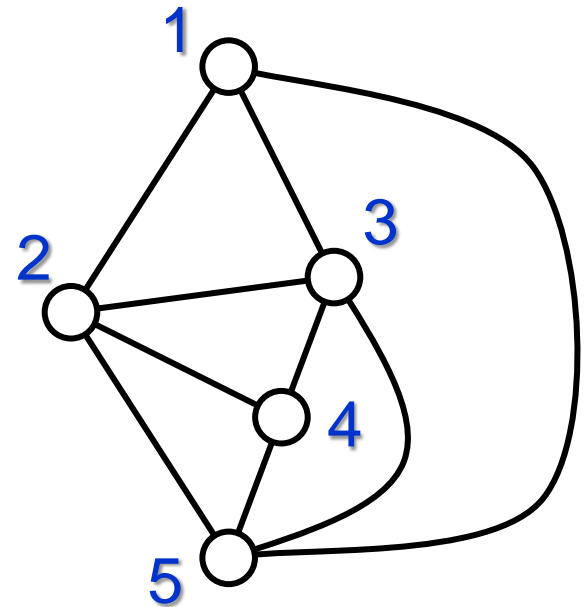


Network Thinking: Some Examples

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.*

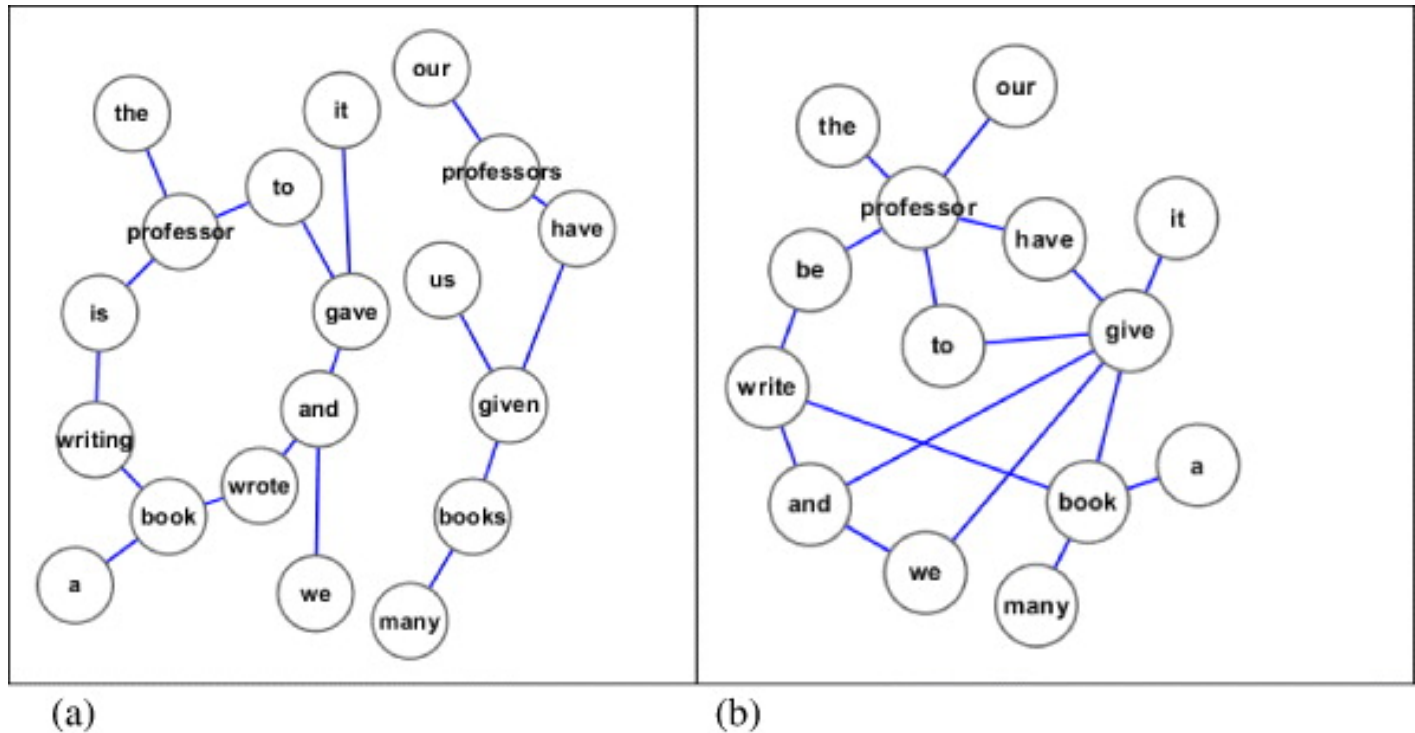
Astonishing Facts

- 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)



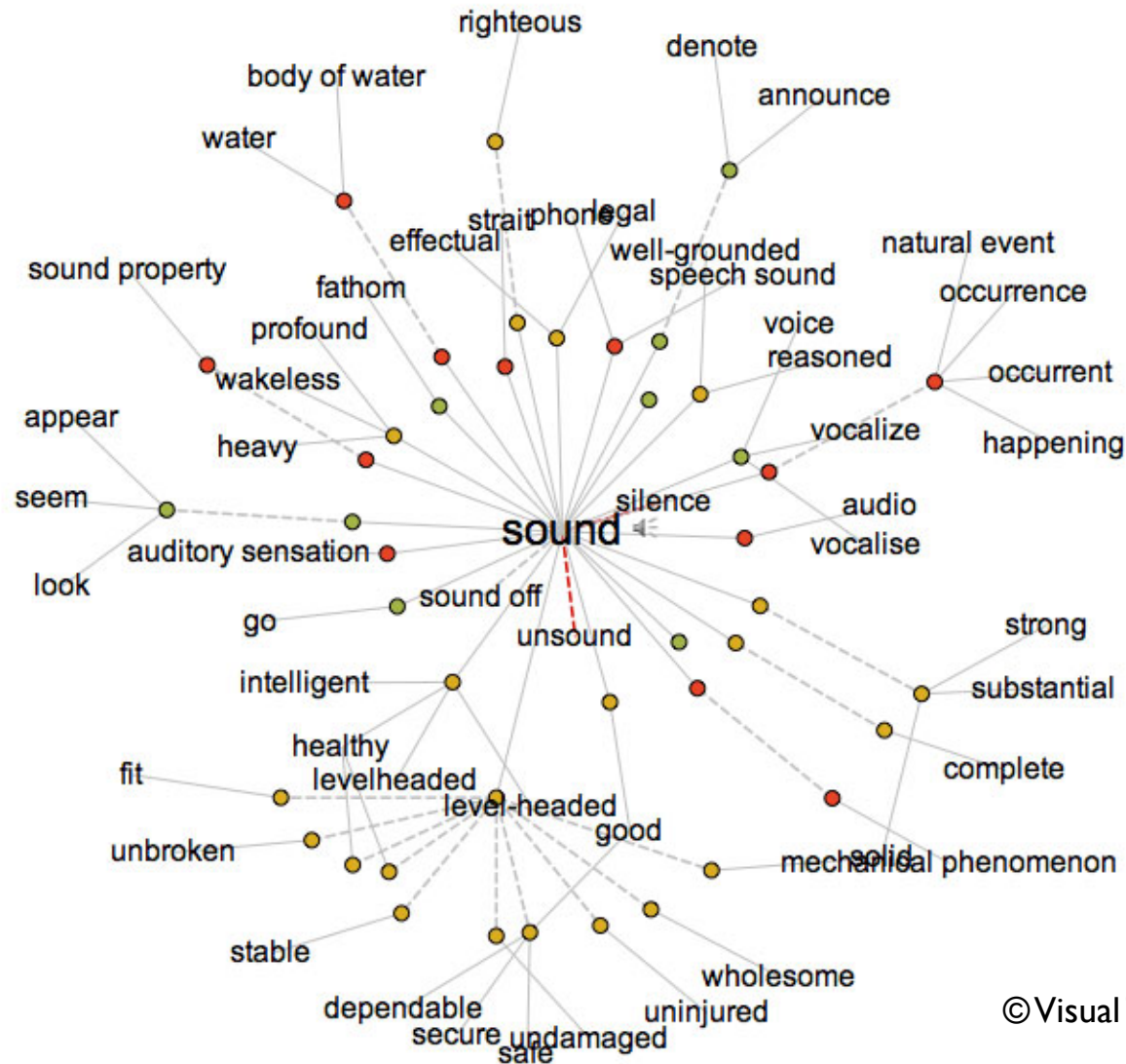
From Liu & Xu 2011; networks were generated from the following three sentences:

This professor is writing a book.

