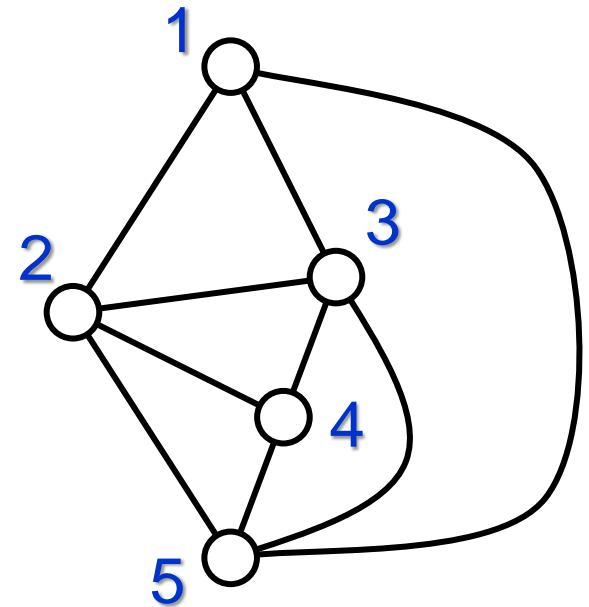


Network Thinking: Some Examples

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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.*

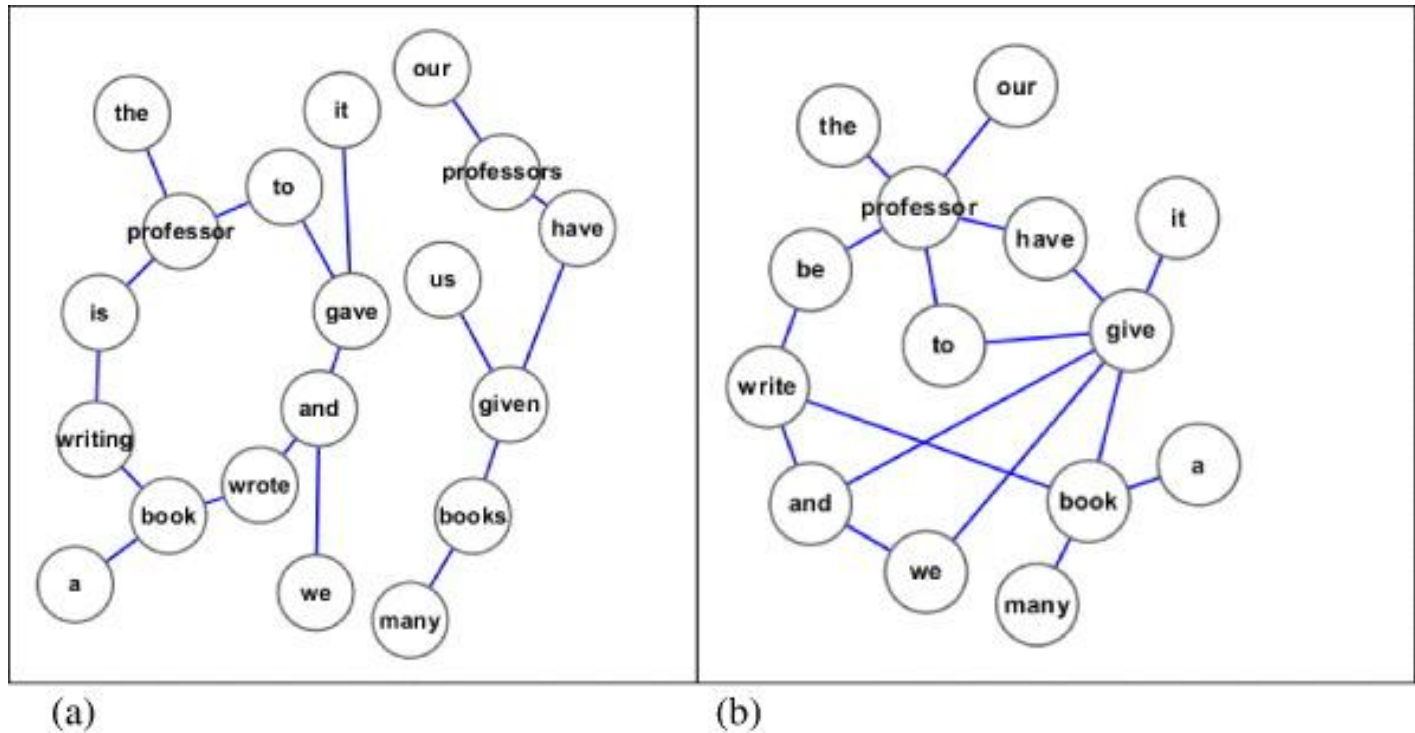
Astonishing Facts

- 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)



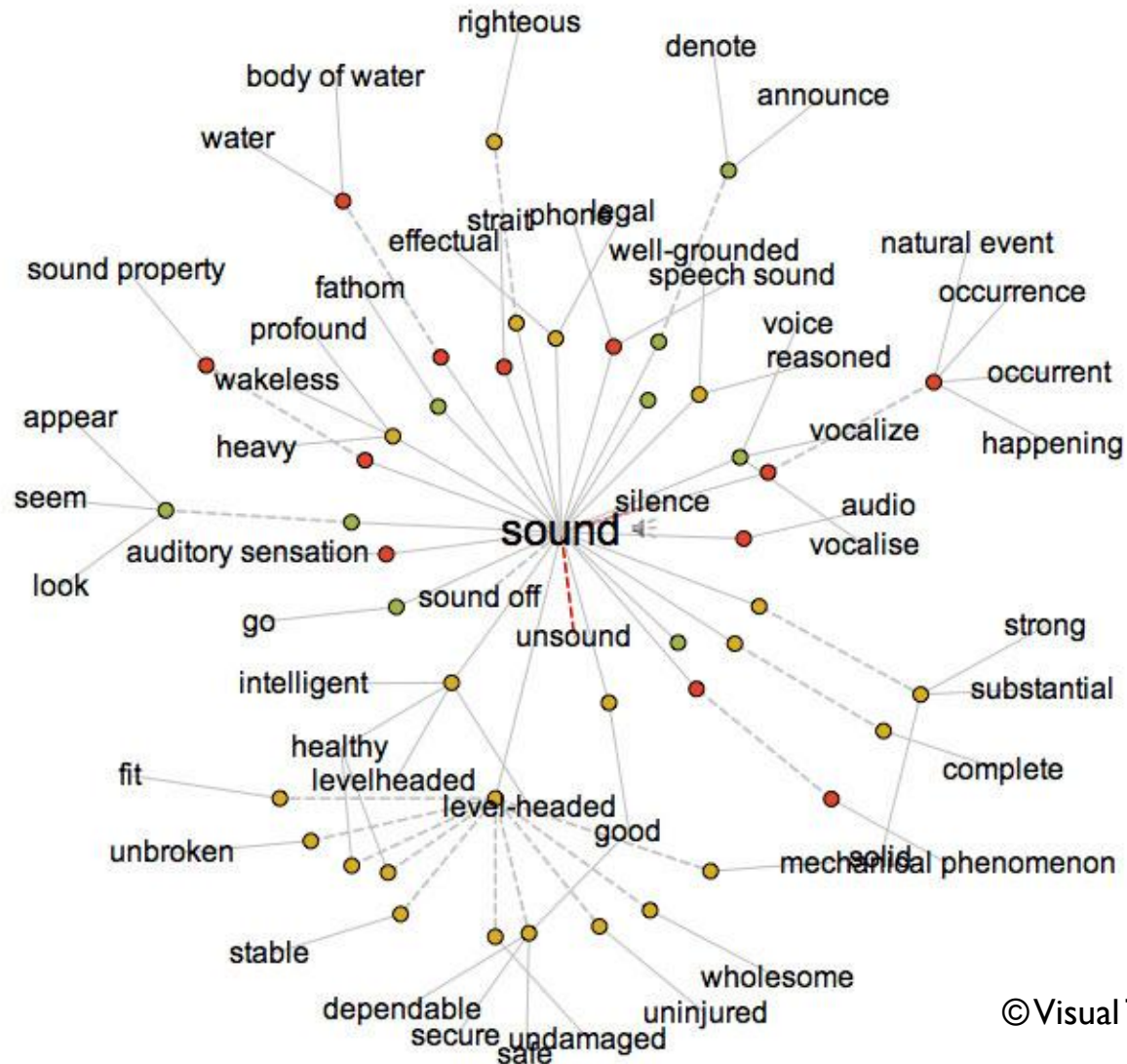
From Liu & Xu 2011; networks were generated from the following three sentences:

This professor is writing a book.

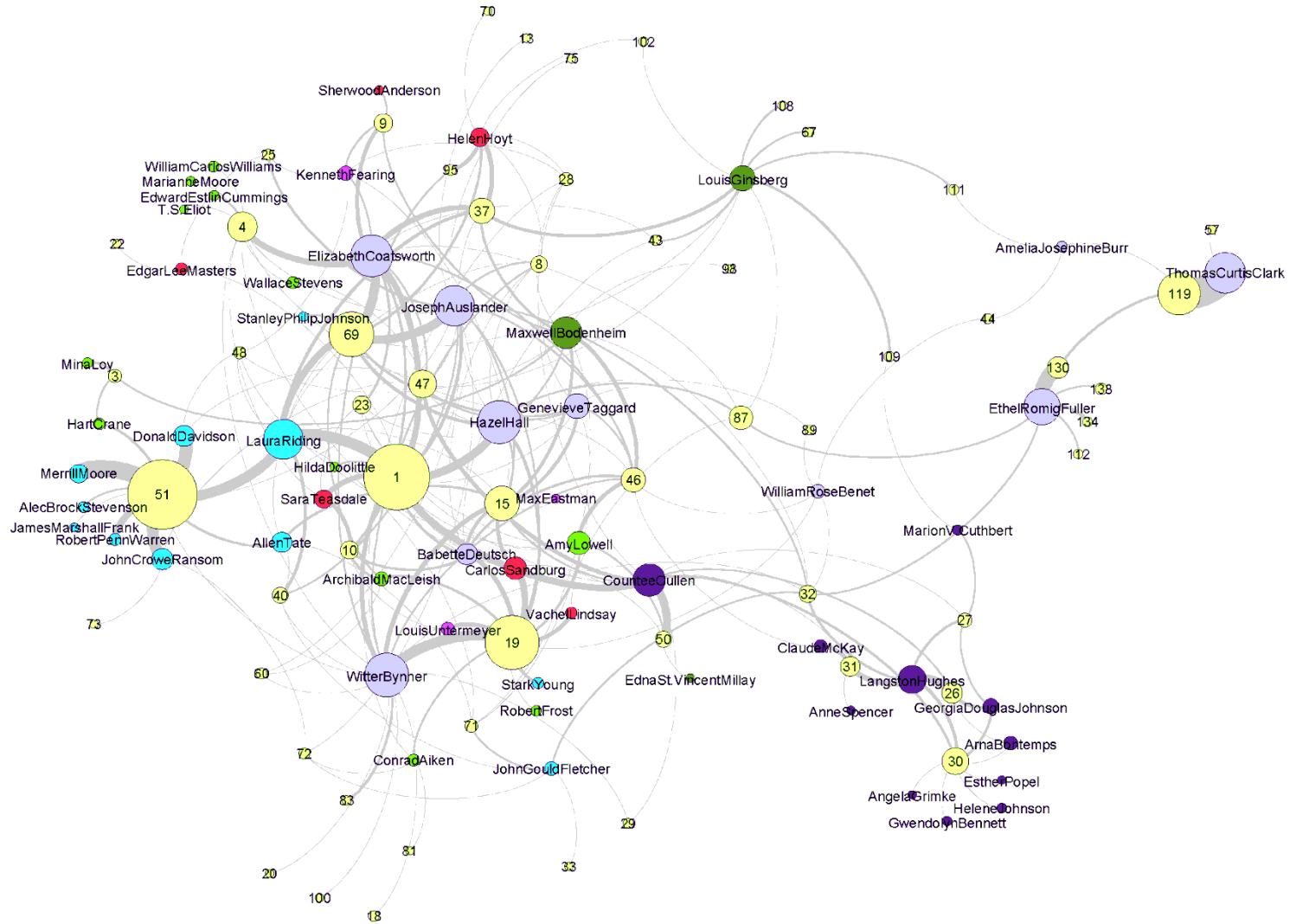
Our professors have given us many books.

We wrote a book and gave it to the professor.

