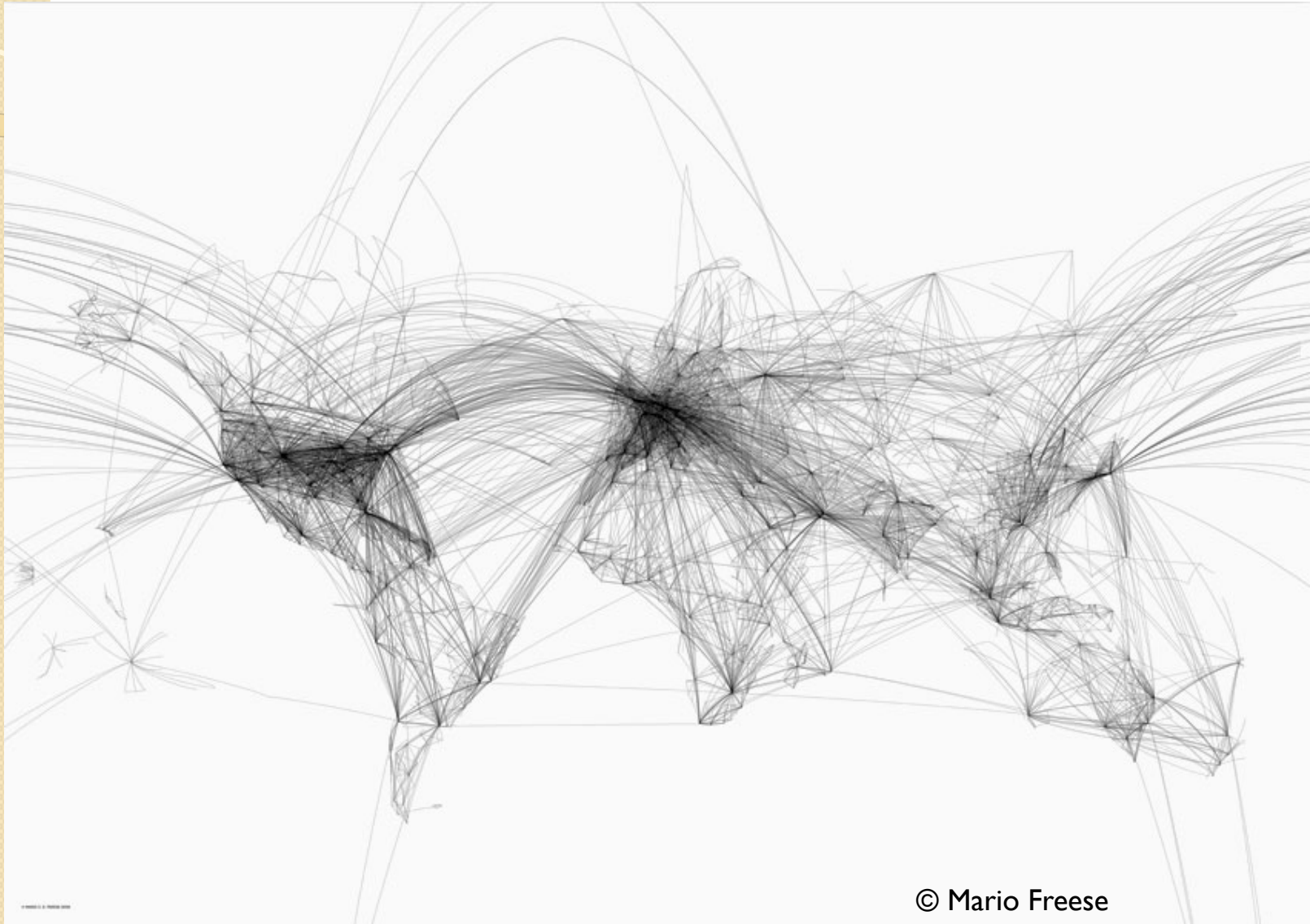


Network of Human Migration

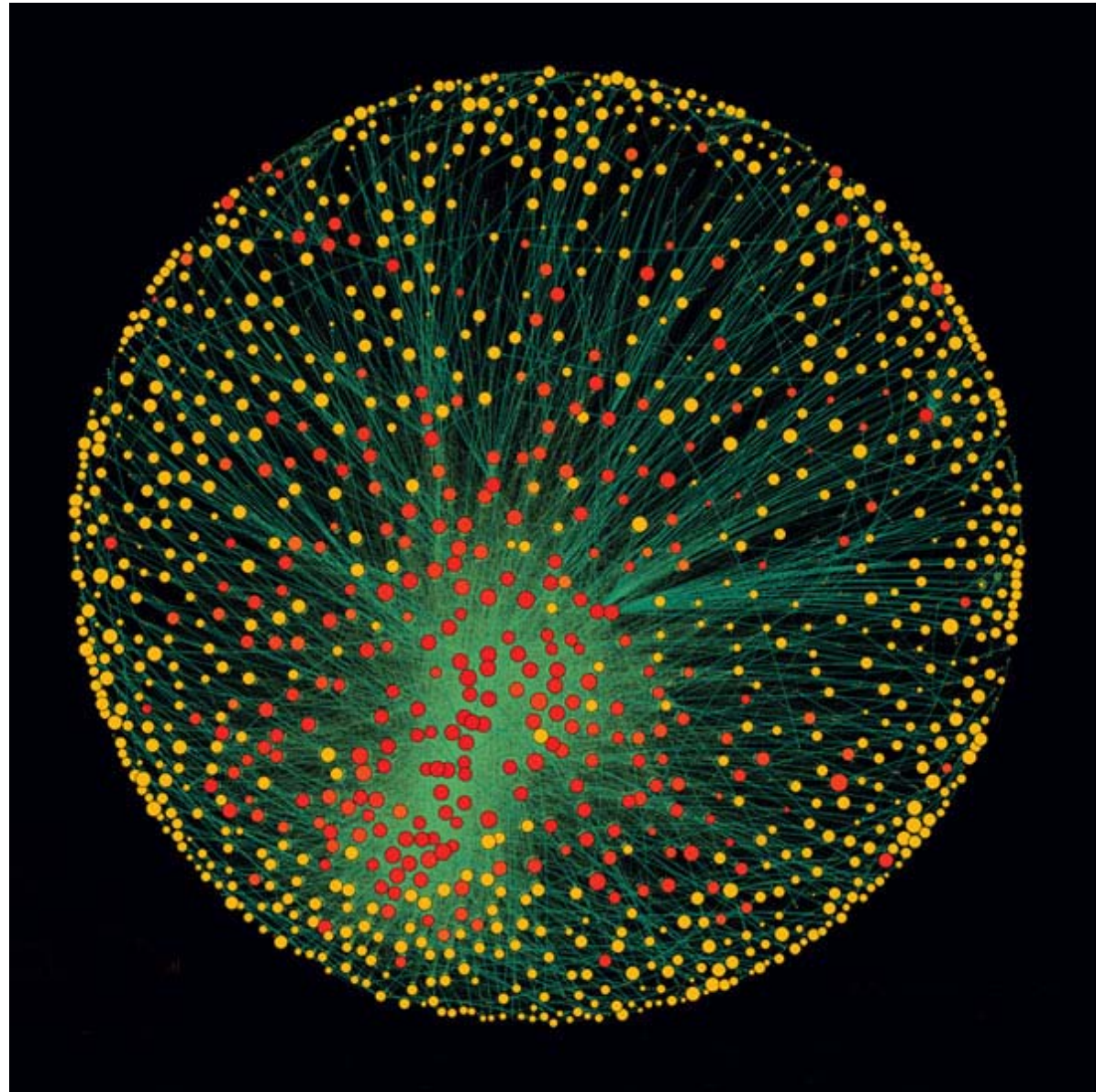


Davis et al., 2013