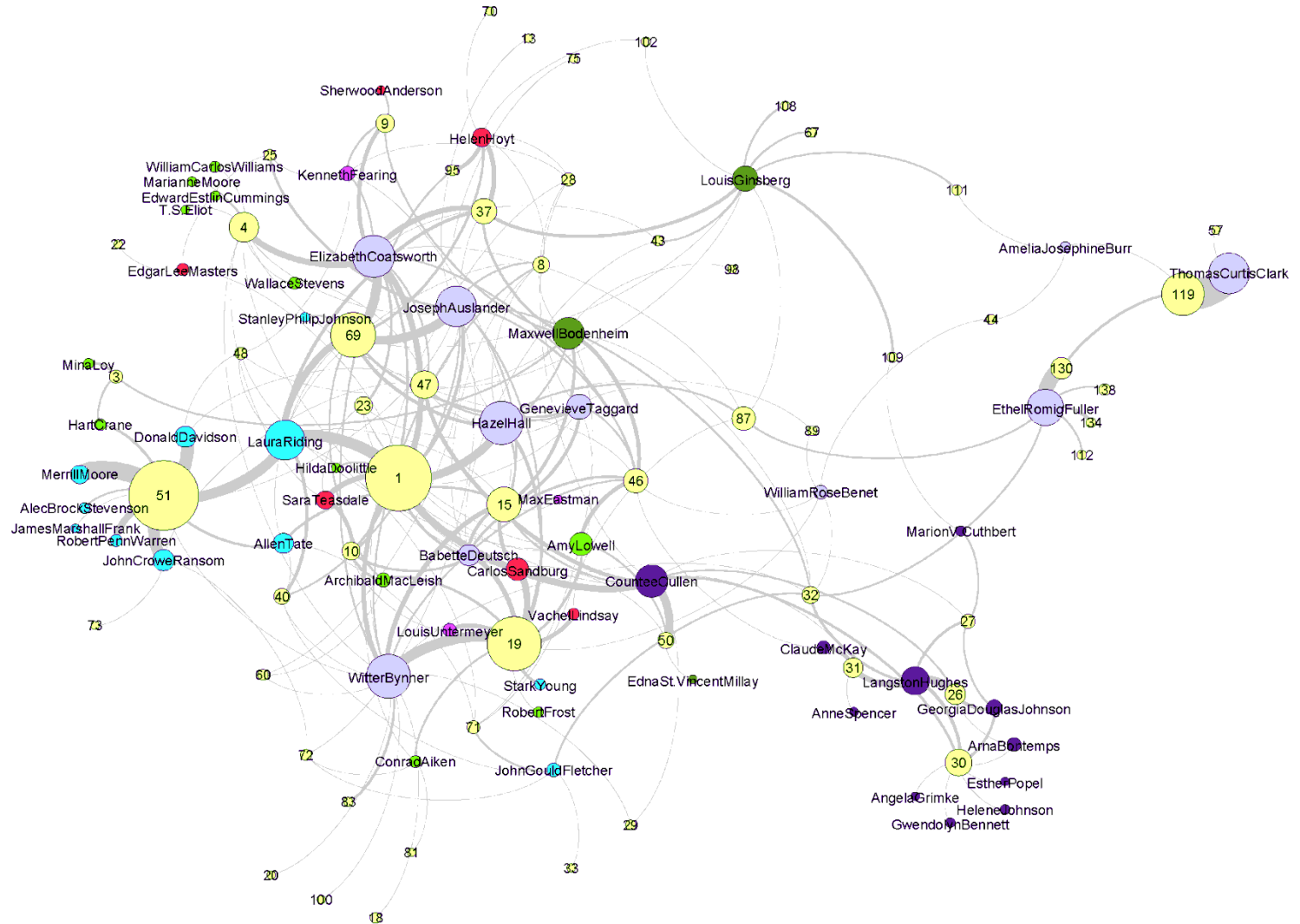
Our professors have given us many books.

We wrote a book and gave it to the professor.

Network of Words (Semantic)

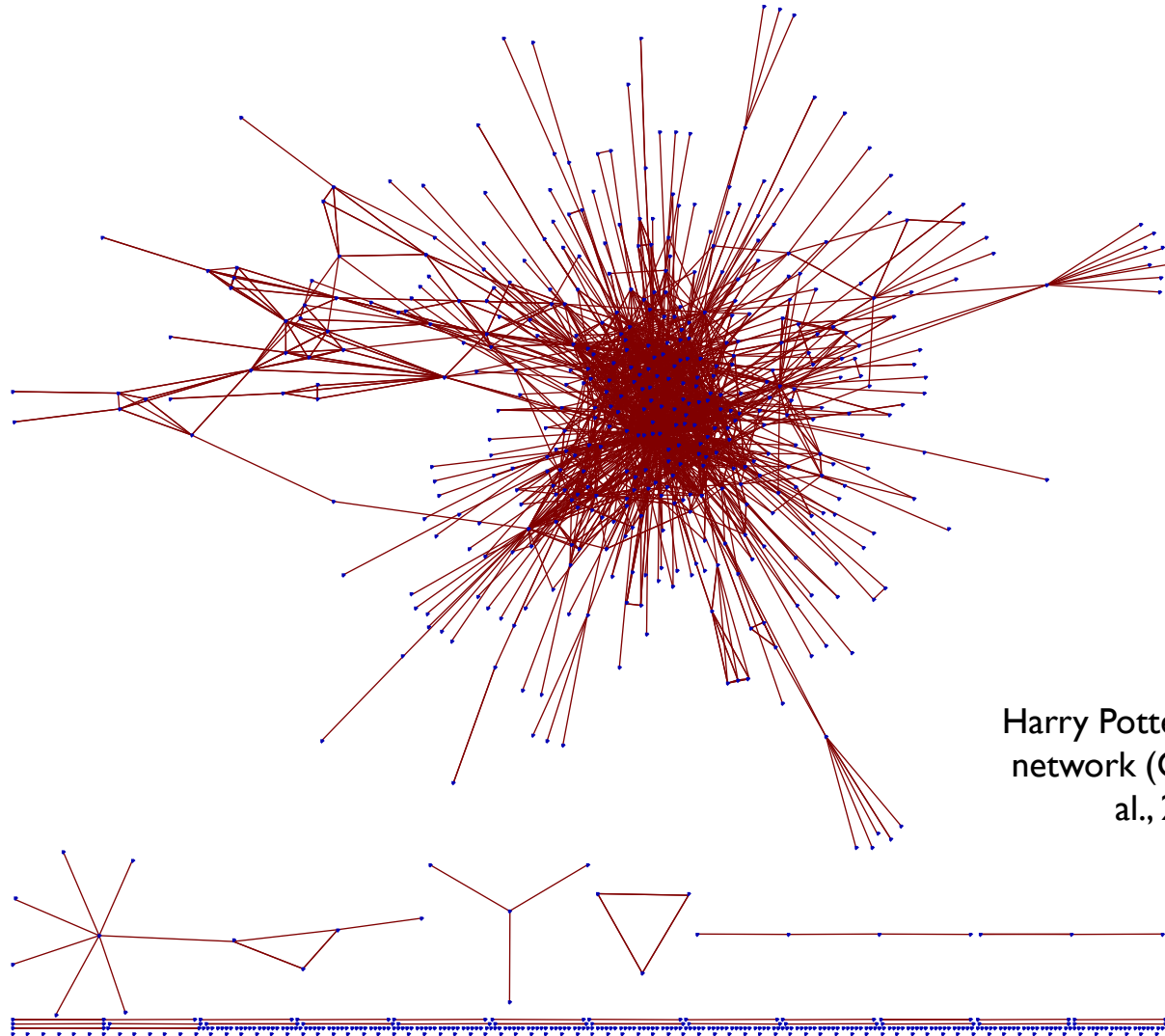


Network of U.S. Poets (1924-25)