Network of Words (Semantic)

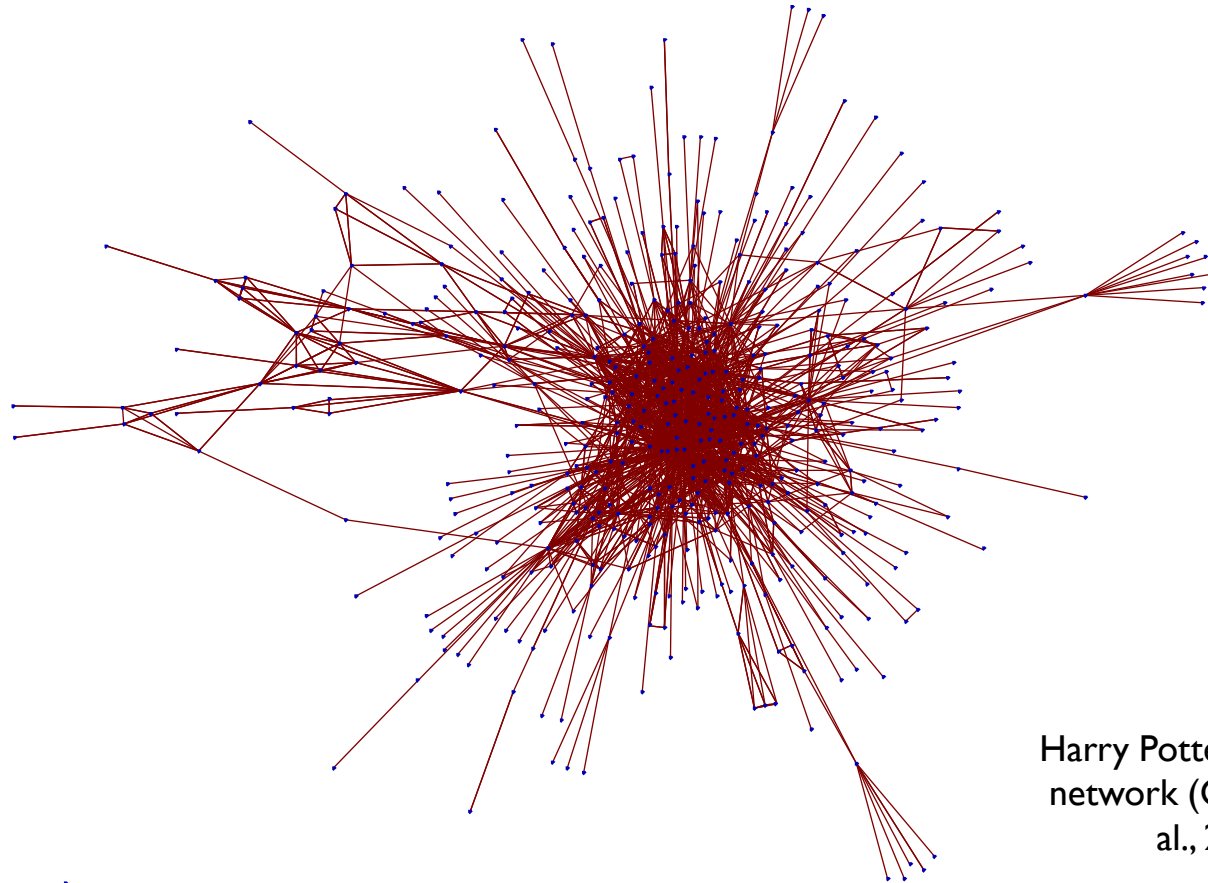


Network of U.S. Poets (1924-25)

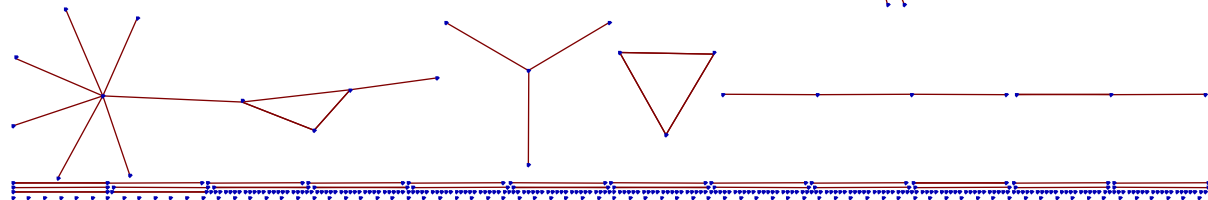


Hoyt Long: Literary Networks. <http://lucian.uchicago.edu/blogs/literarynetworks/>

Network of Fictional Characters



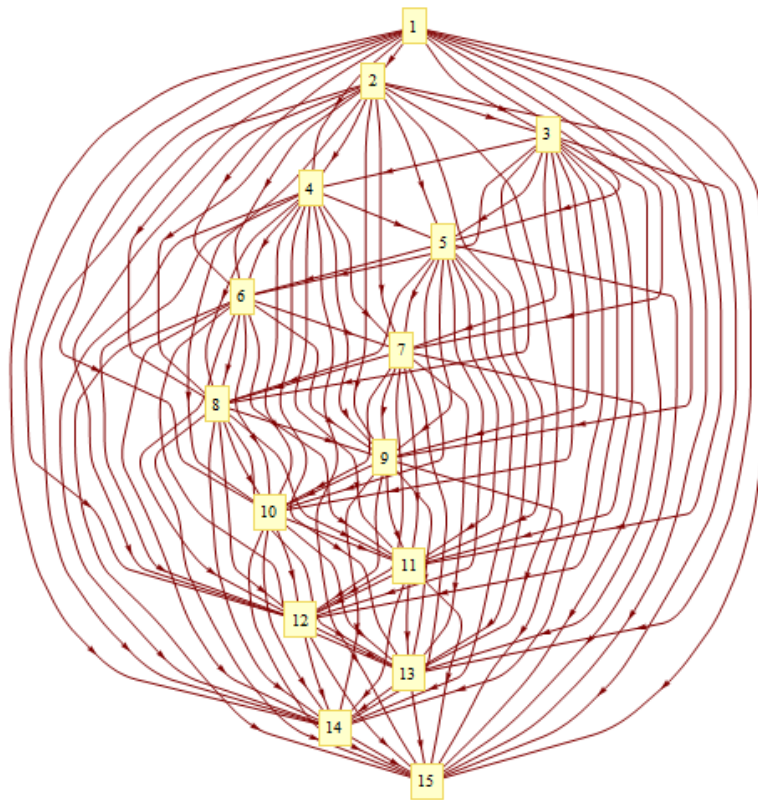
Harry Potter's character network (Calderone et al., 2011)



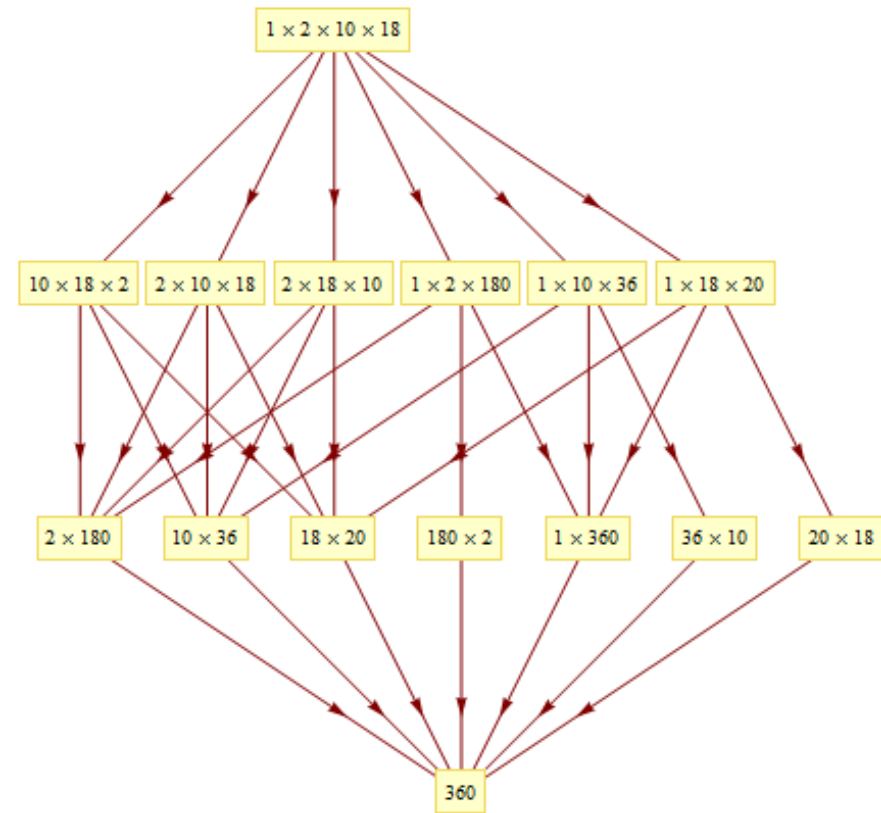


Networks in Math

Networks of Numbers (I)

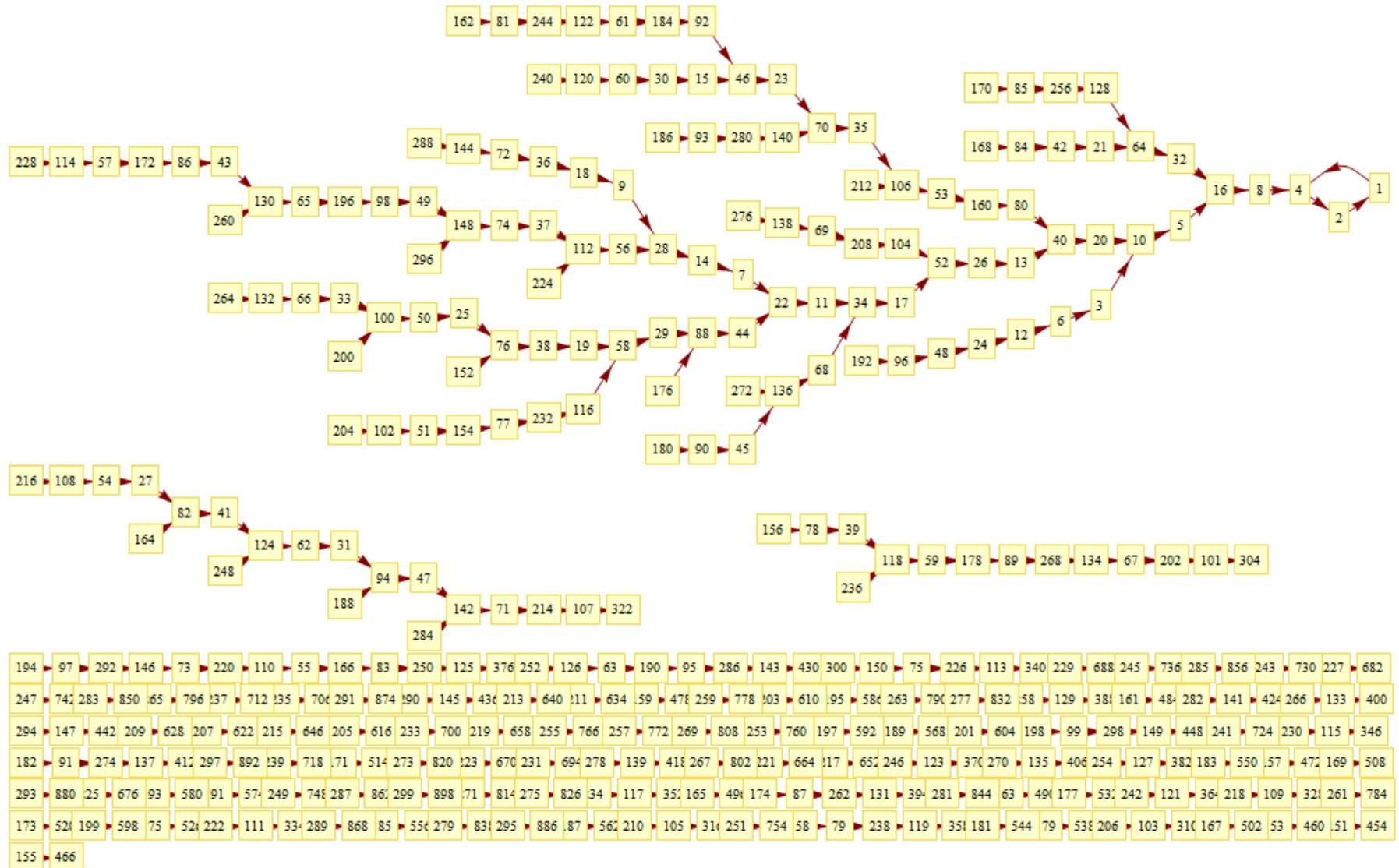


Transitivity network ($i \rightarrow j$ if and only if $i < j$)