Network of Transportations

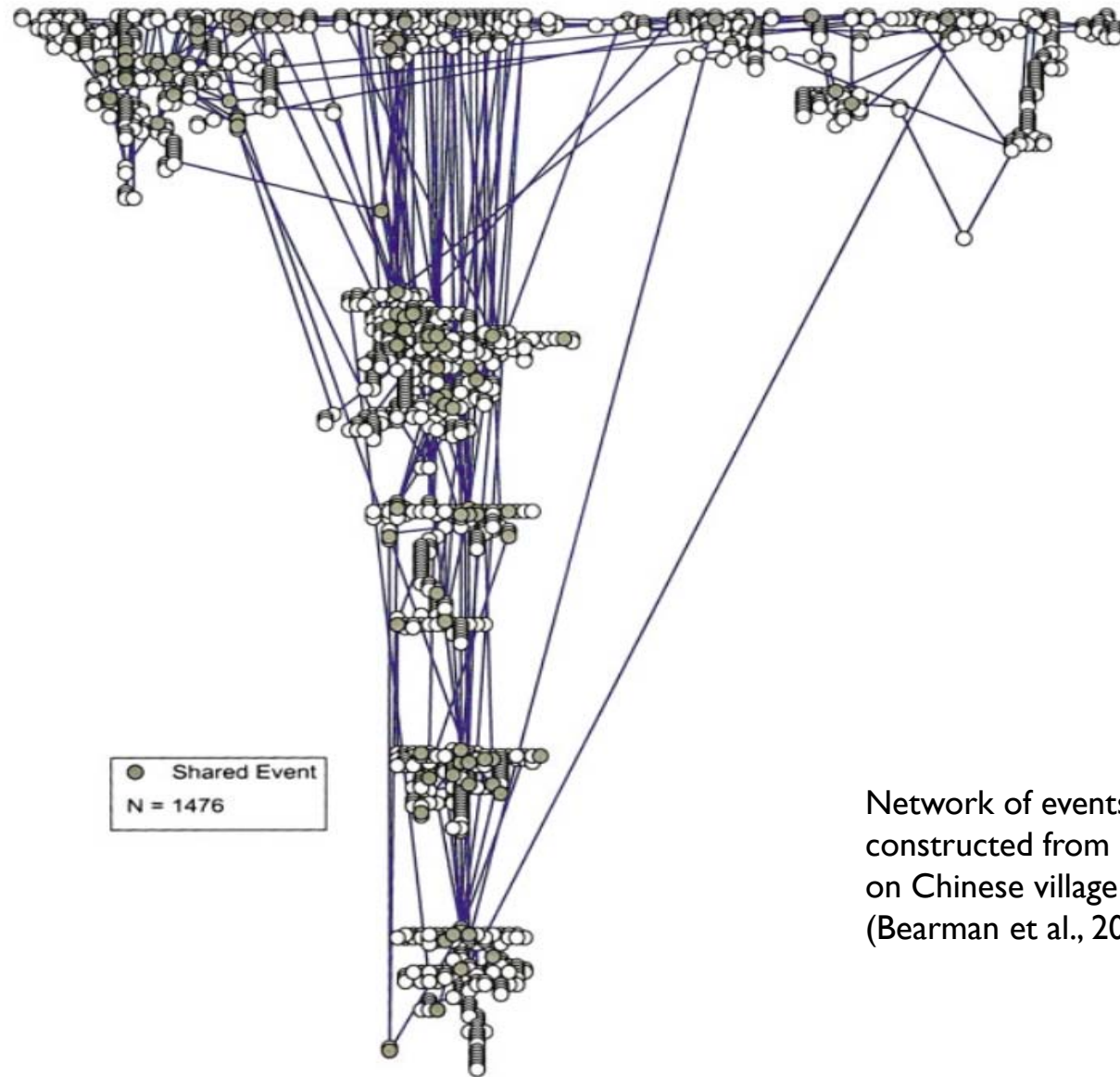


Network of Corporations



Vitali et al.,
2011

Network of Historical Events