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

Network of Fictional Characters

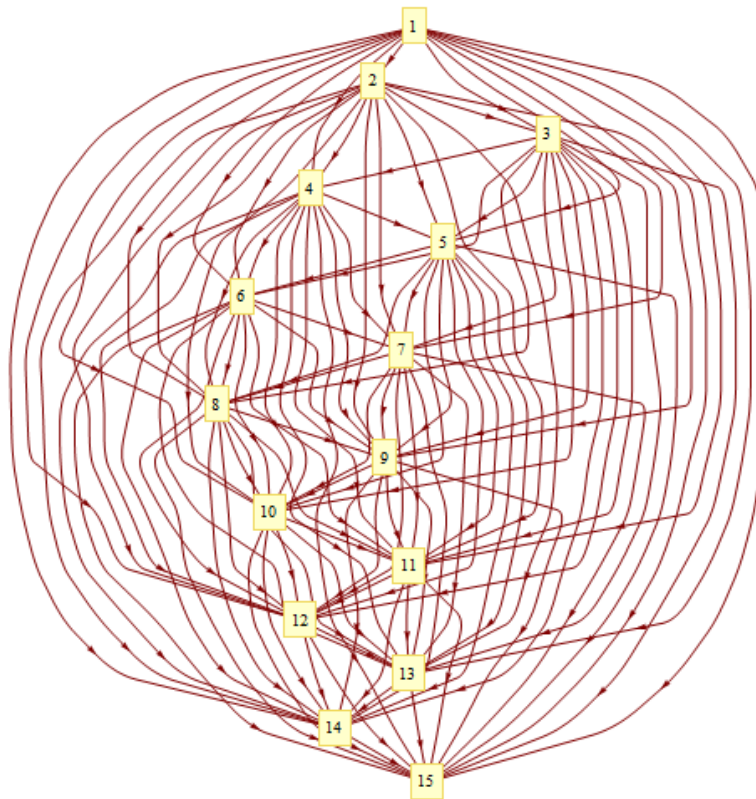


Harry Potter's character
network (Calderone et
al., 2011)

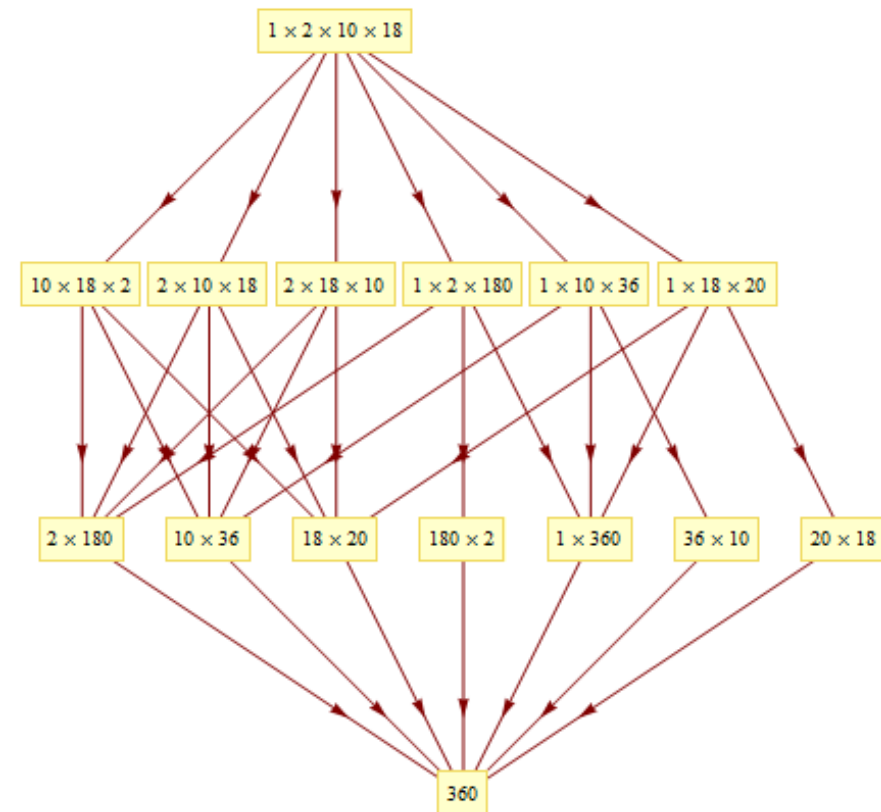


Networks in Math

Networks of Numbers (I)

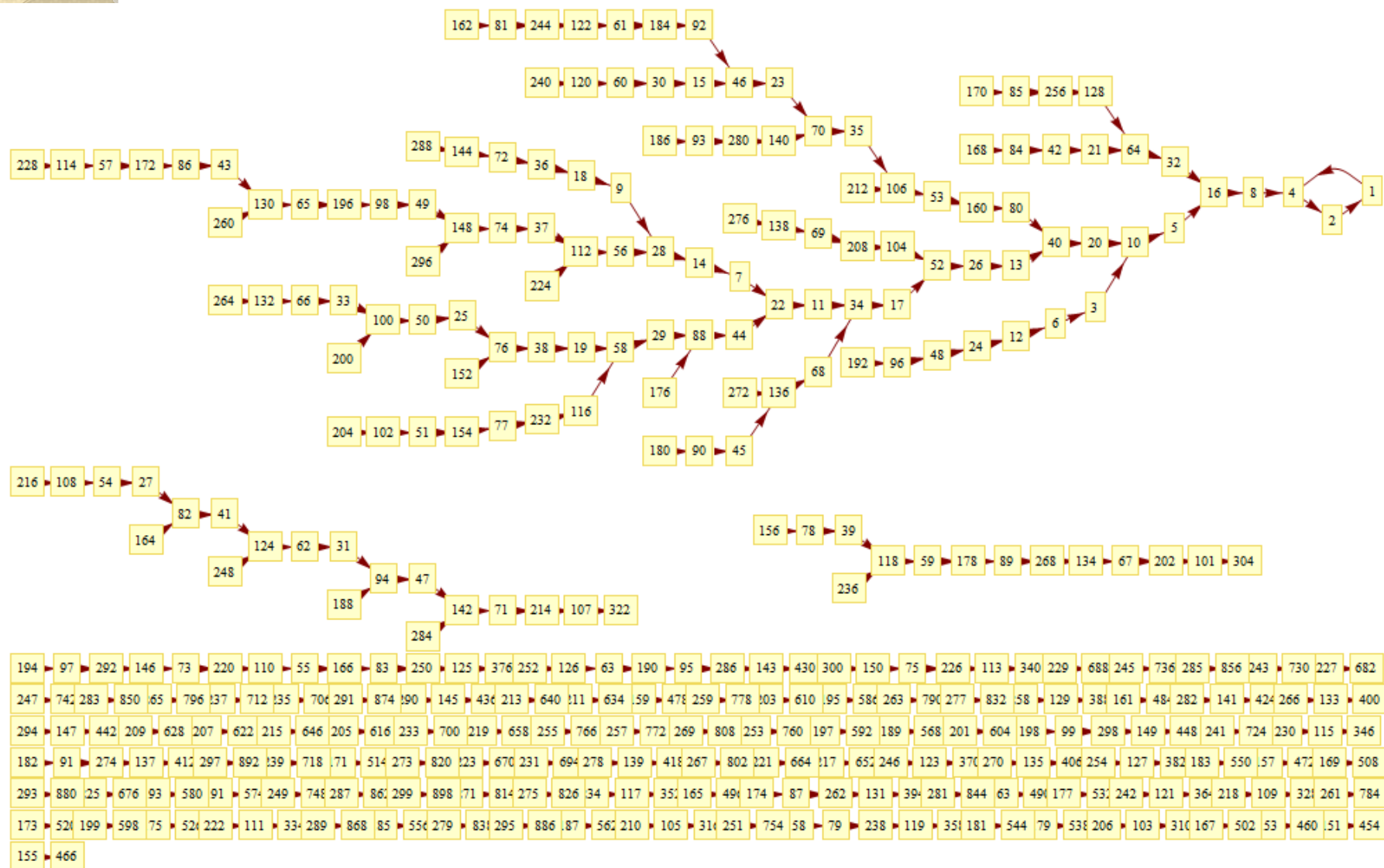


Transitivity network ($i \rightarrow j$ if and only if $i < j$)