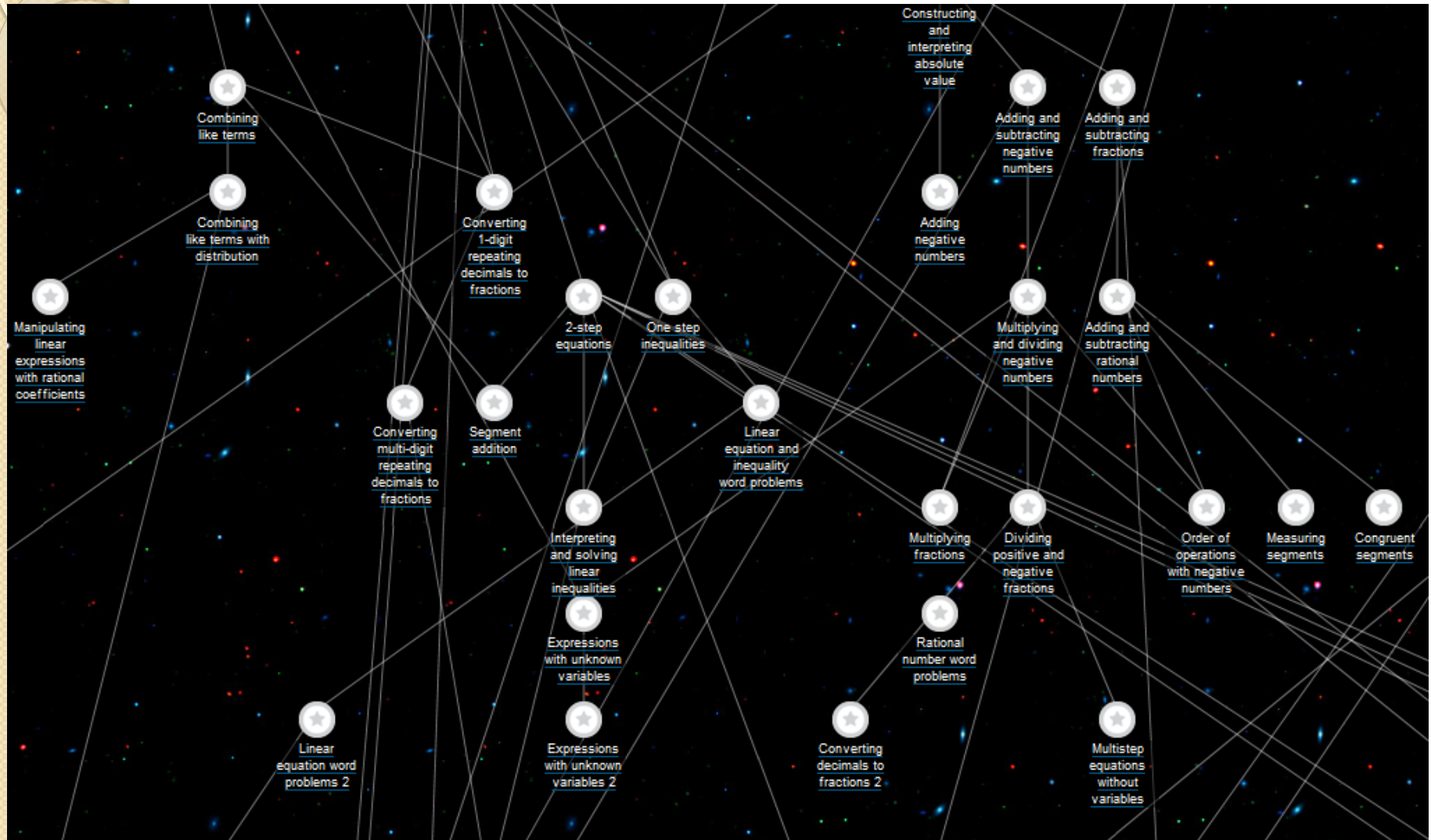
Associativity network (about multiplication)

Networks of Numbers (2)



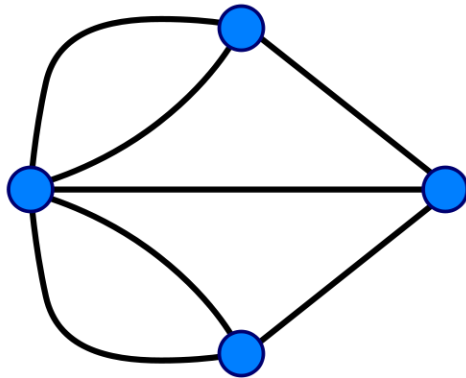
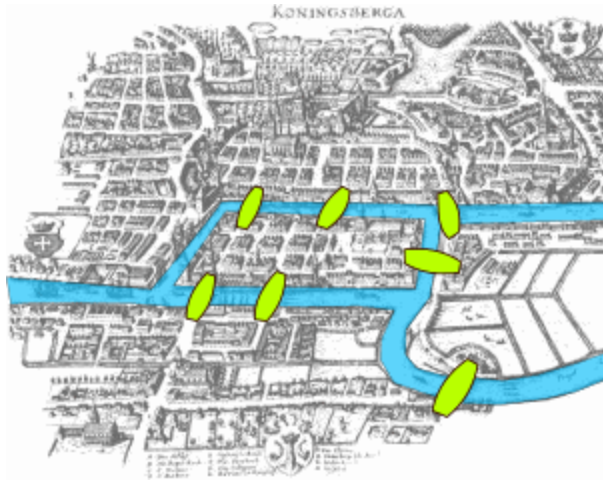
Collatz sequence ($x \rightarrow y$; $y = x/2$ if x is even, or $3x+1$ otherwise)

Network of Concepts



Knowledge Map (from Khan Academy)

Networks in Math Puzzles



Seven bridges of Königsberg
(images from Wikipedia)

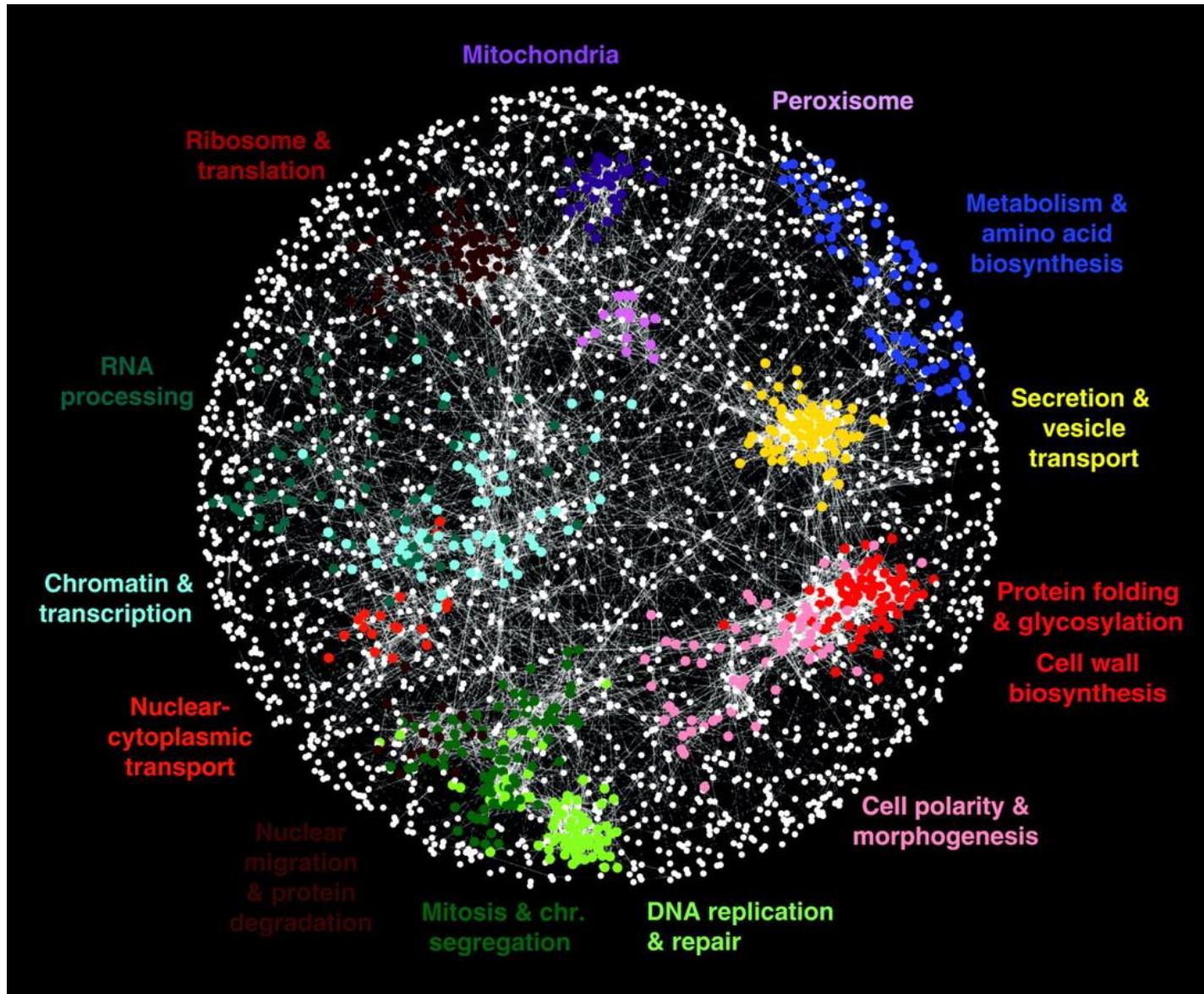


42 bridges in Bristol, UK
(images from Bristol Post / Dr. Thilo Gross)