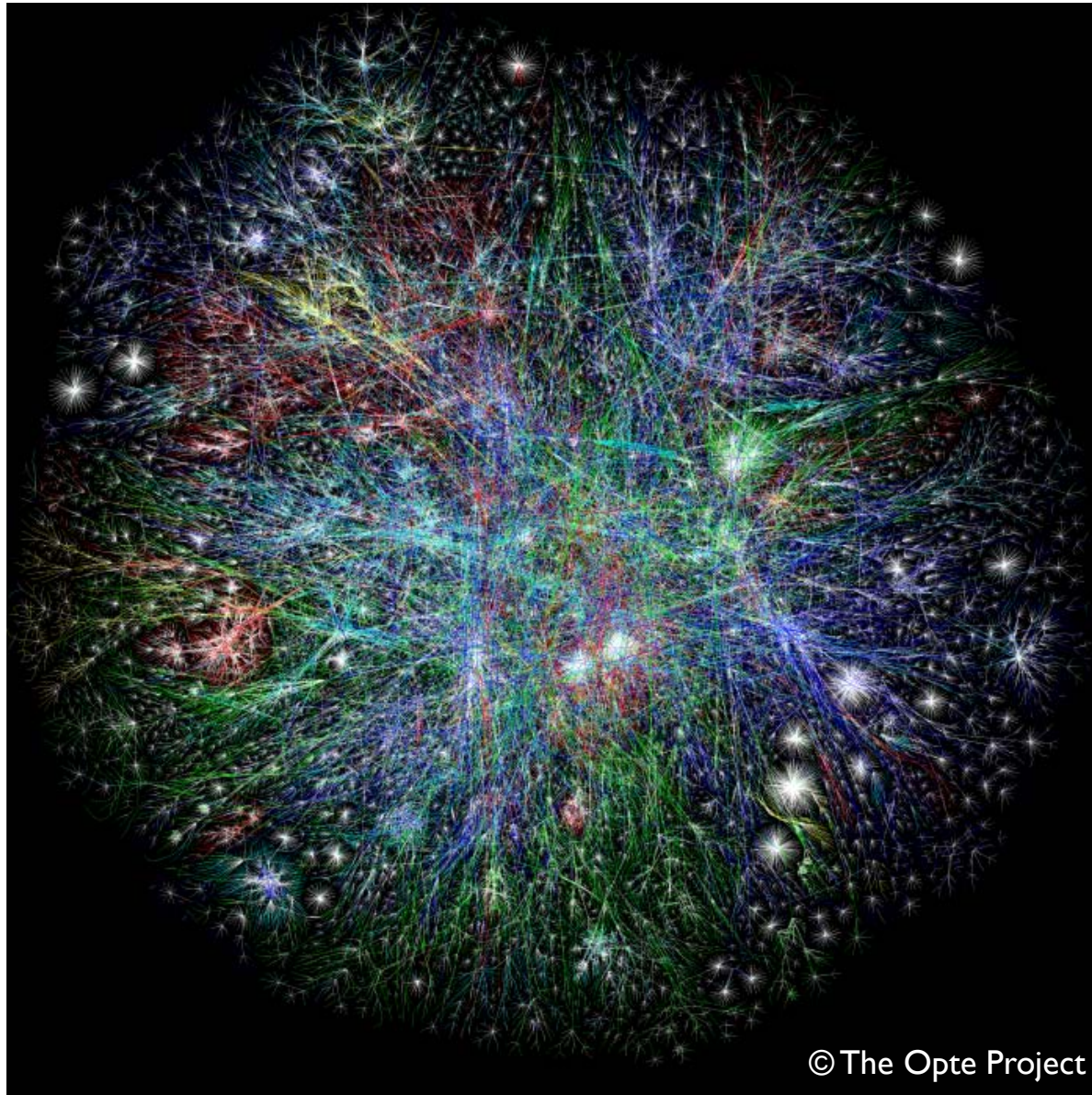


Network of events
constructed from narratives
on Chinese village Liu Ling
(Bearman et al., 2003)