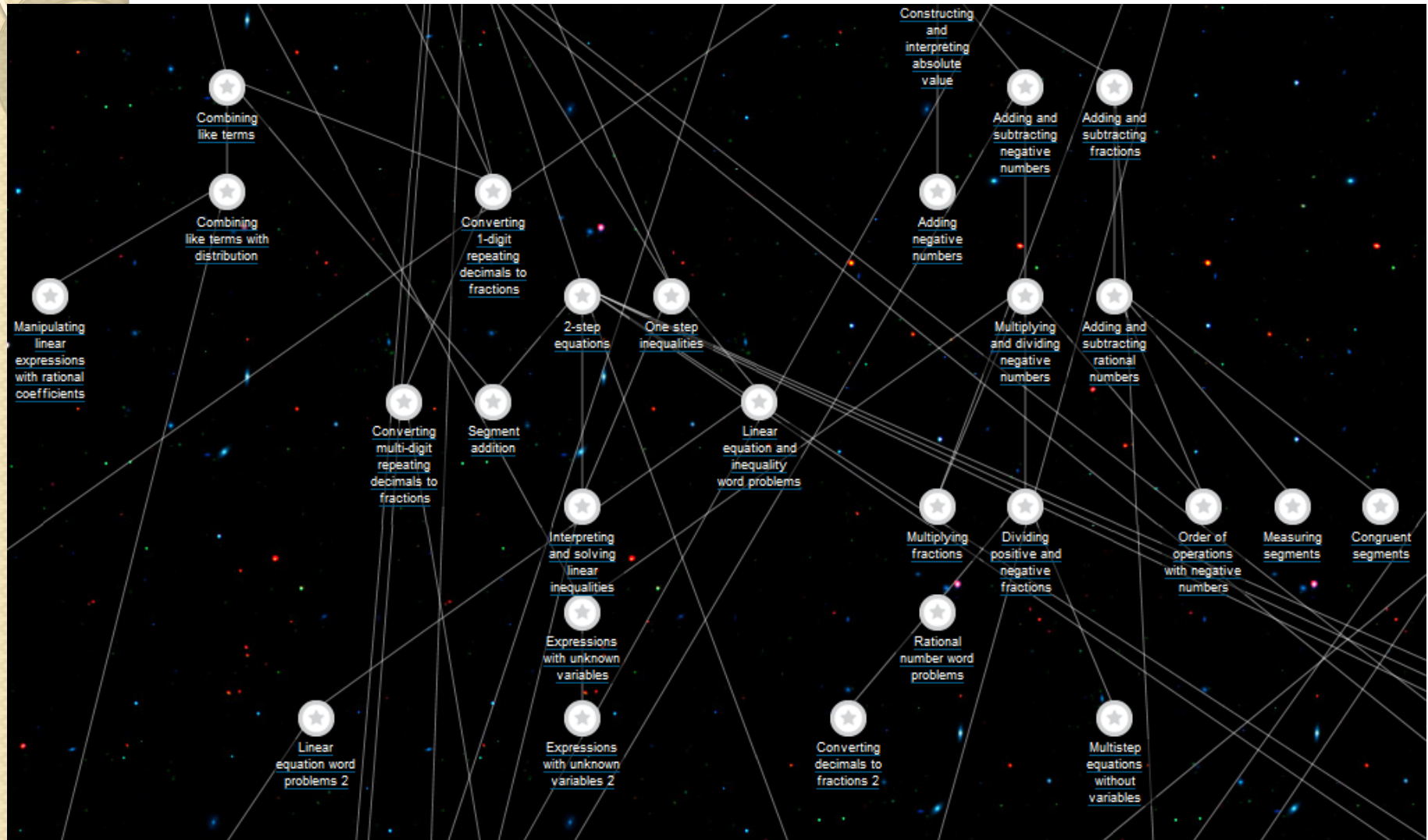
Associativity network (about multiplication)

Networks of Numbers (2)

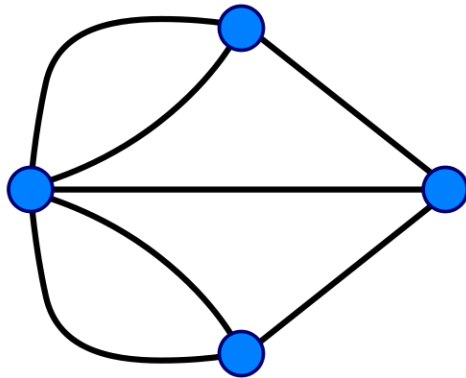
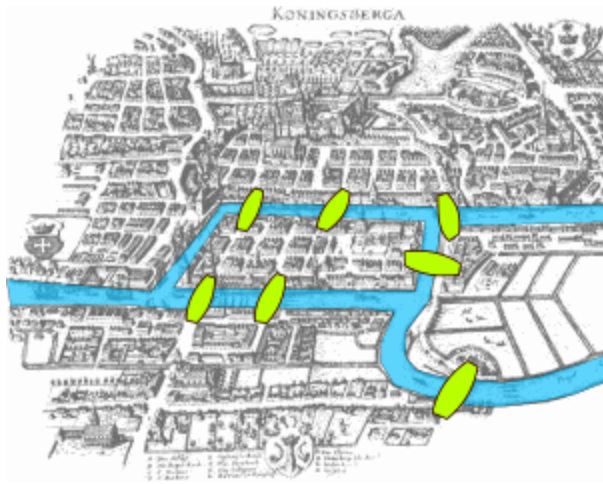


Collatz sequence ($x \rightarrow y$; $y = x/2$ if x is even, or $3x+1$ otherwise)

Network of Concepts



Networks in Math Puzzles



Seven bridges of Königsberg
(images from Wikipedia)

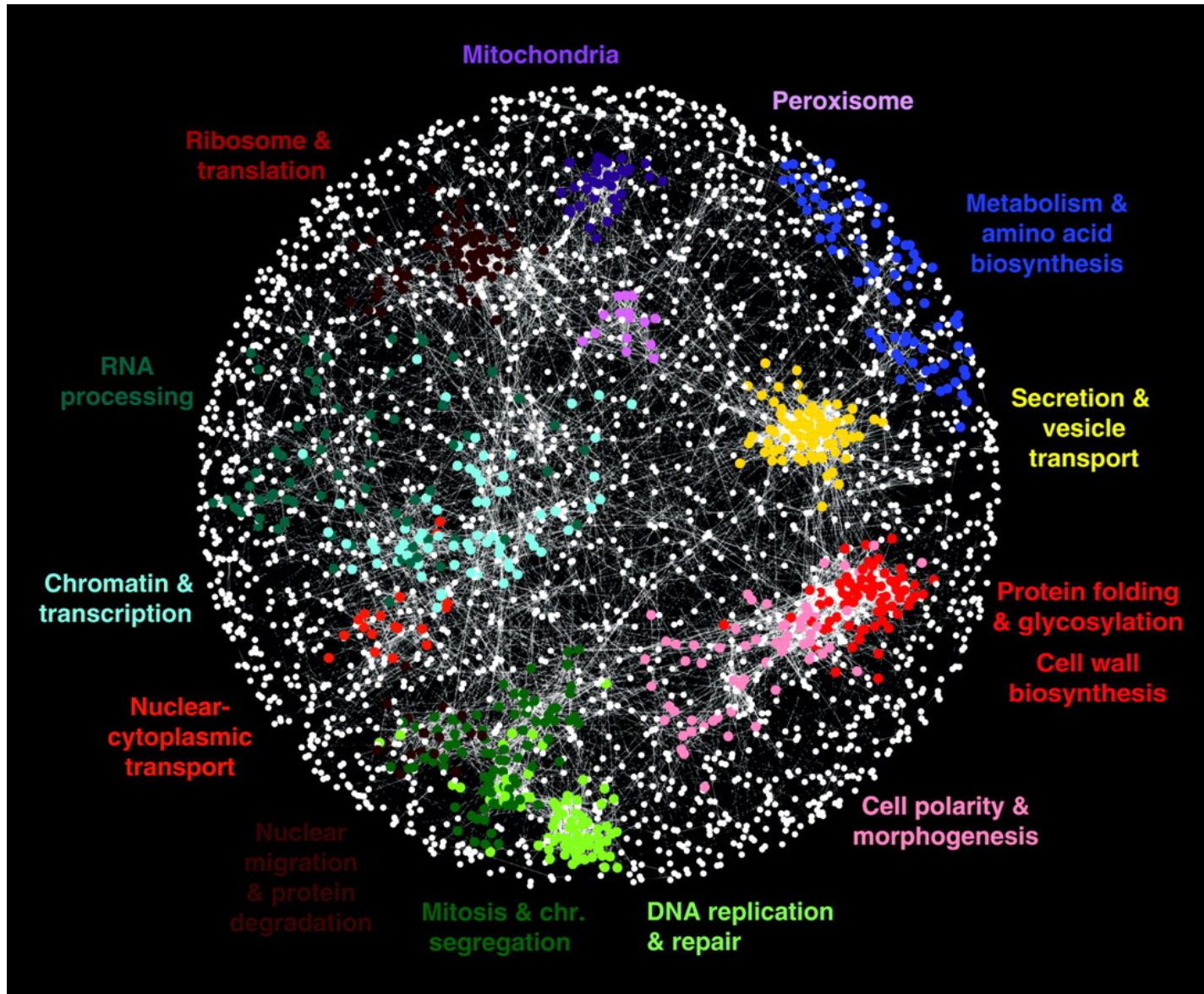


42 bridges in Bristol, UK
(images from Bristol Post / Dr. Thilo Gross)