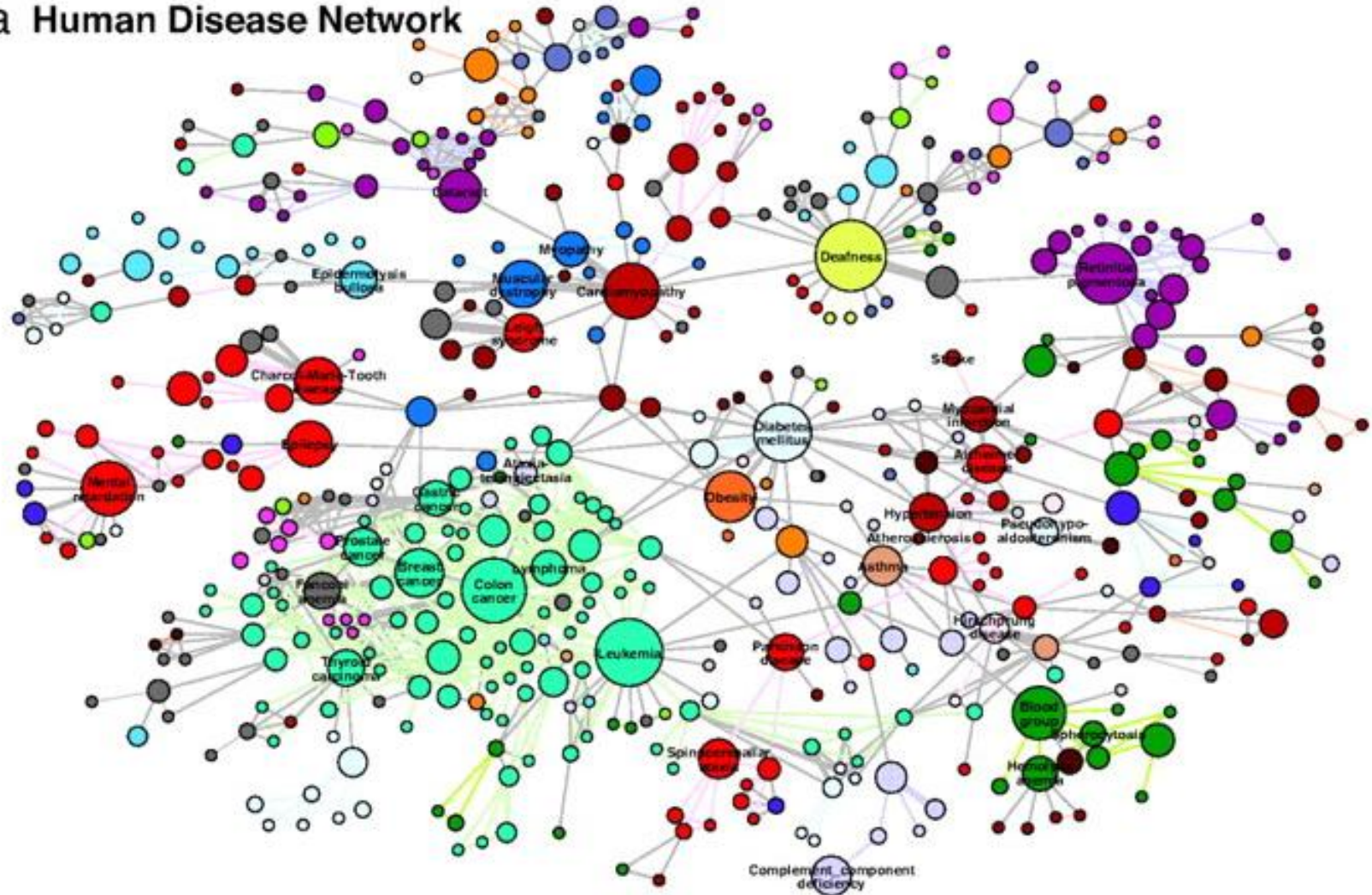
Networks in Science

Network of Genes

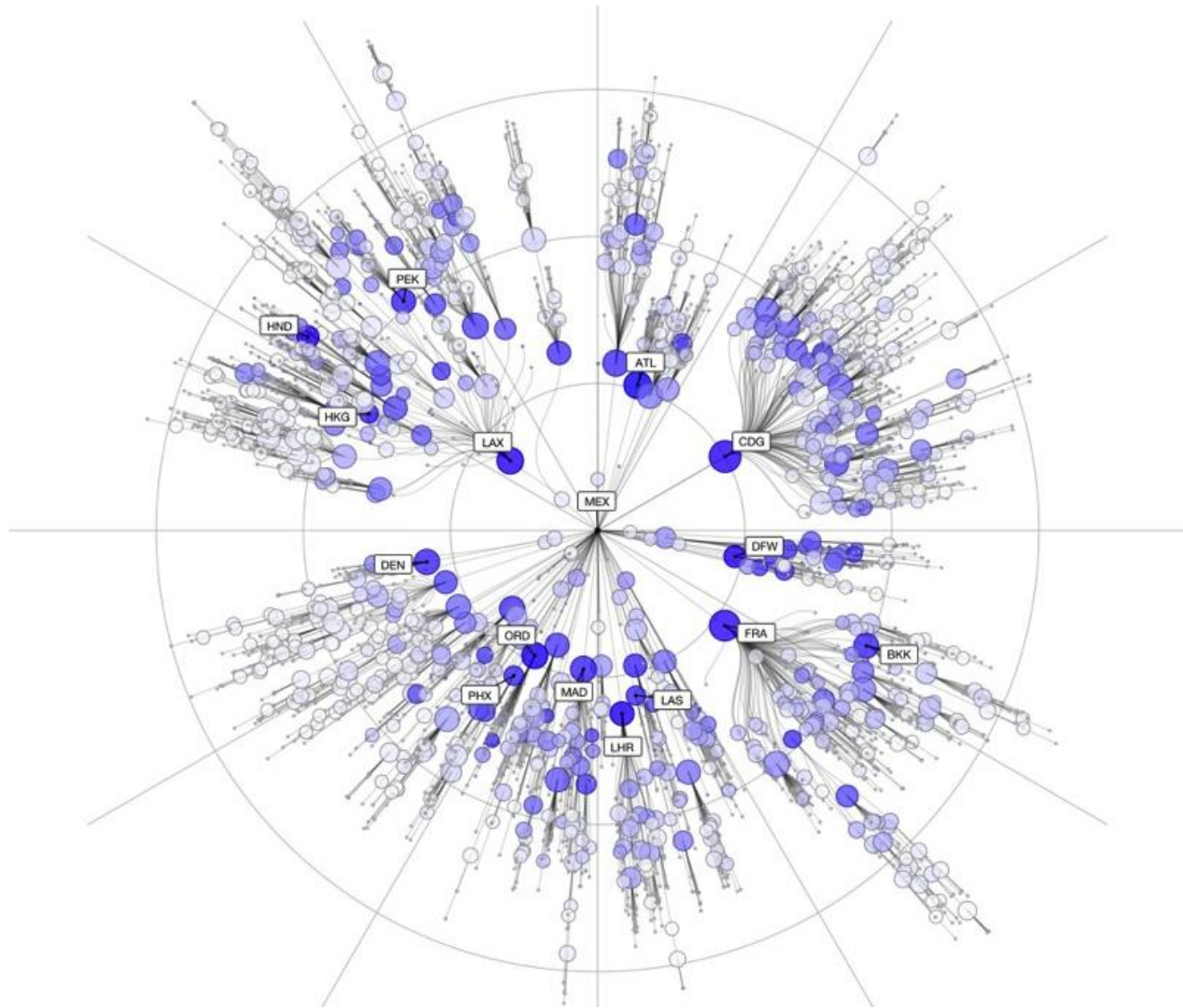


Network of Diseases

a Human Disease Network

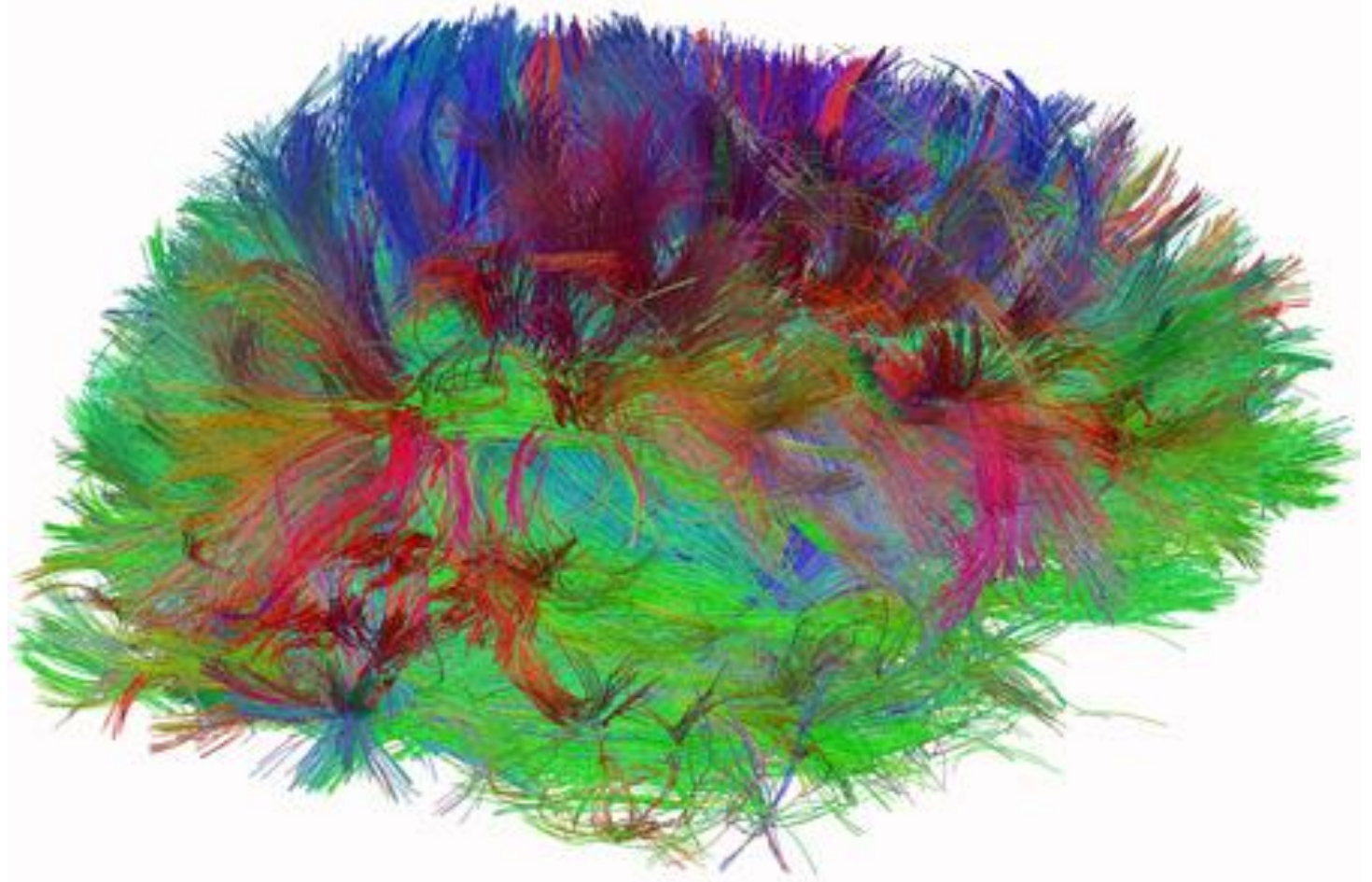


Network of Disease Propagation



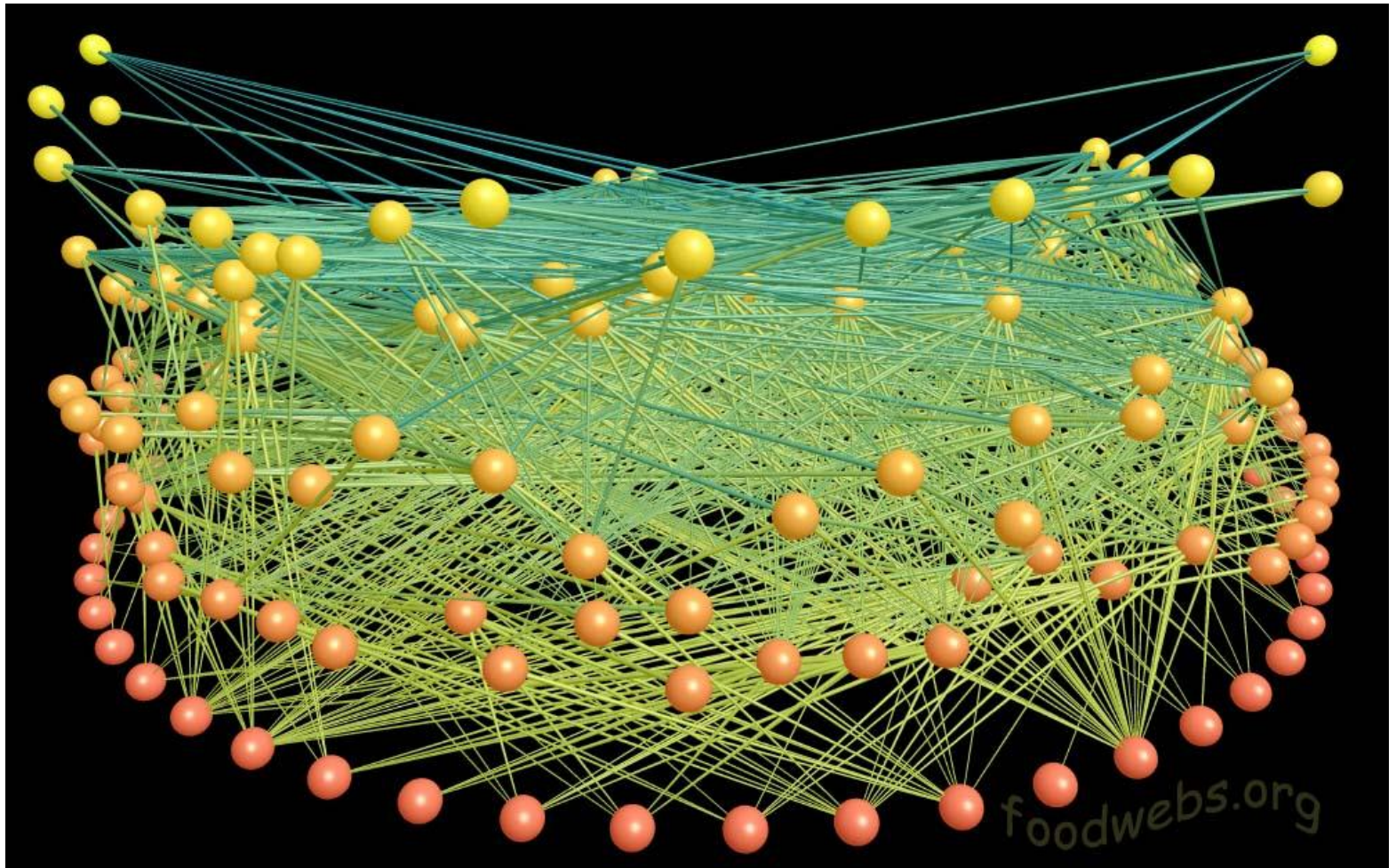
H1N1 activities illustrated according to distance from MEX airport (Brockmann, 2013)