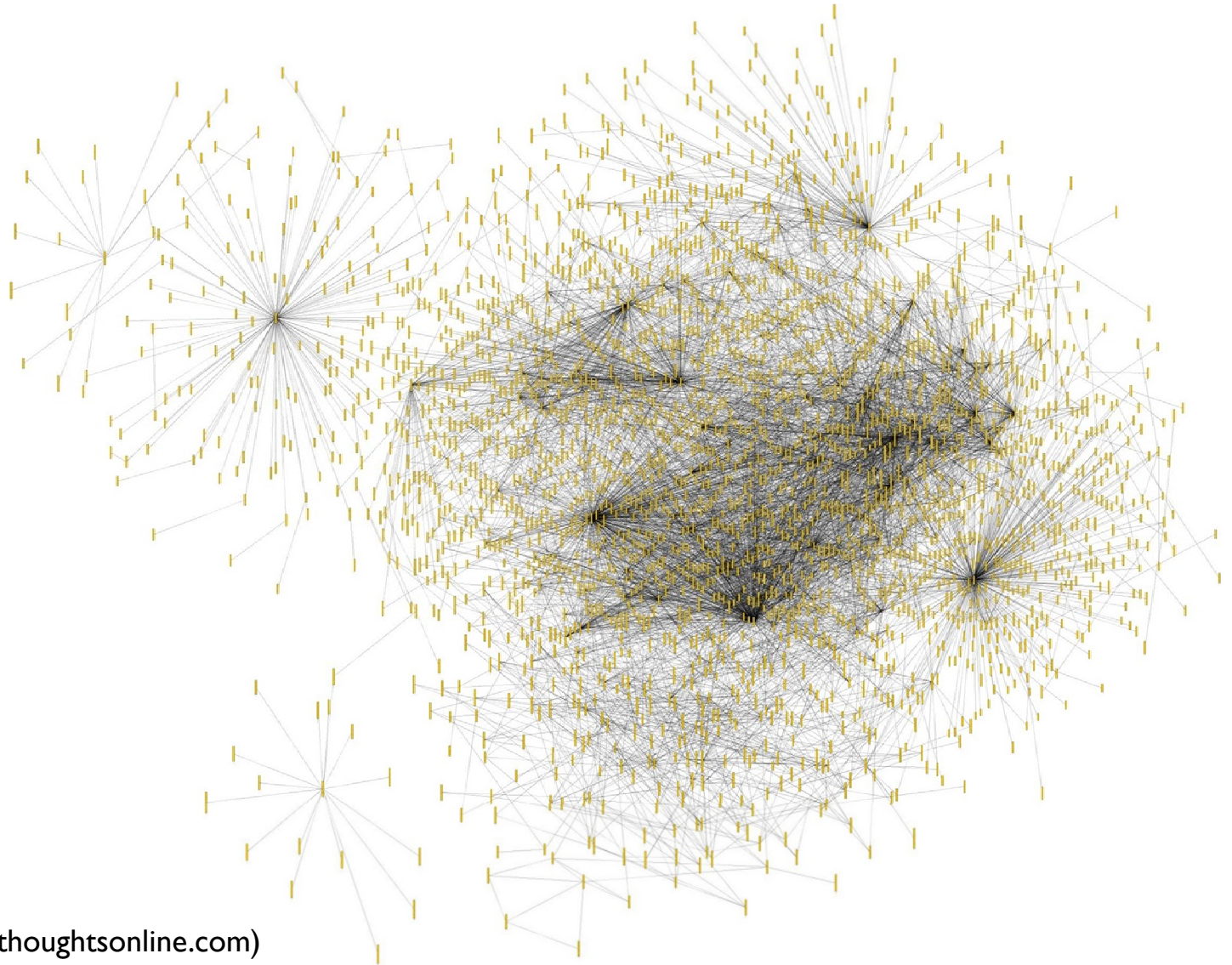


Networks in Technical Education

The Internet