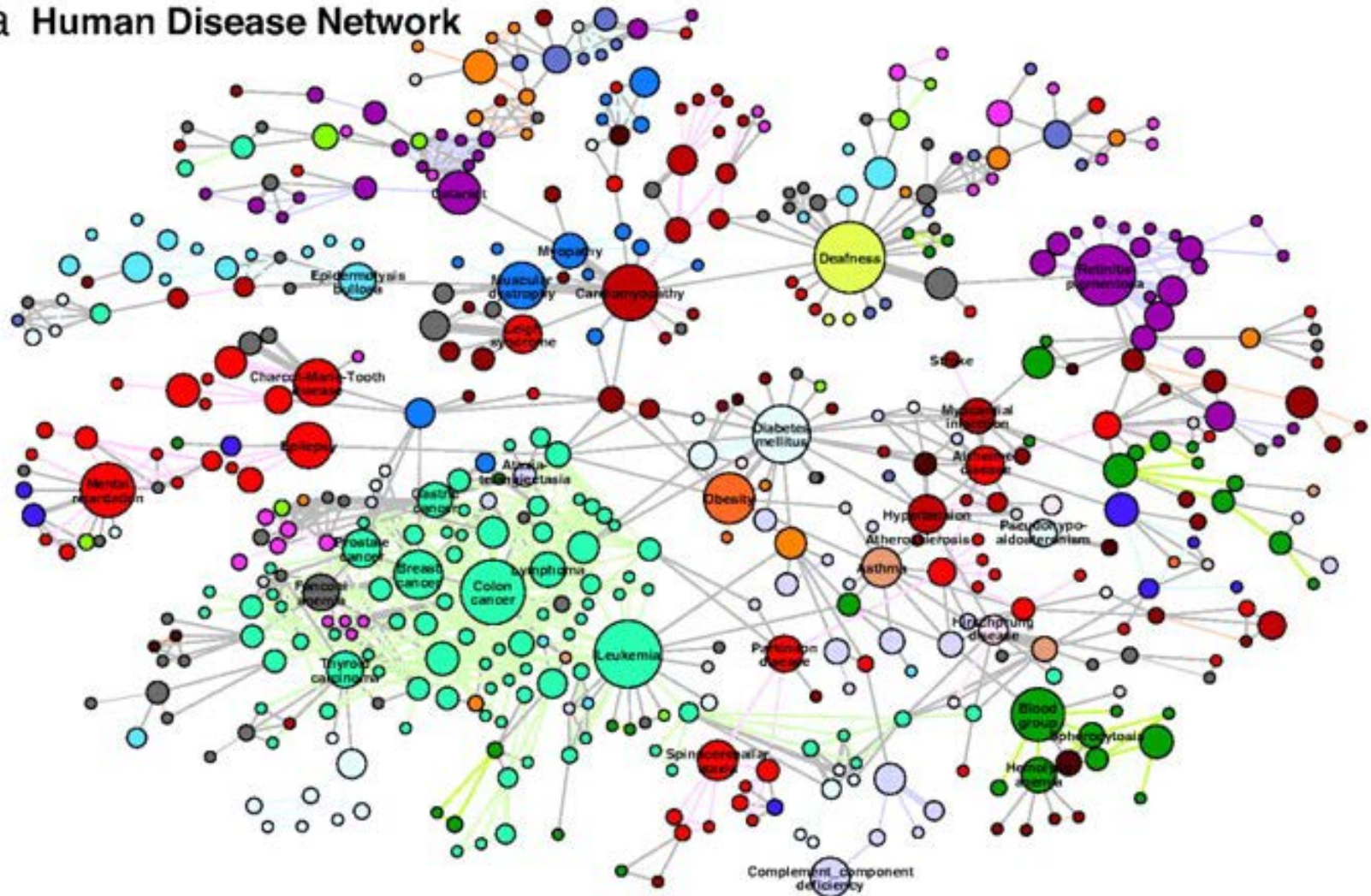


Networks in Science

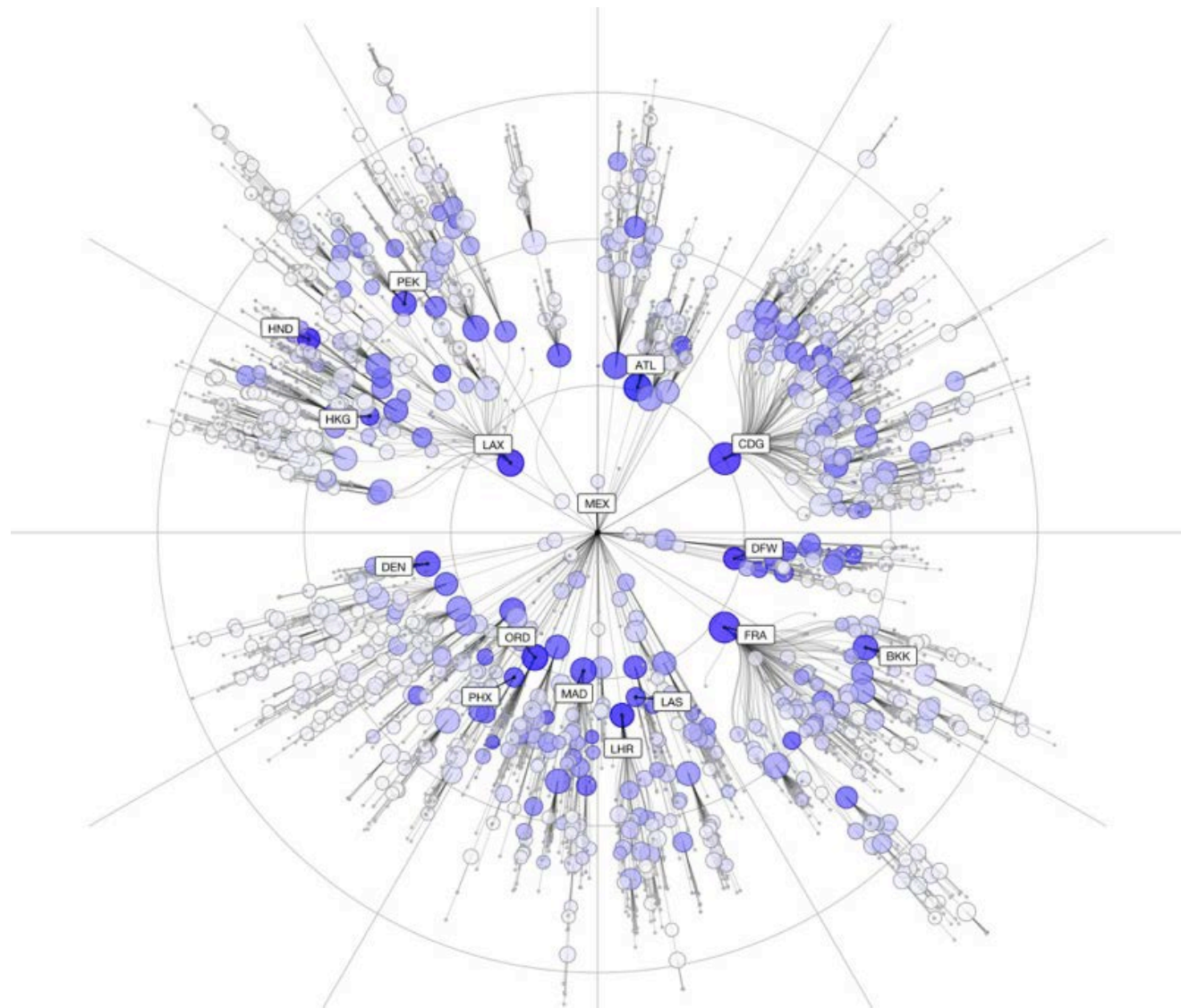
Network of Genes



a Human Disease Network

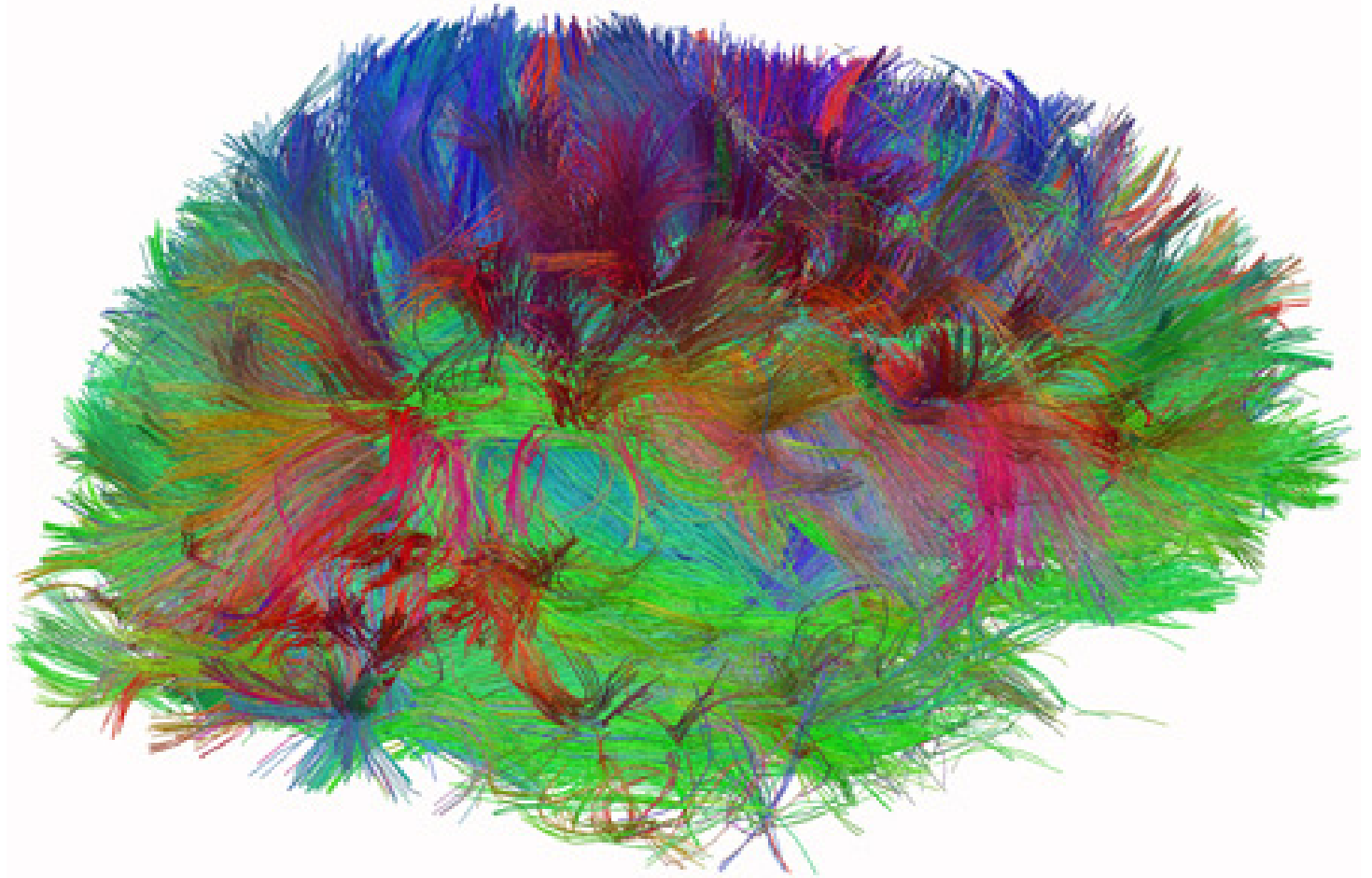


Network of Disease Propagation