Network of the Brain



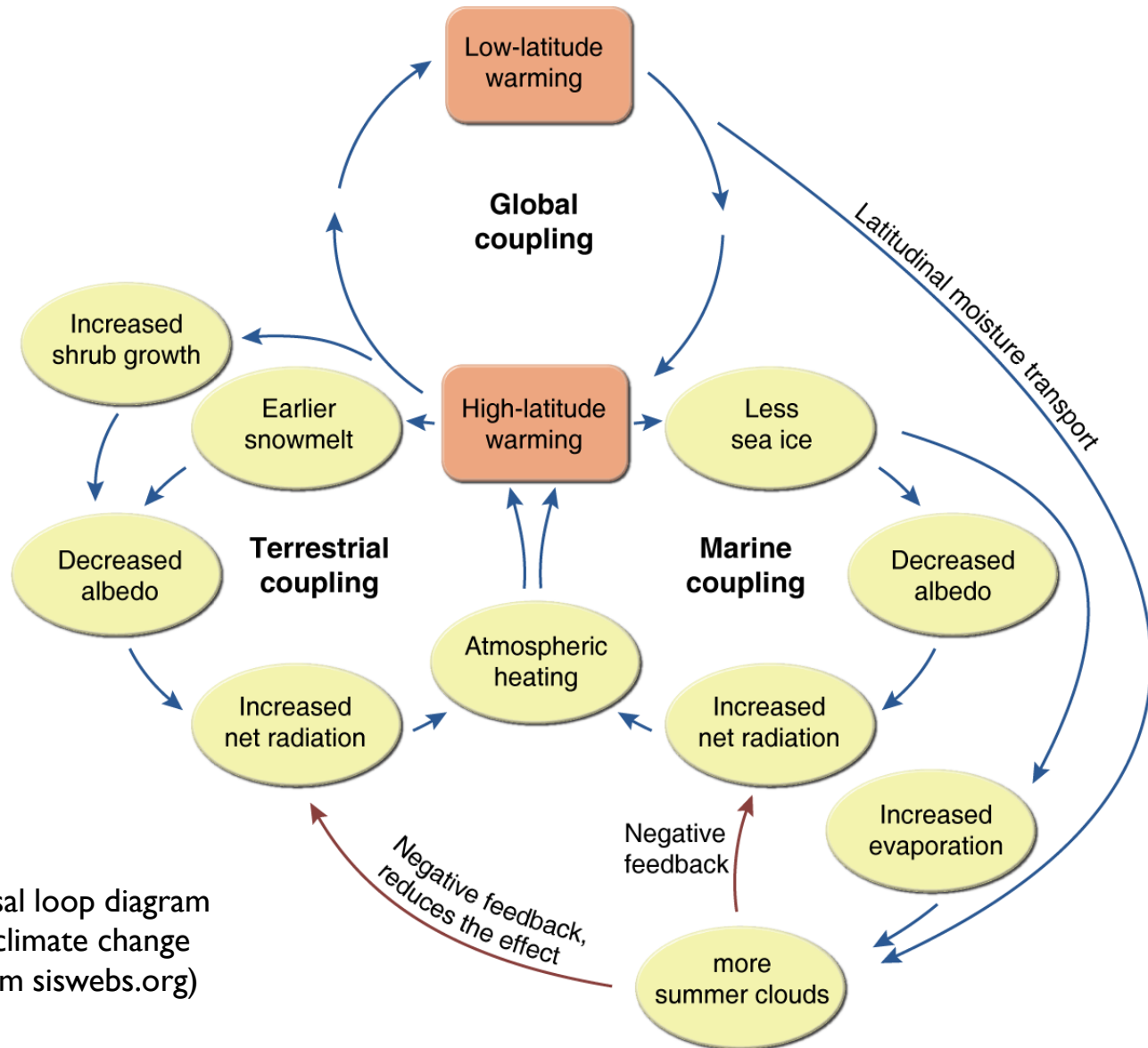
Van J. Wedeen, M.D., MGH/Harvard U.

Food Webs



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

Causal Loop Diagram

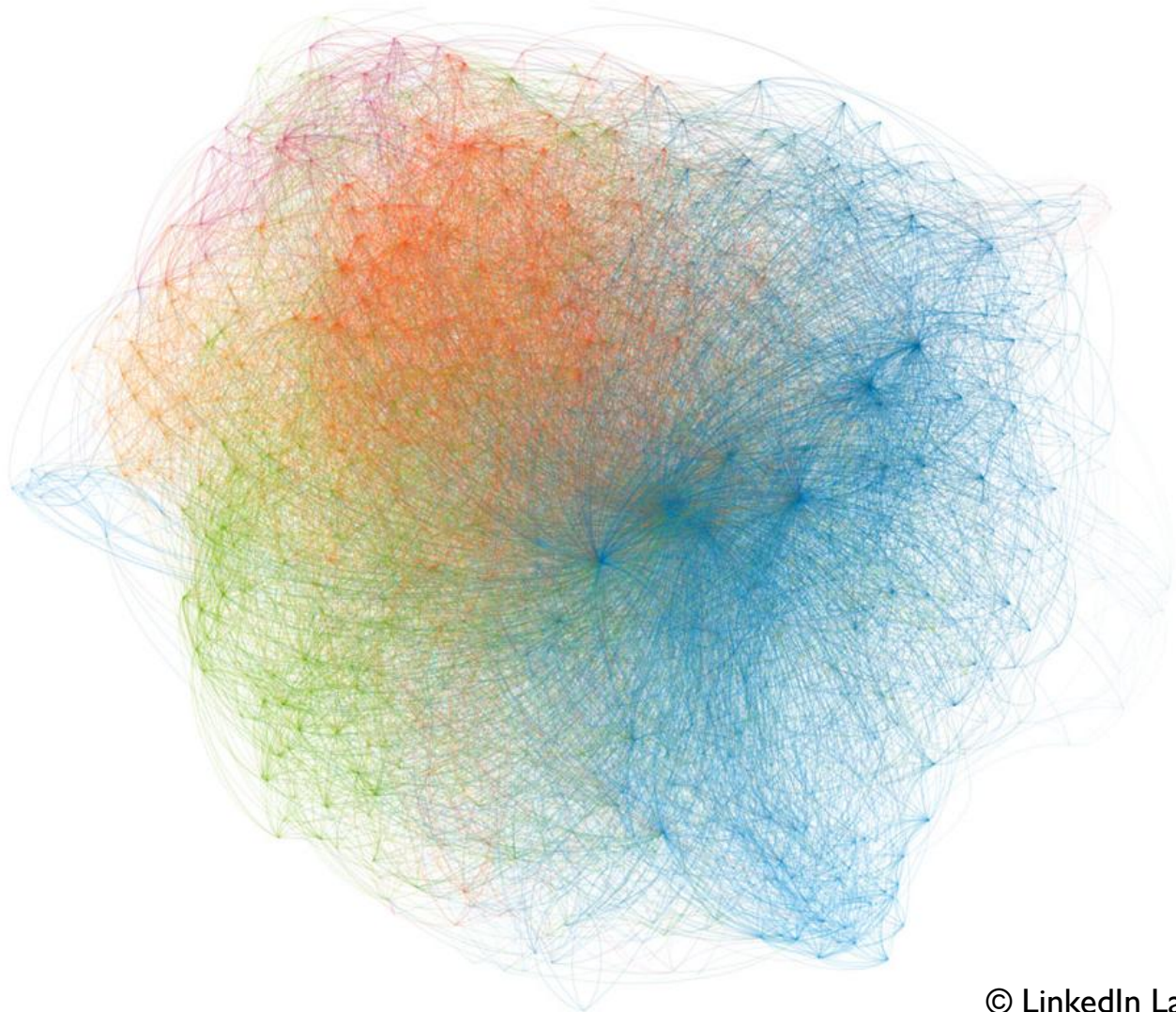


Causal loop diagram
of climate change
(from siswebs.org)