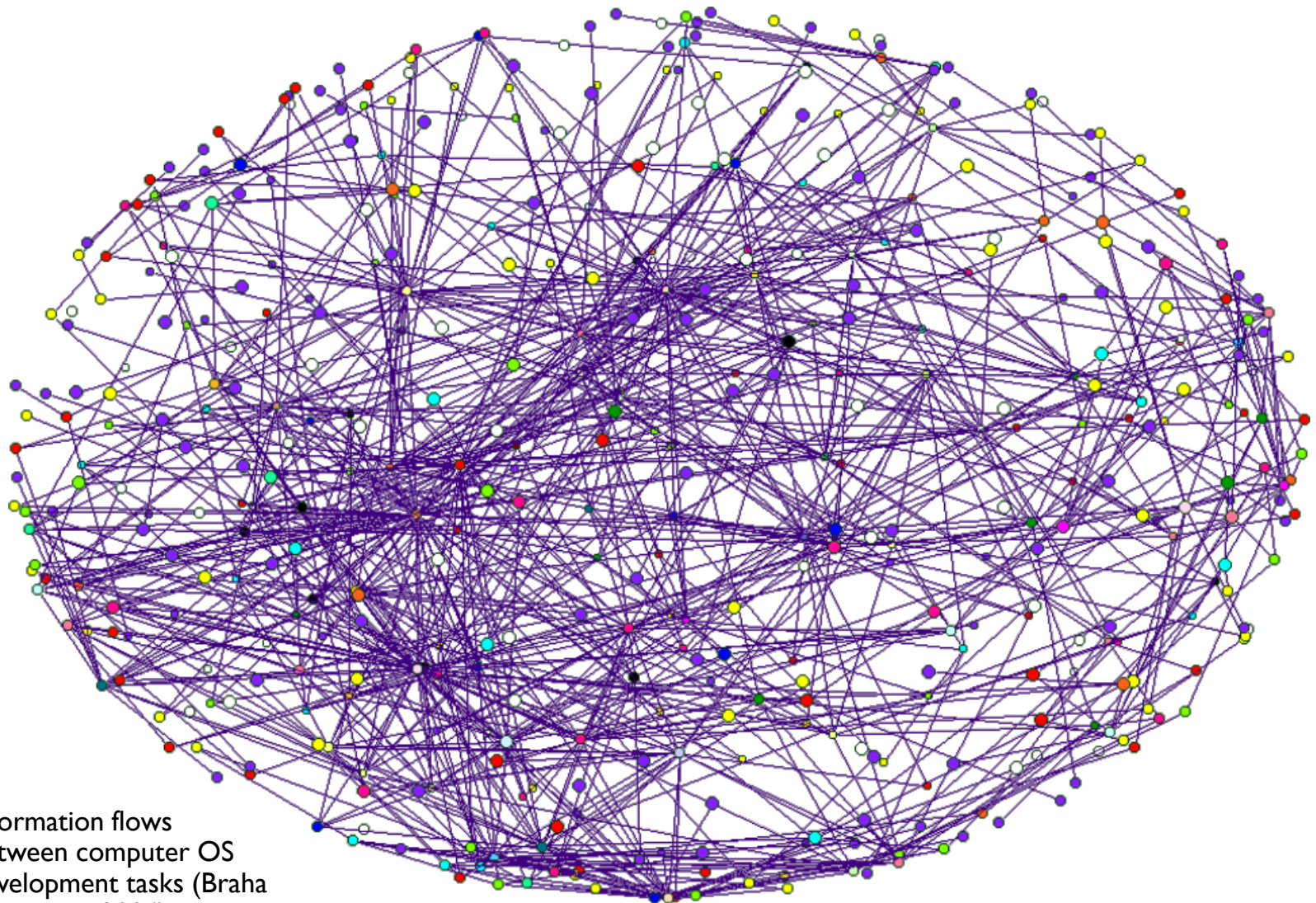


Network of Java Classes



Cavlin, 2012
(from simplethoughtsonline.com)