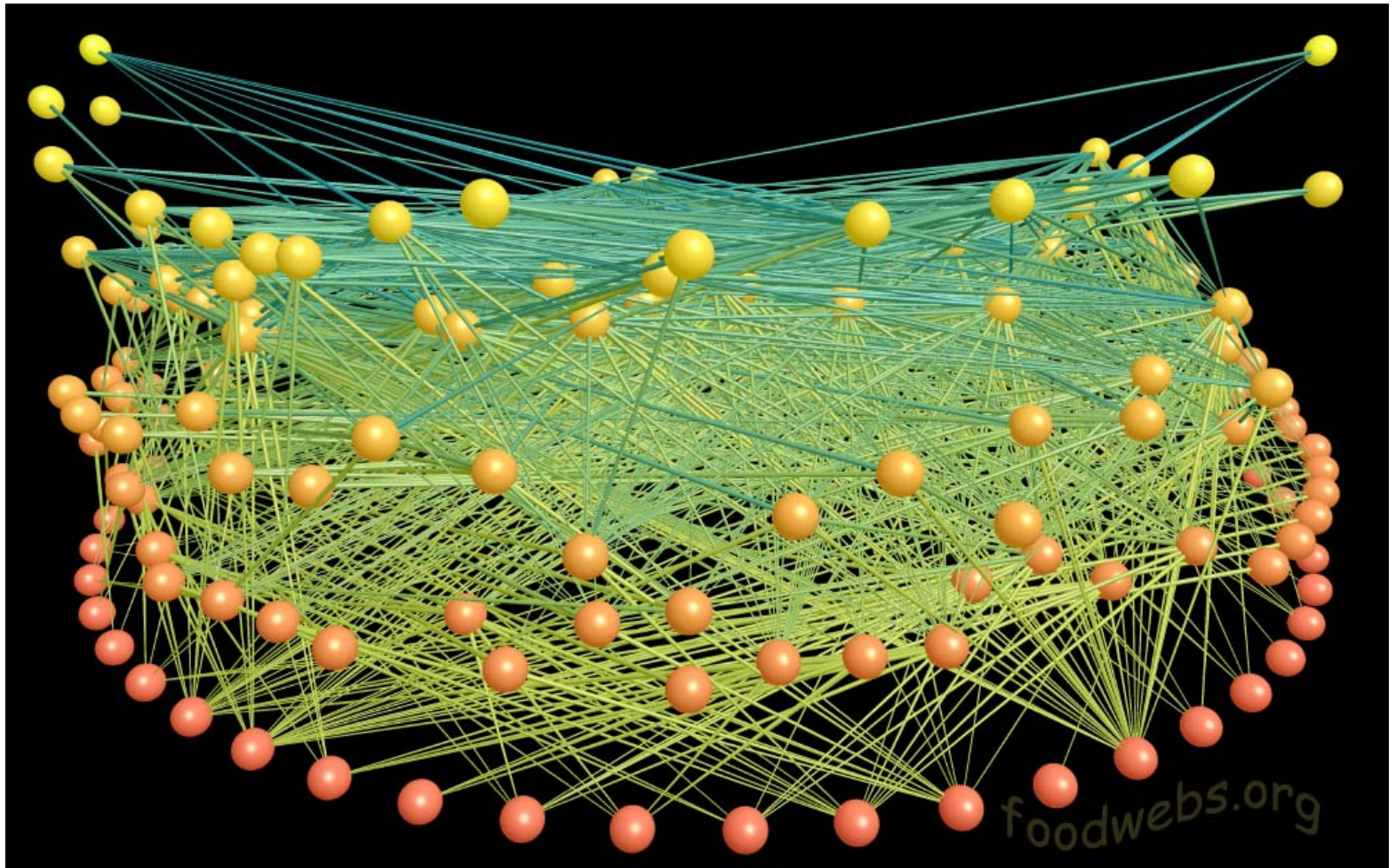
H1N1 activities illustrated according to distance from MEX airport (Brockmann, 2013)

Network of the Brain



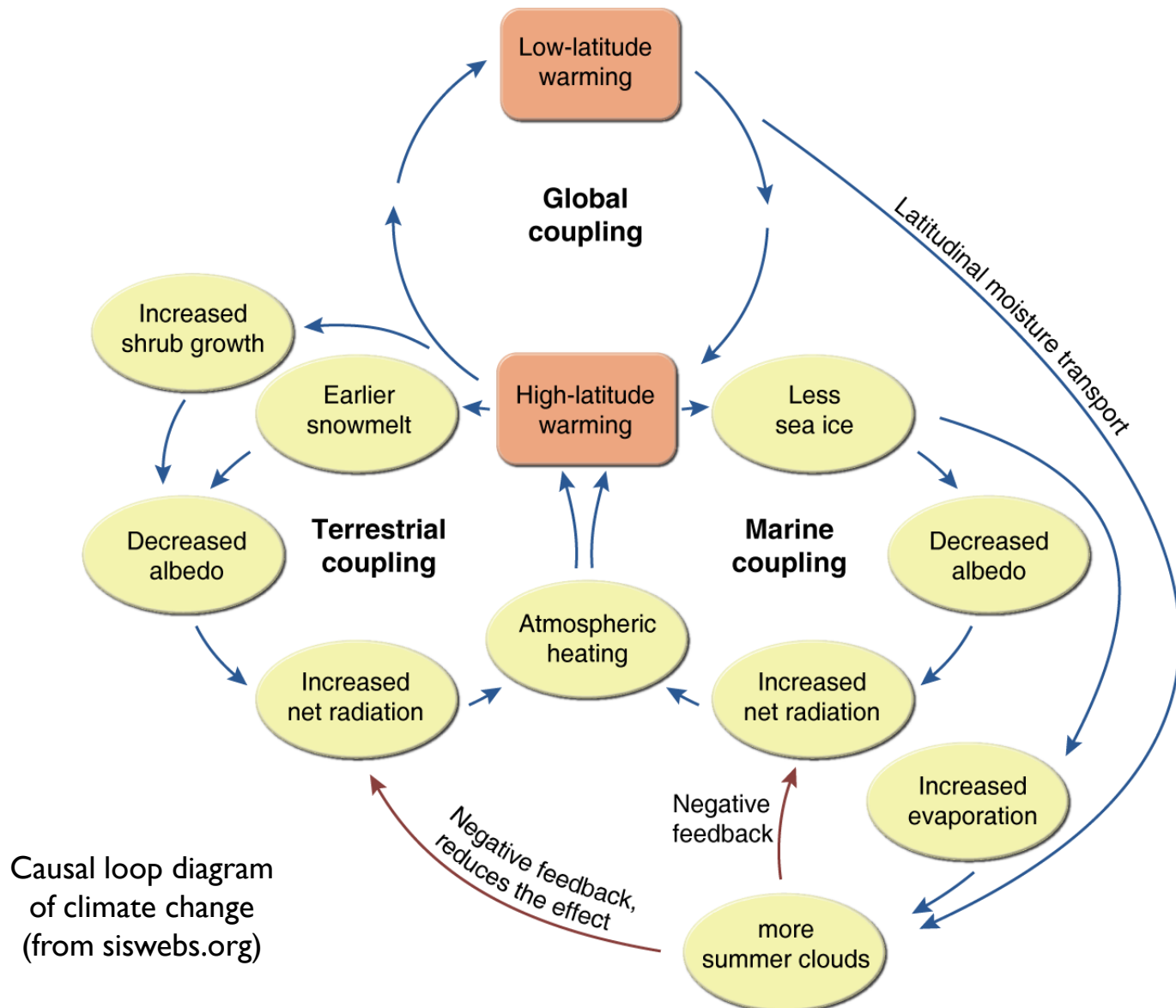
Van J. Wedeen, M.D., MGH/Harvard U.