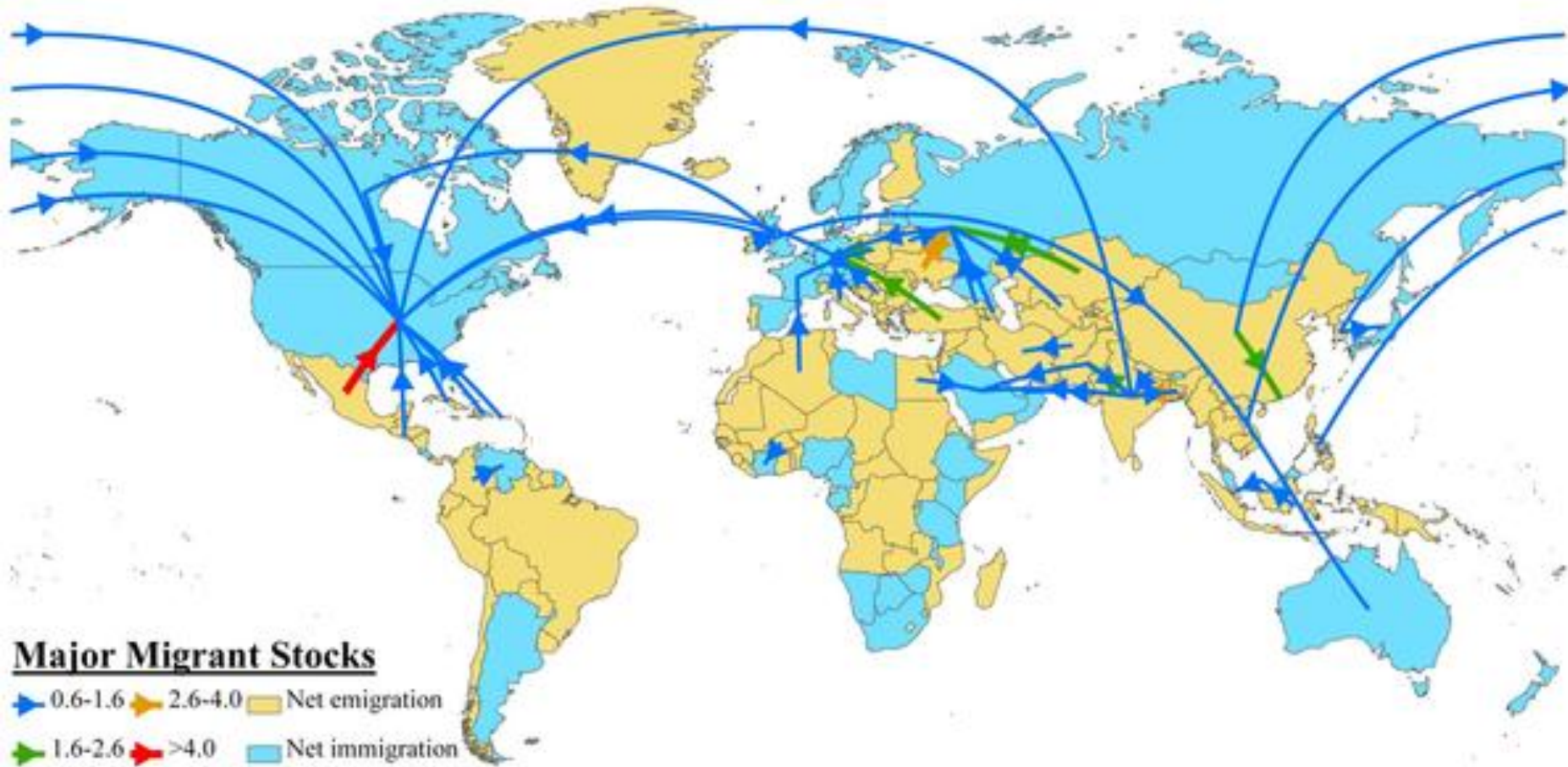


Networks in Social Studies

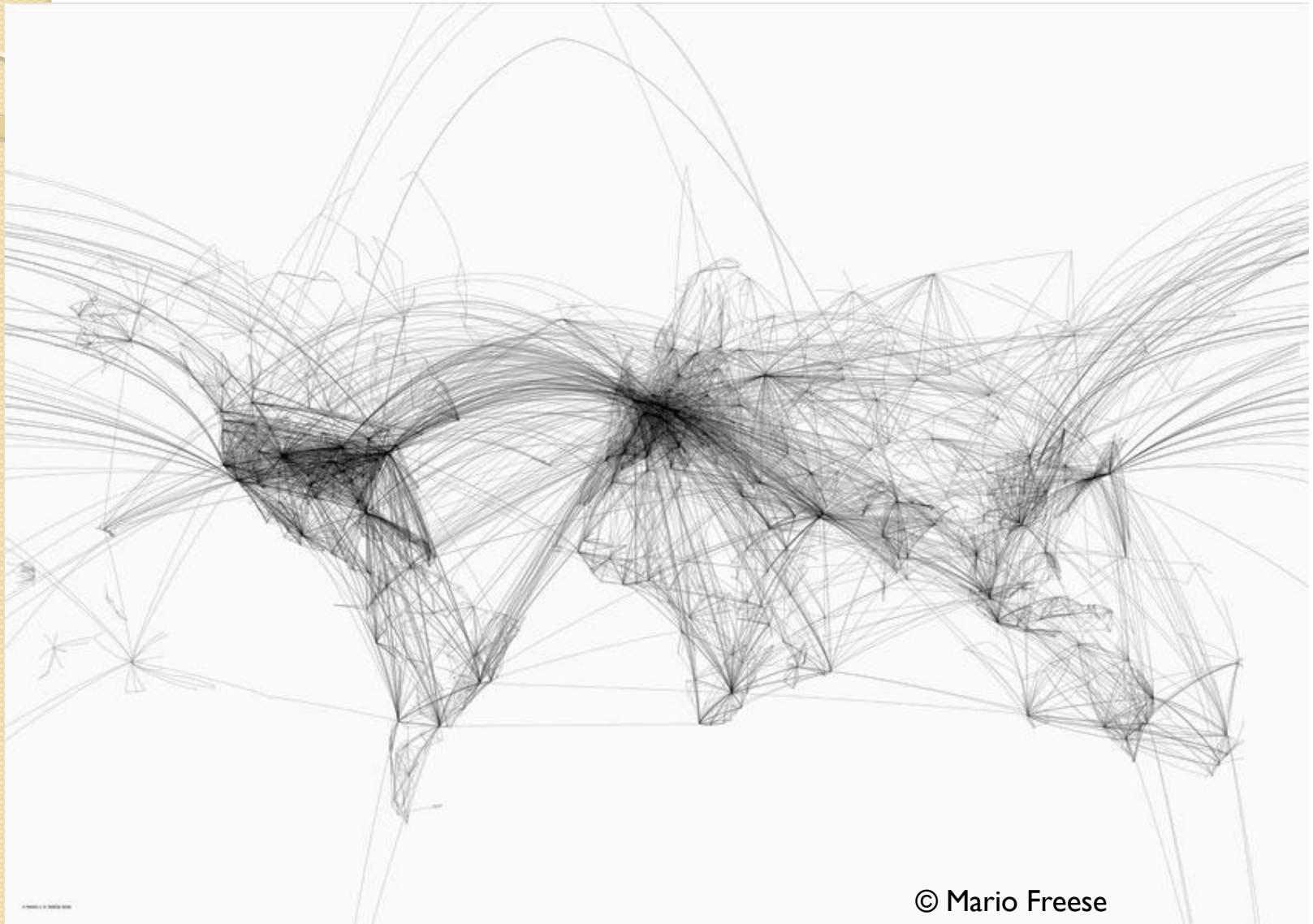
Network of People Around You



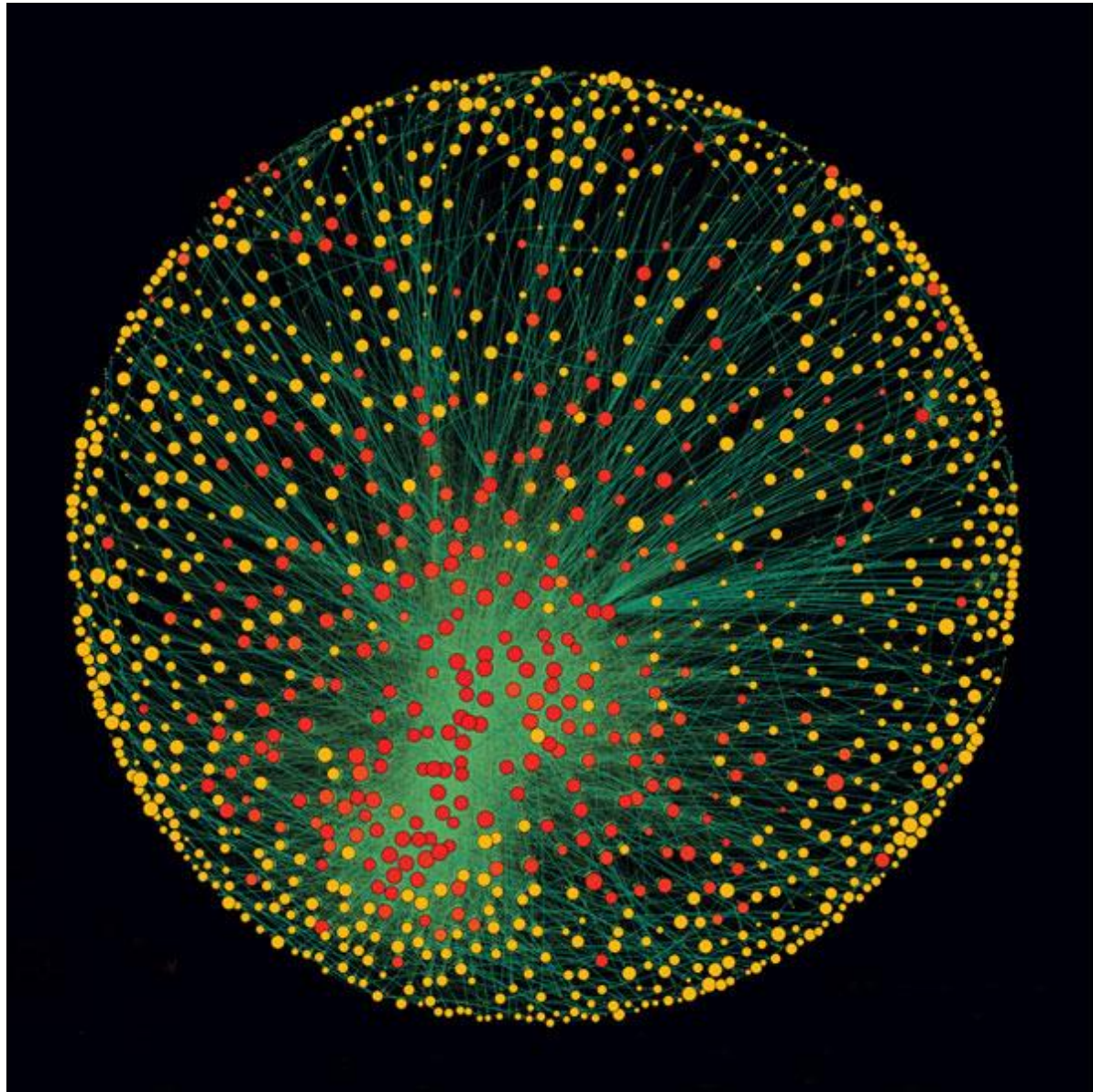
Network of Human Migration



Network of Transportations

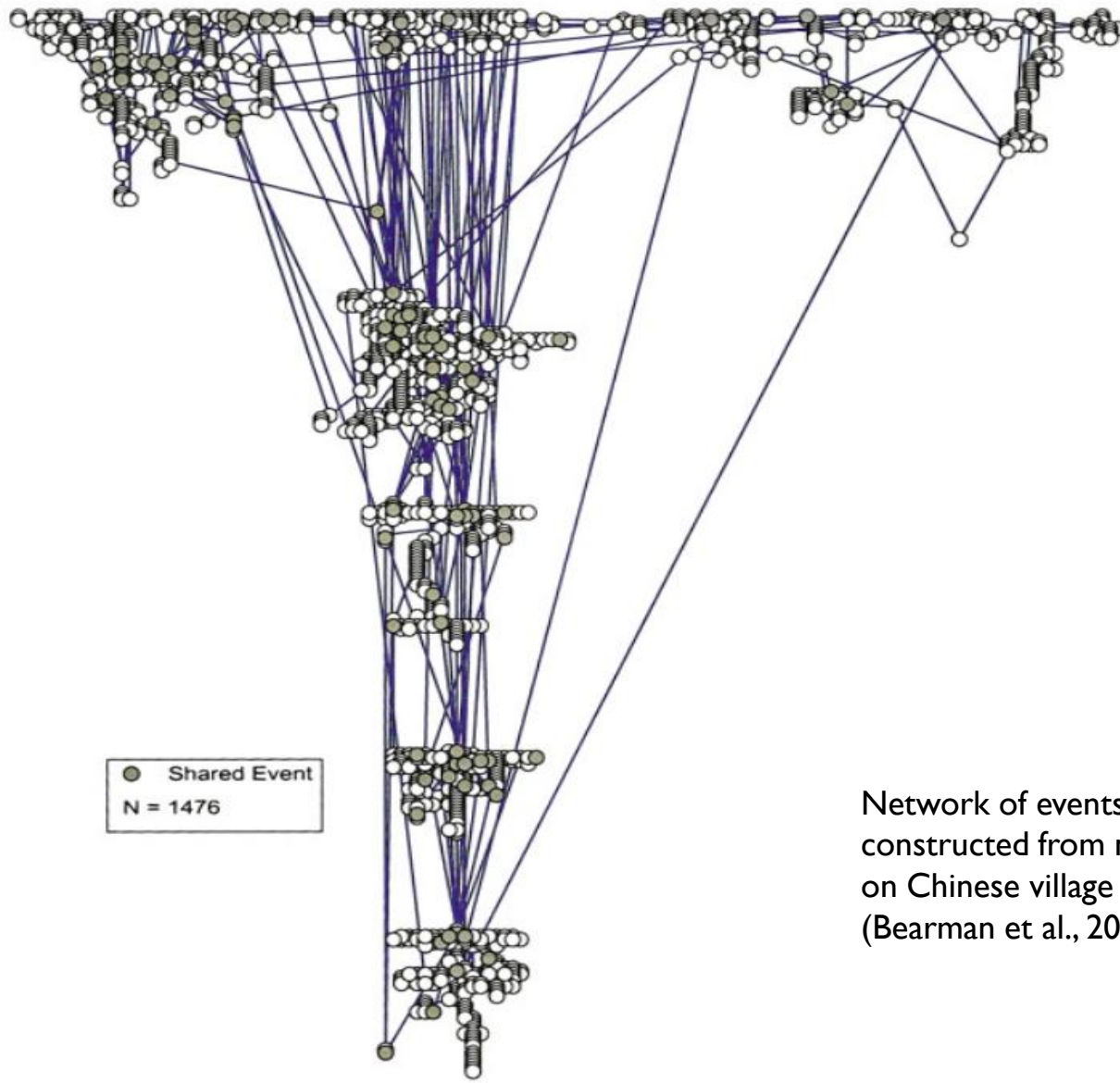


Network of Corporations



Vitali et al.,
2011

Network of Historical Events

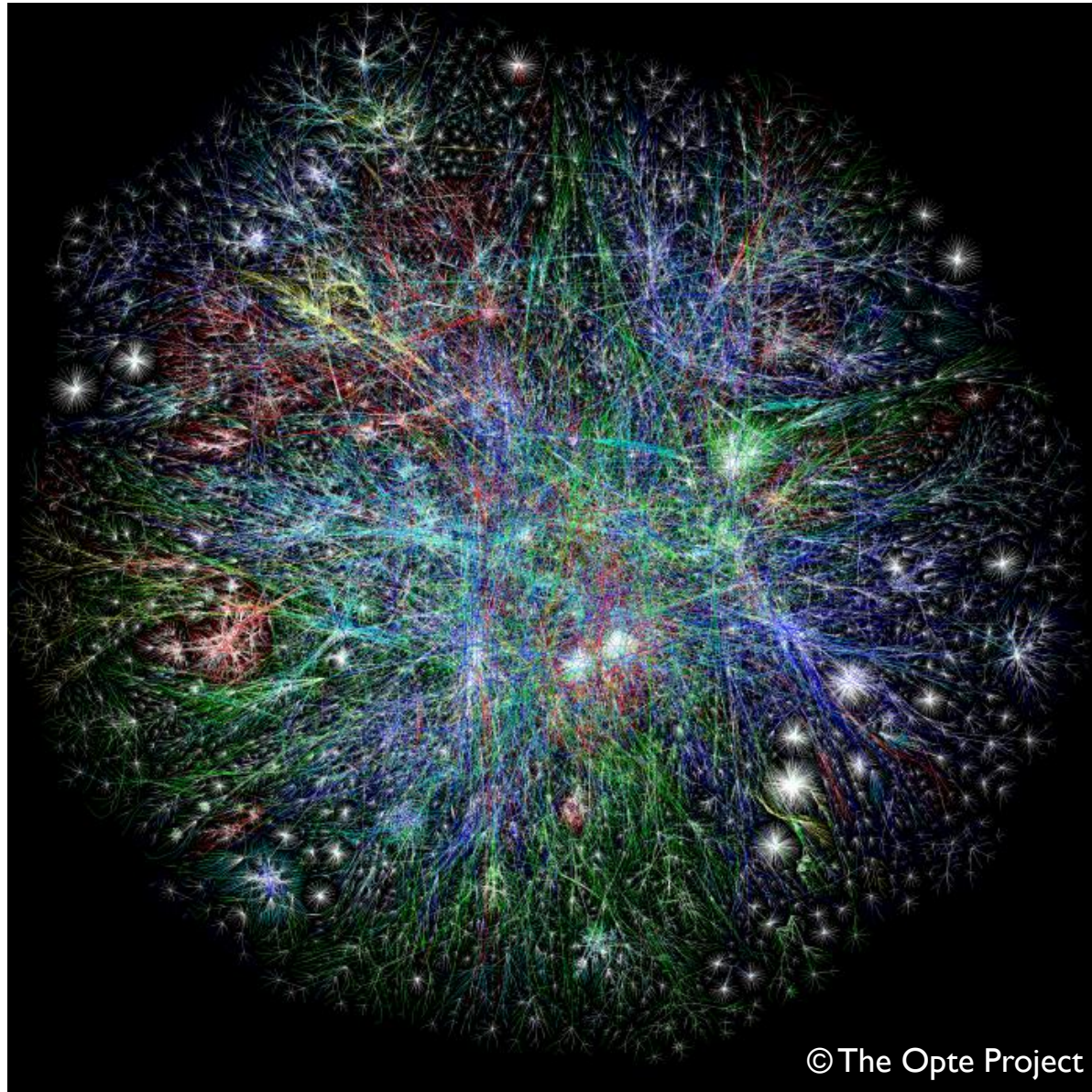


Network of events