Network of Product Design

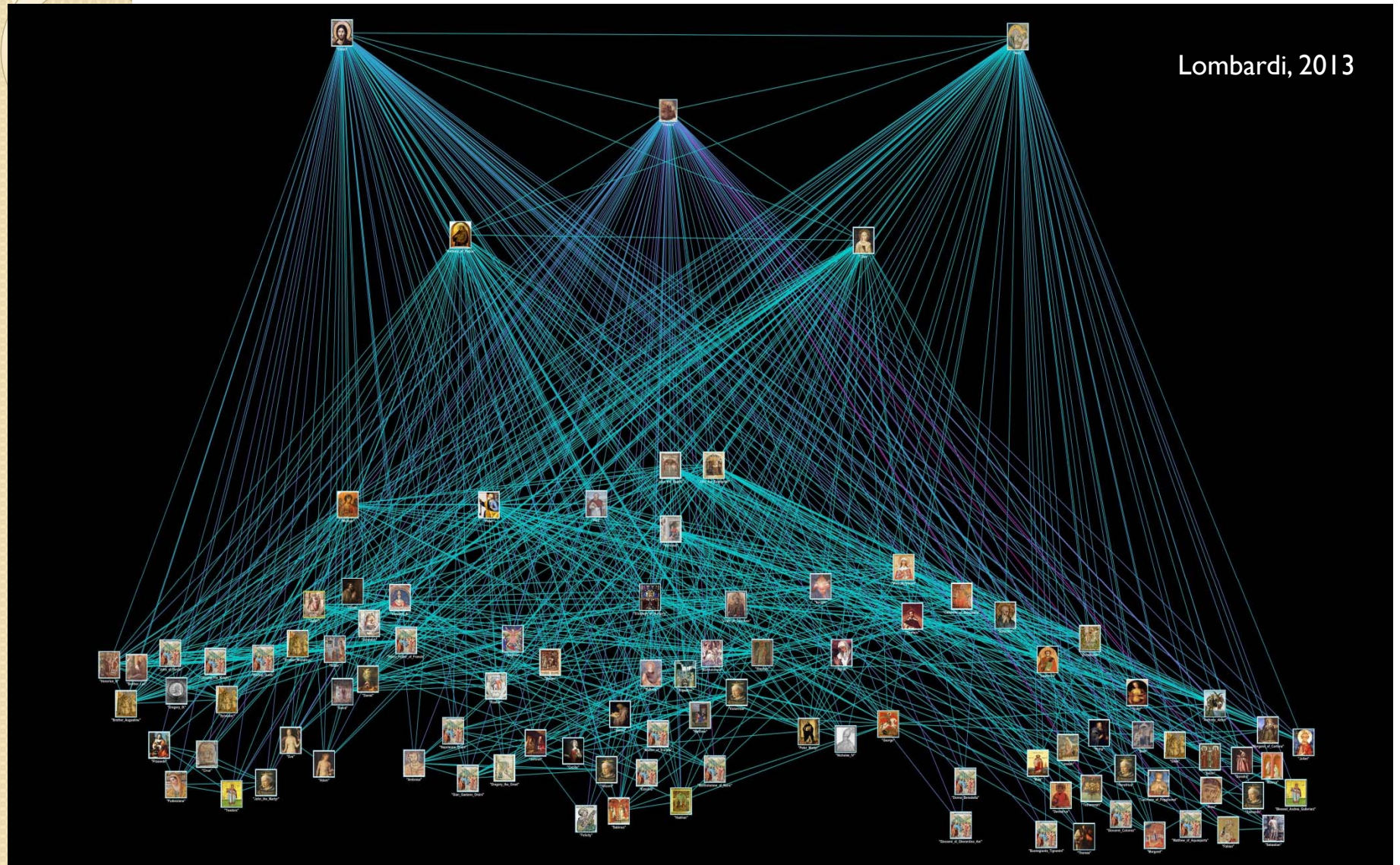


Information flows
between computer OS
development tasks (Braha
& Bar-Yam, 2004)