Food Webs



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

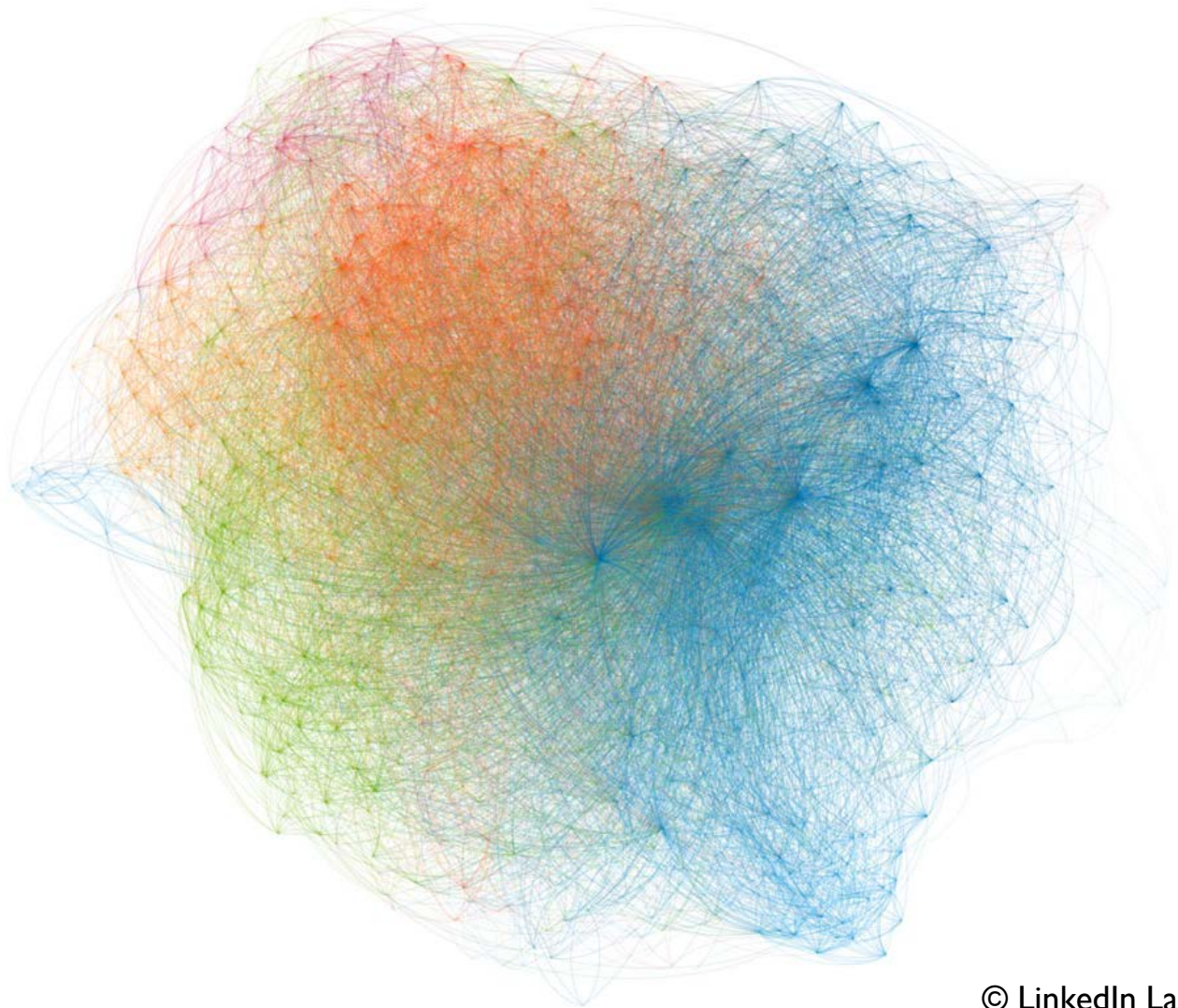
Causal Loop Diagram



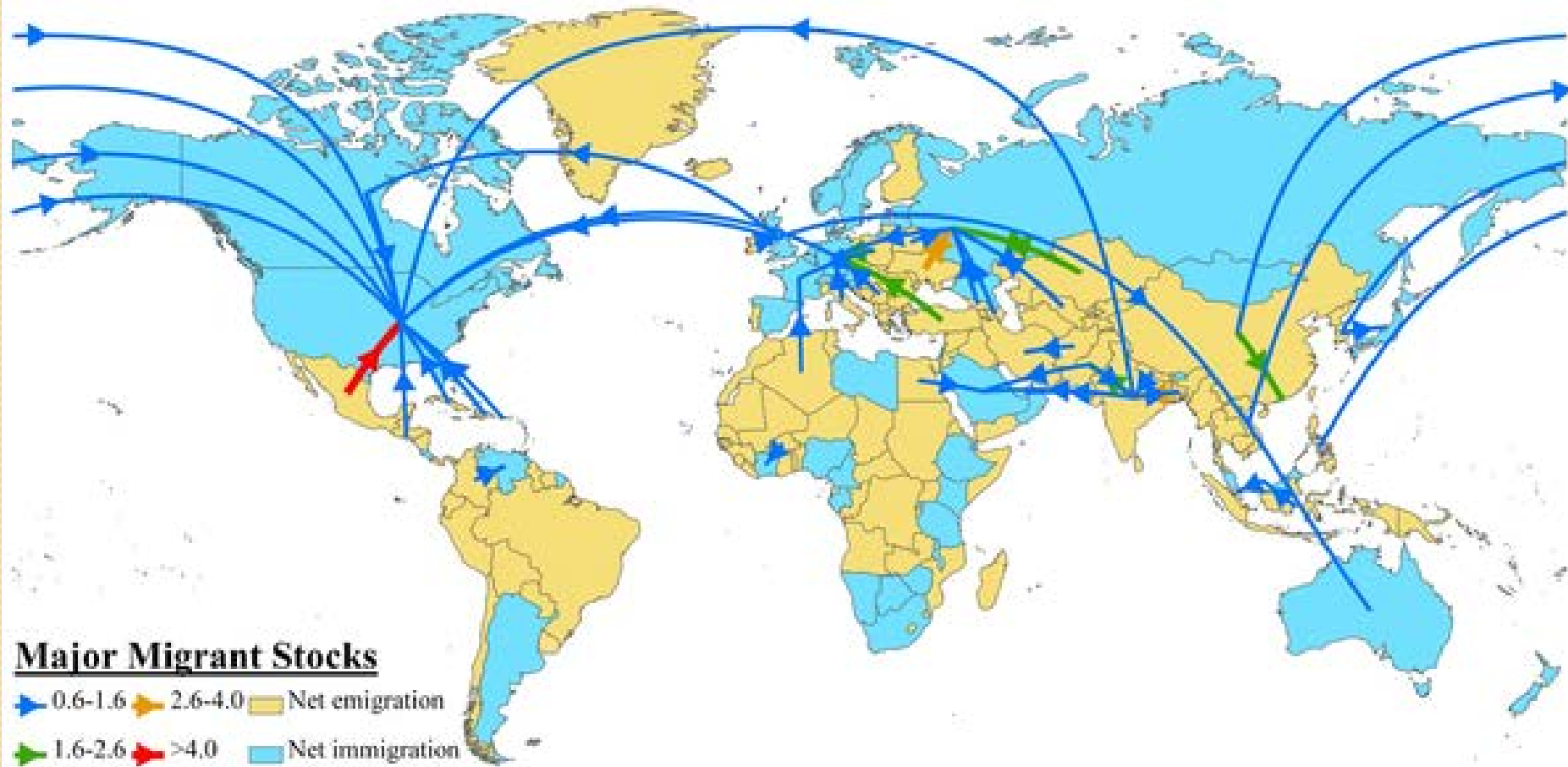


Networks in Social Studies