constructed from narratives
on Chinese village Liu Ling
(Bearman et al., 2003)

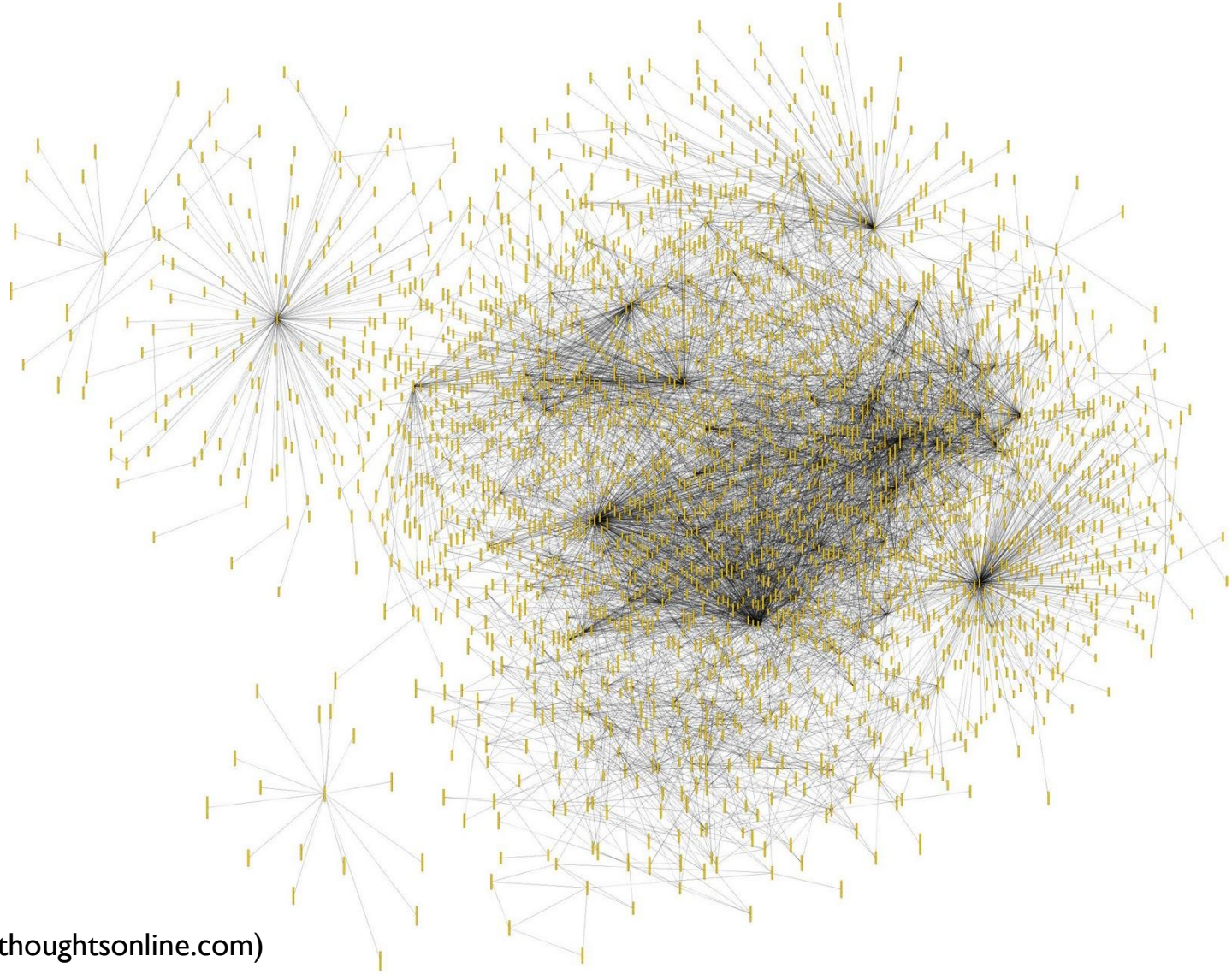


Networks in Technical Education

The Internet



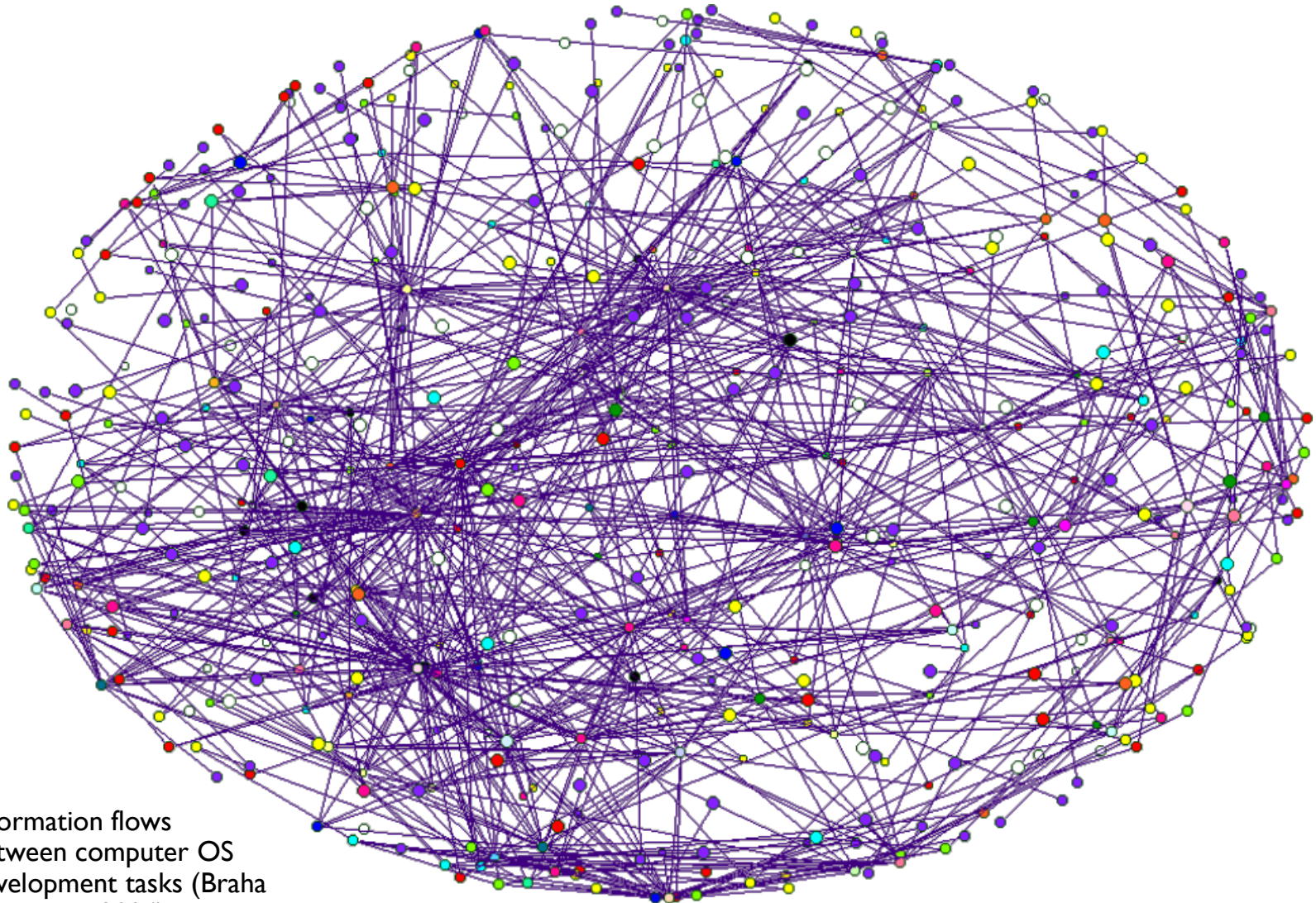
Network of Java Classes



Cavlin, 2012

(from simplethoughtsonline.com)

Network of Product Design



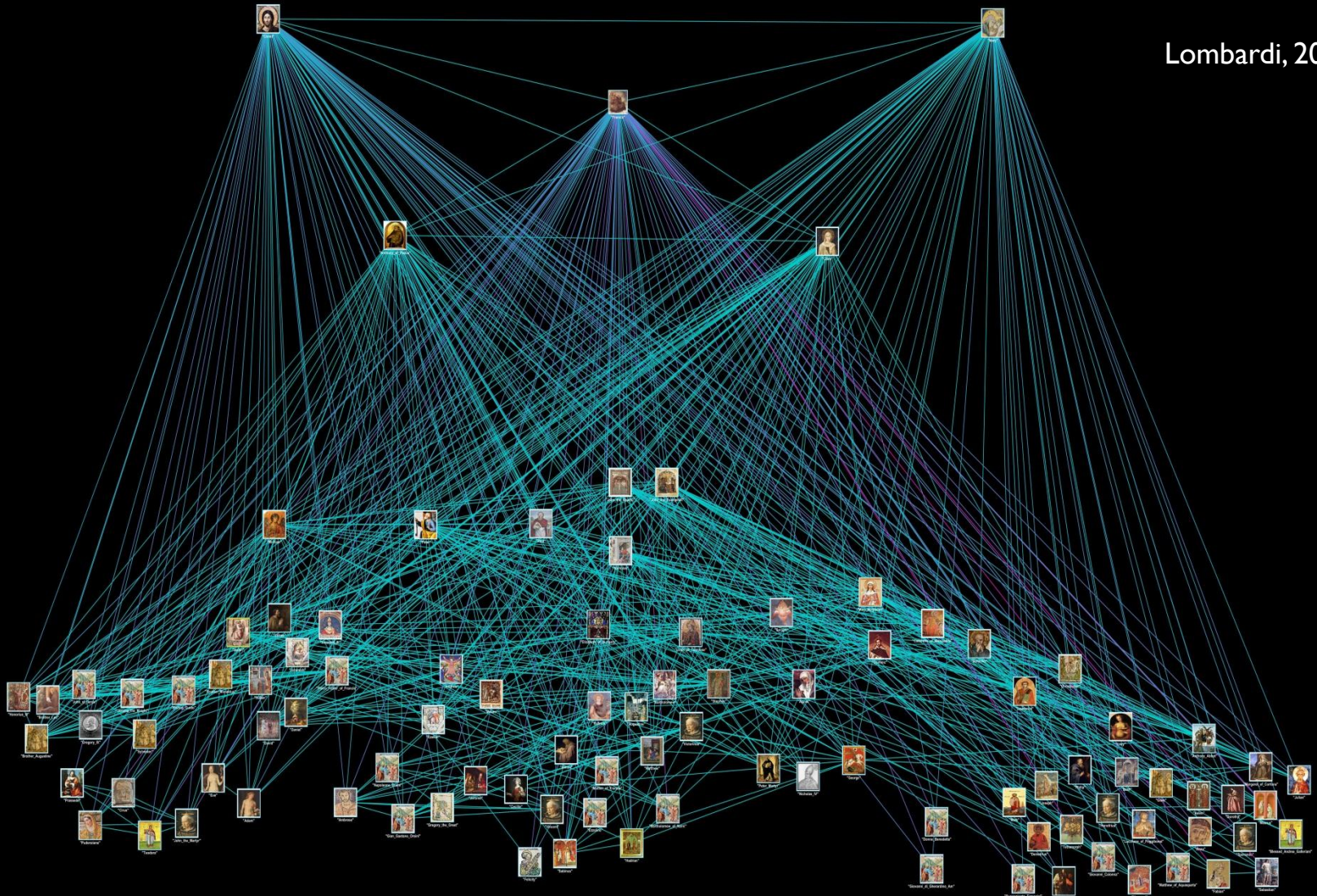
Information flows
between computer OS
development tasks (Braha
& Bar-Yam, 2004)