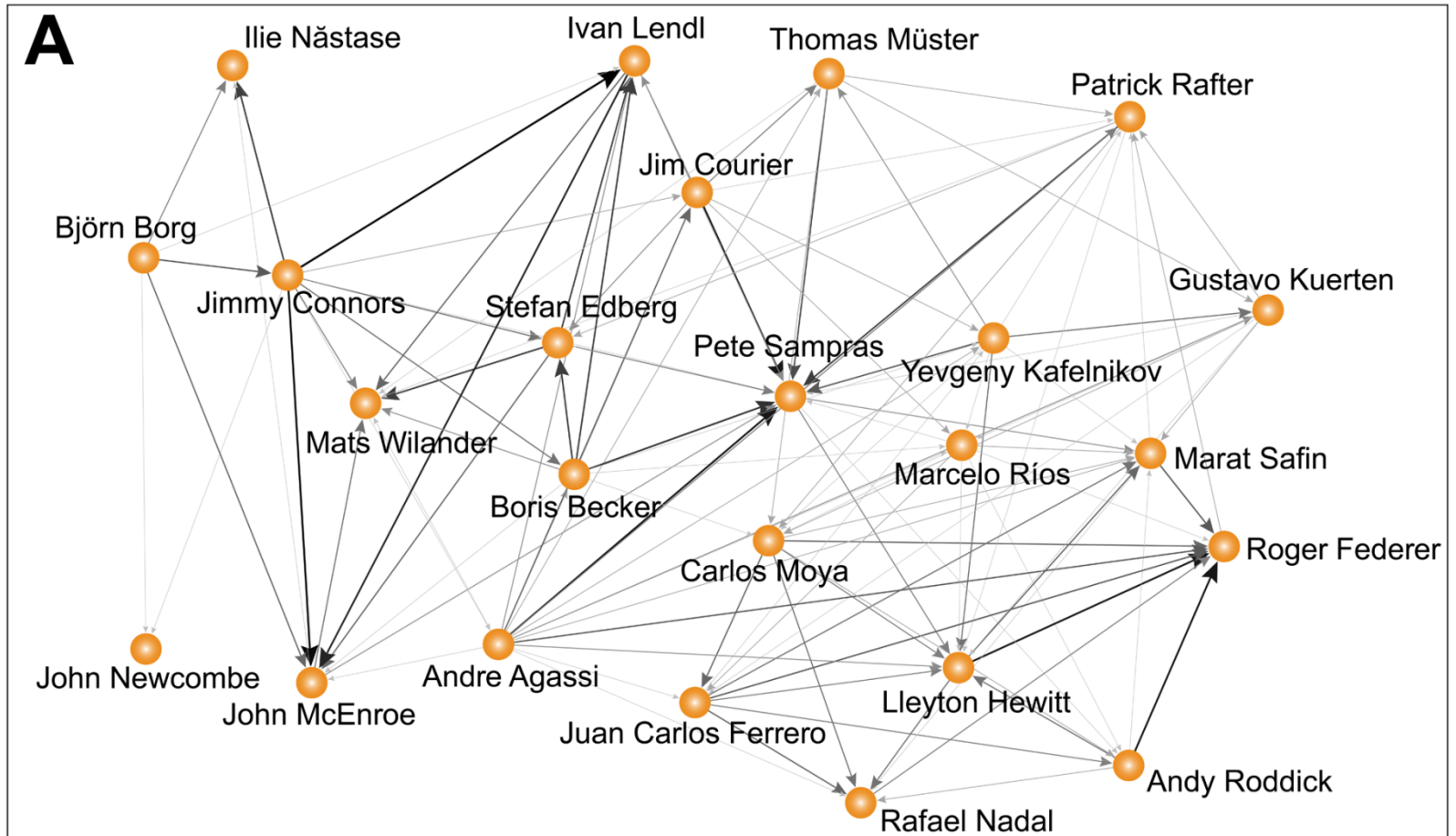


Networks in Other Subjects

Network of Saints in Iconography



Network of Top Tennis Players

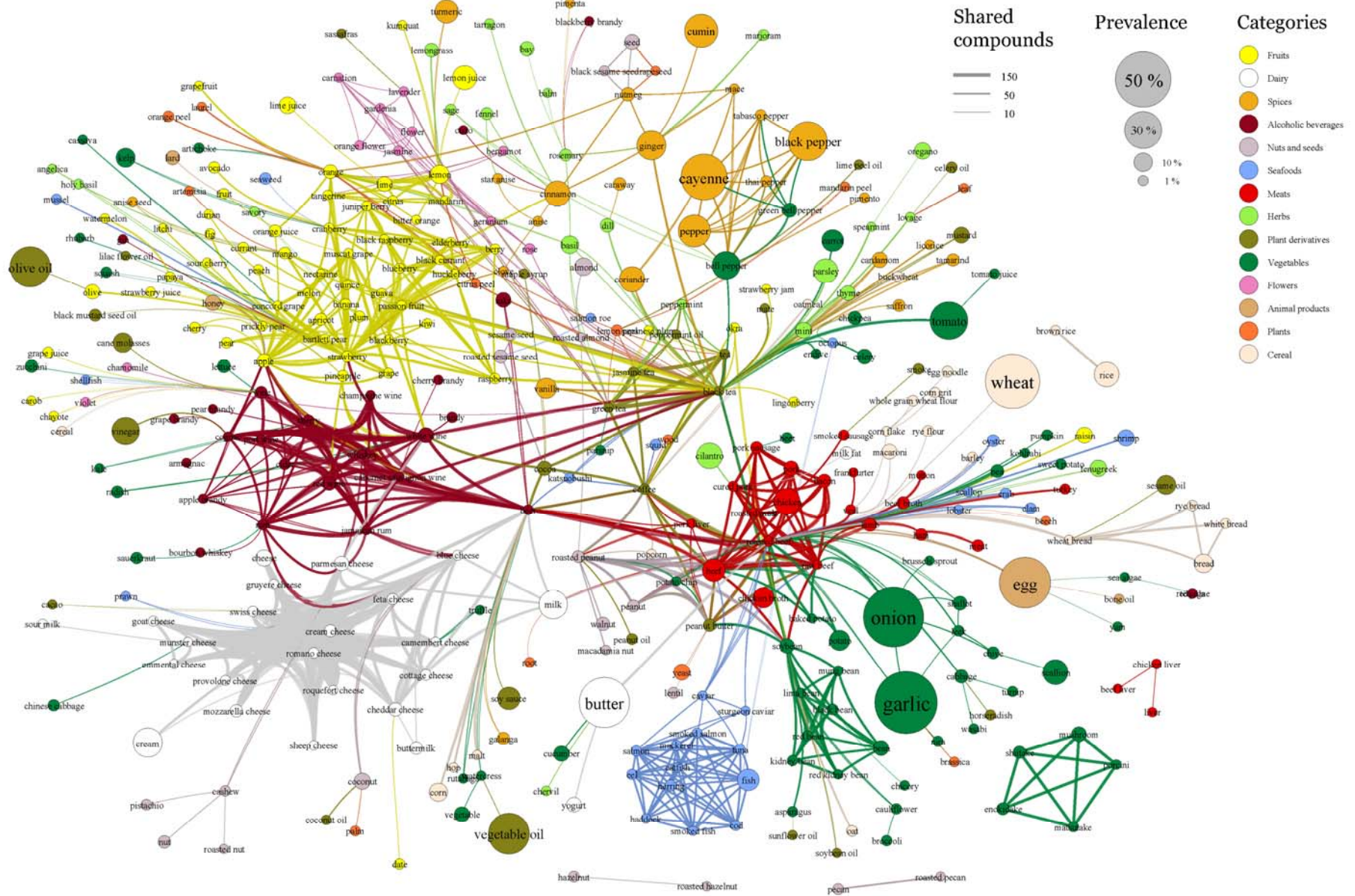


Radicchi, 2011

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, menupan.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 structure of networks is universal and general, and it describes how things are connected to each other. Networks are present in many aspects of life.
- Networks describe the connections between individuals, companies, animals, the human electrical grid, the brain, and more.
- There are networks of people—e.g., human connections, computer networks, Facebook/Flickr/MySpace, professional groups, etc.
- There are economic networks—e.g., a network of products, financial transactions, cooperation on learning, transportation, etc.
- There are biological and ecological networks—e.g., food webs, genetic networks, interactions between cells.
- There are cultural networks—e.g., the connections between people that shape their beliefs, values, and behaviors, which are passed on to others.
- Networks can be used to understand complex systems.

2 NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- There is a central node, or hub, that connects to many other nodes. These hubs are often the most important nodes in a network.
- A network is a collection of nodes that are connected to each other. The nodes are often represented by circles, and the connections are represented by lines.
- A network can be used to describe the connections between people, companies, animals, and more.
- A network can be used to describe the connections between products, financial transactions, cooperation on learning, transportation, etc.
- A network can be used to describe the connections between cells, genes, and more.