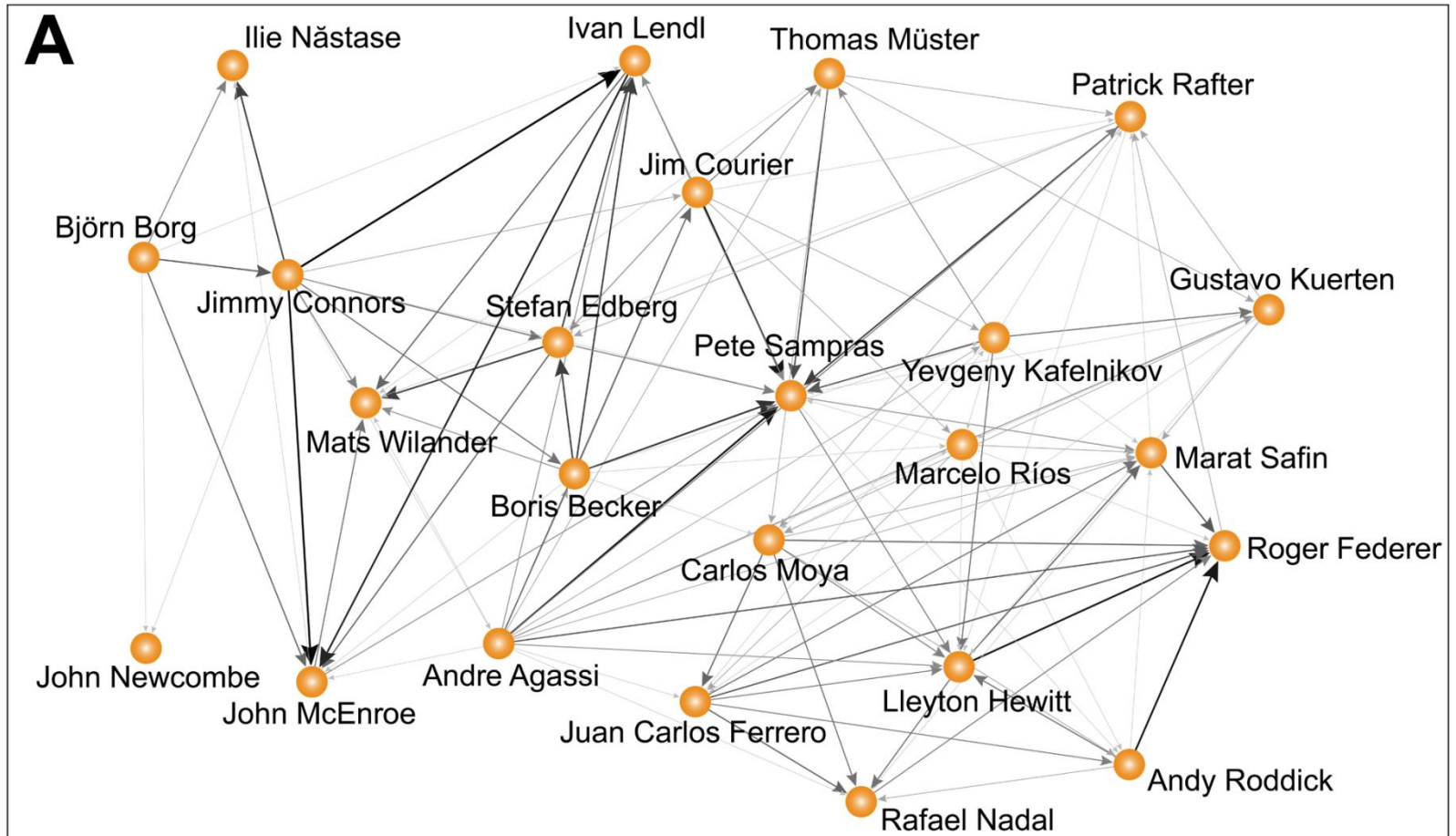
Networks in Other Subjects

Network of Saints in Iconography

Lombardi, 2013



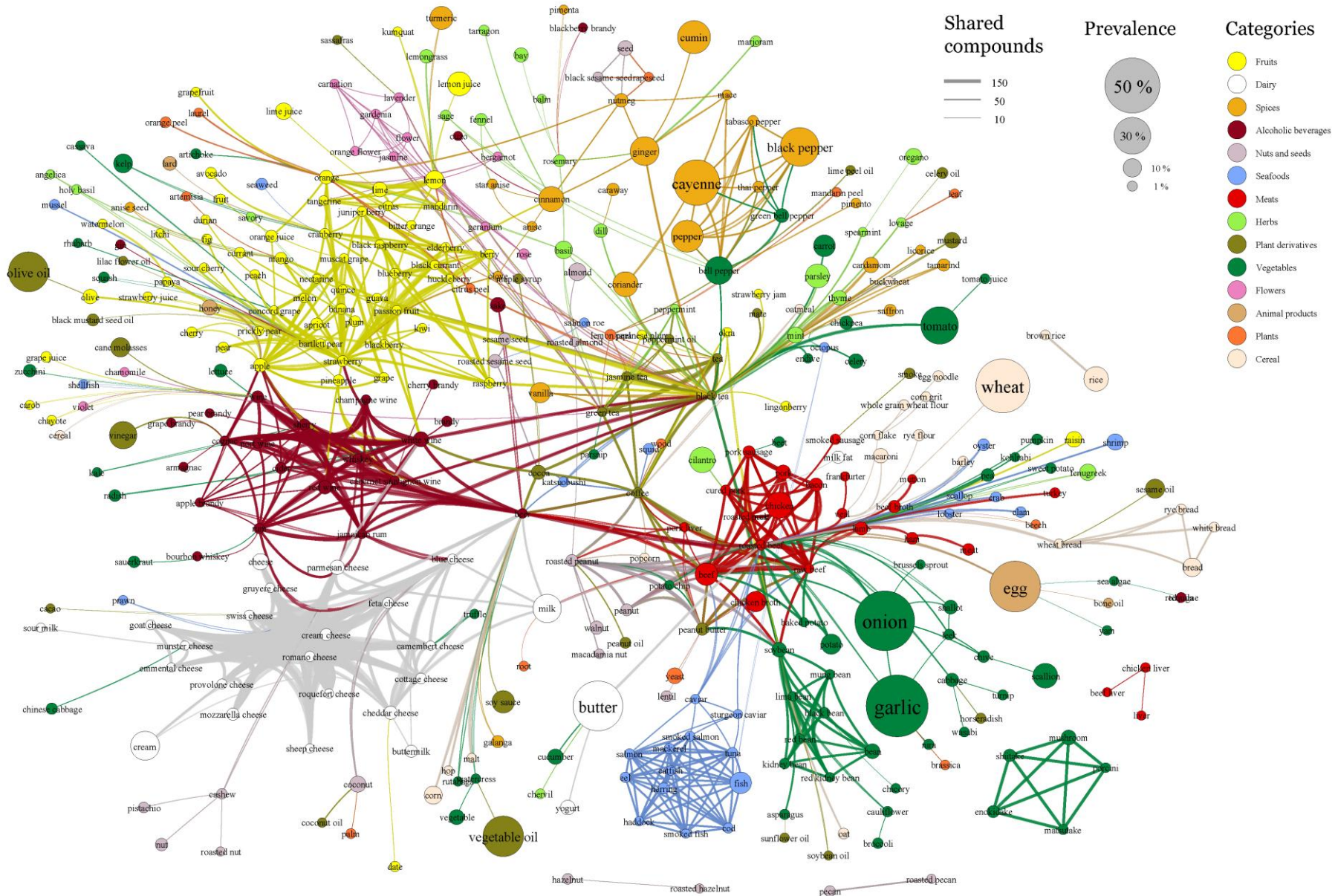
Network of Top Tennis Players



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)

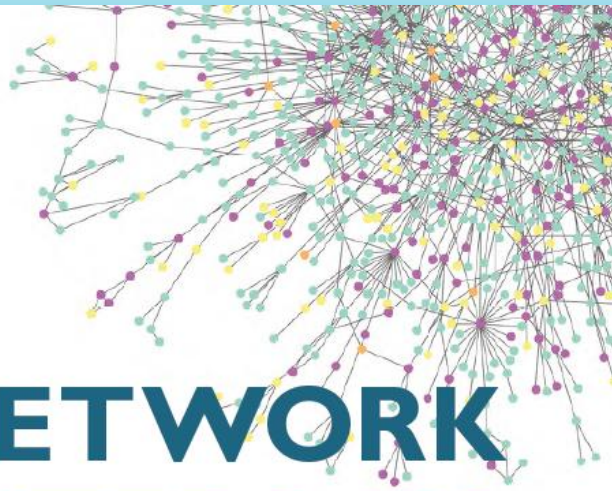


Flavor network. Culinary ingredients (circles) and their chemical relationship are illustrated. The color of each ingredient represents the food category that the ingredient belongs to, and the size of an ingredient is proportional to the usage frequency (collected from online recipe databases: epicurious.com, allrecipes.com, 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 concept of networks (social and general) and of discrete low-frequency oscillations can be used to describe many systems in many aspects of life.
- There are networks that have the structure of networks in many aspects of life: the human brain, the Internet, the social network, the world wide web, etc.
- There are networks of people—e.g., social networks, communication networks, transportation networks, etc.
- There are economic networks—e.g., financial networks, supply chains, etc.
- There are biological and ecological networks—e.g., food webs, gene networks, etc.
- There are cultural networks—e.g., language networks, etc.
- Networks can be used to model many other systems.

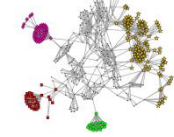


2 NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- There is a notion of connectivity, that is, the ability of nodes to interact with each other.
- Connections are called links, edges, or bonds.
- Connections can be weighted (strength of interaction).
- The number of connections of a node is called its degree.
- There are many types of networks: social, biological, etc.
- Networks can be used to model many other systems.

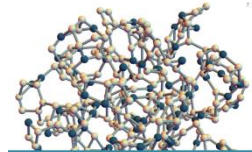
3 NETWORKS CAN HELP REVEAL PATTERNS

- Networks can help reveal patterns in data.
- Networks can help reveal patterns in behavior.
- Networks can help reveal patterns in communication.
- Networks can help reveal patterns in transportation.
- Networks can help reveal patterns in social networks.
- Networks can help reveal patterns in biological networks.
- Networks can help reveal patterns in economic networks.
- Networks can help reveal patterns in cultural networks.



4 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

- Visualizations can help provide an understanding of networks.
- Visualizations can help provide an understanding of network structure.
- Visualizations can help provide an understanding of network dynamics.
- Visualizations can help provide an understanding of network evolution.
- Visualizations can help provide an understanding of network control.
- Visualizations can help provide an understanding of network optimization.
- Visualizations can help provide an understanding of network robustness.
- Visualizations can help provide an understanding of network resilience.



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

- Network structure can influence its state.
- Network structure can influence its dynamics.
- Network structure can influence its evolution.
- Network structure can influence its control.
- Network structure can influence its optimization.
- Network structure can influence its robustness.
- Network structure can influence its resilience.
- Network structure can influence its adaptability.

6 NETWORKS HELP YOU TO COMPARE A WIDE VARIETY OF SYSTEMS

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

- Computer technology allows us to study real-world networks.
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