- A network can be used to describe the connections between people, their beliefs, values, and behaviors, which are passed on to others.
- The number of connections a node has is called its degree.

3 NETWORKS CAN HELP REVEAL PATTERNS

- You can reveal patterns in a network by looking at the connections between nodes. This can help you understand how things are connected.
- In many networks, you can find a central node that connects to many other nodes. This is called a hub.
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4 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

- Networks can be visualized in many ways.
- There are a variety of tools available for visualizing networks.
- Visualizations of networks often help to understand the structure and function of a network.
- There are many tools available for visualizing networks.
- It is important to be careful when interpreting network visualizations.

5 TODAY'S COMPUTER TECHNOLOGY ALLOWS YOU TO STUDY REAL-WORLD NETWORKS

- Computer technology has dramatically advanced the ability to study networks, and this is especially important for large-scale networks.
- There are many free software tools available for studying networks.
- Many computer programs can be used to study networks.
- Through the Internet, everyone has access to many interesting network data sets.
- Computers allow you to simulate, model, and analyze networks. It is also possible to study the structure and function of a network.
- Learning computer literacy skills opens up new opportunities for a career. These include scientific data analysis, software engineering, and more.

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

- Network structure influences how information flows through a network.
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- Network structure influences how information flows through a network.

<http://tinyurl.com/networkliteracy>