Network of People Around You

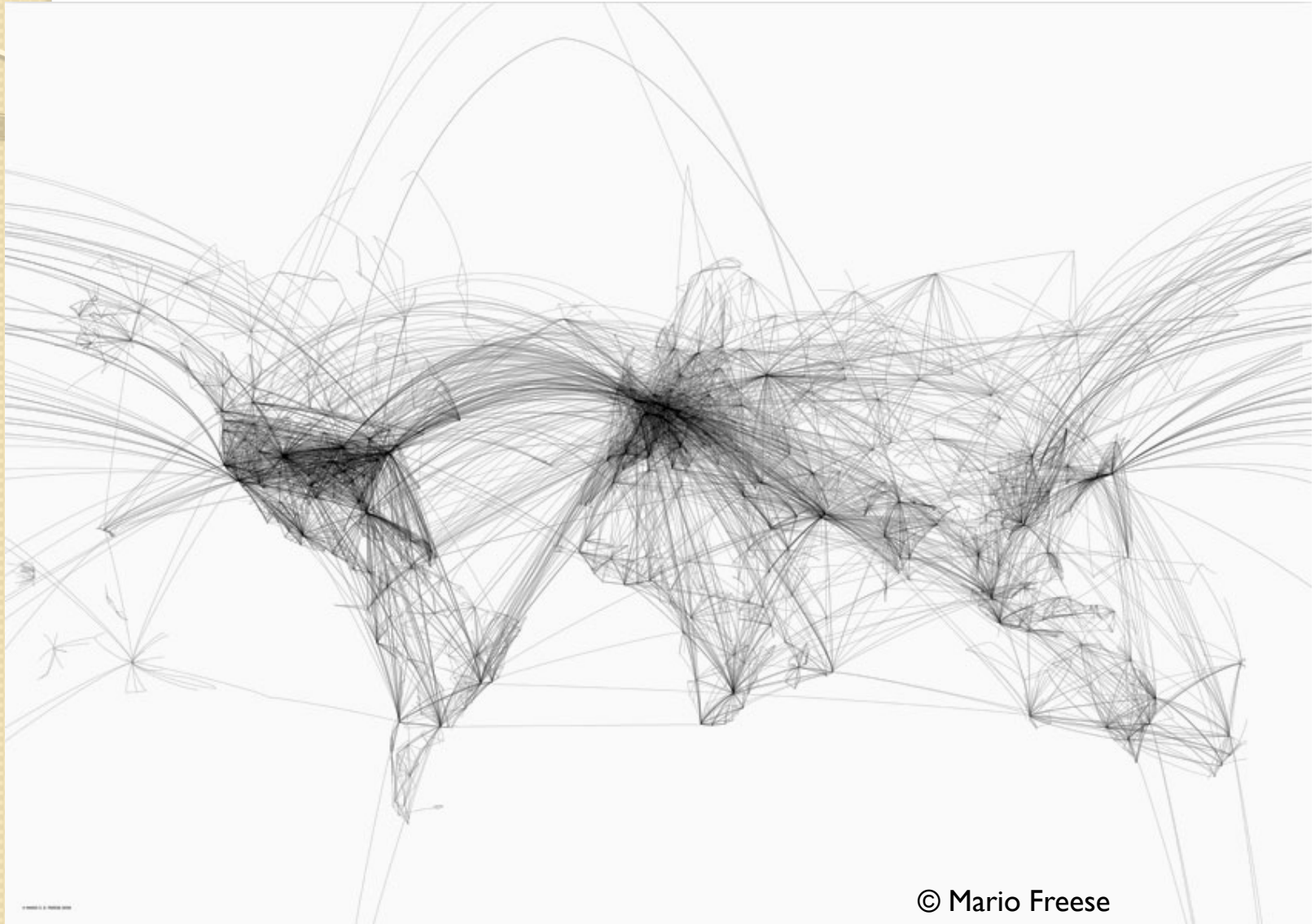


Network of Human Migration

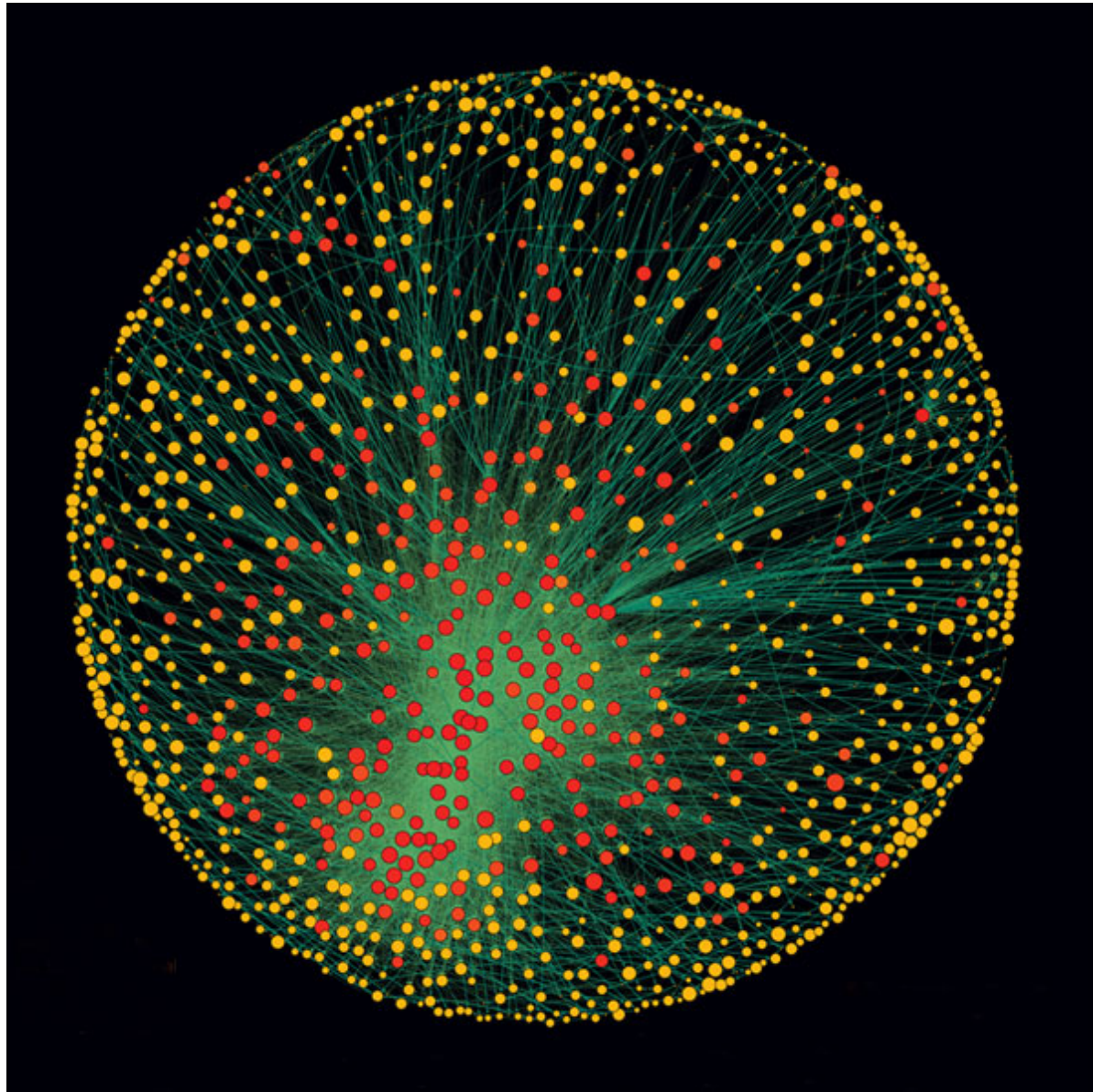


Davis et al., 2013

Network of Transportations

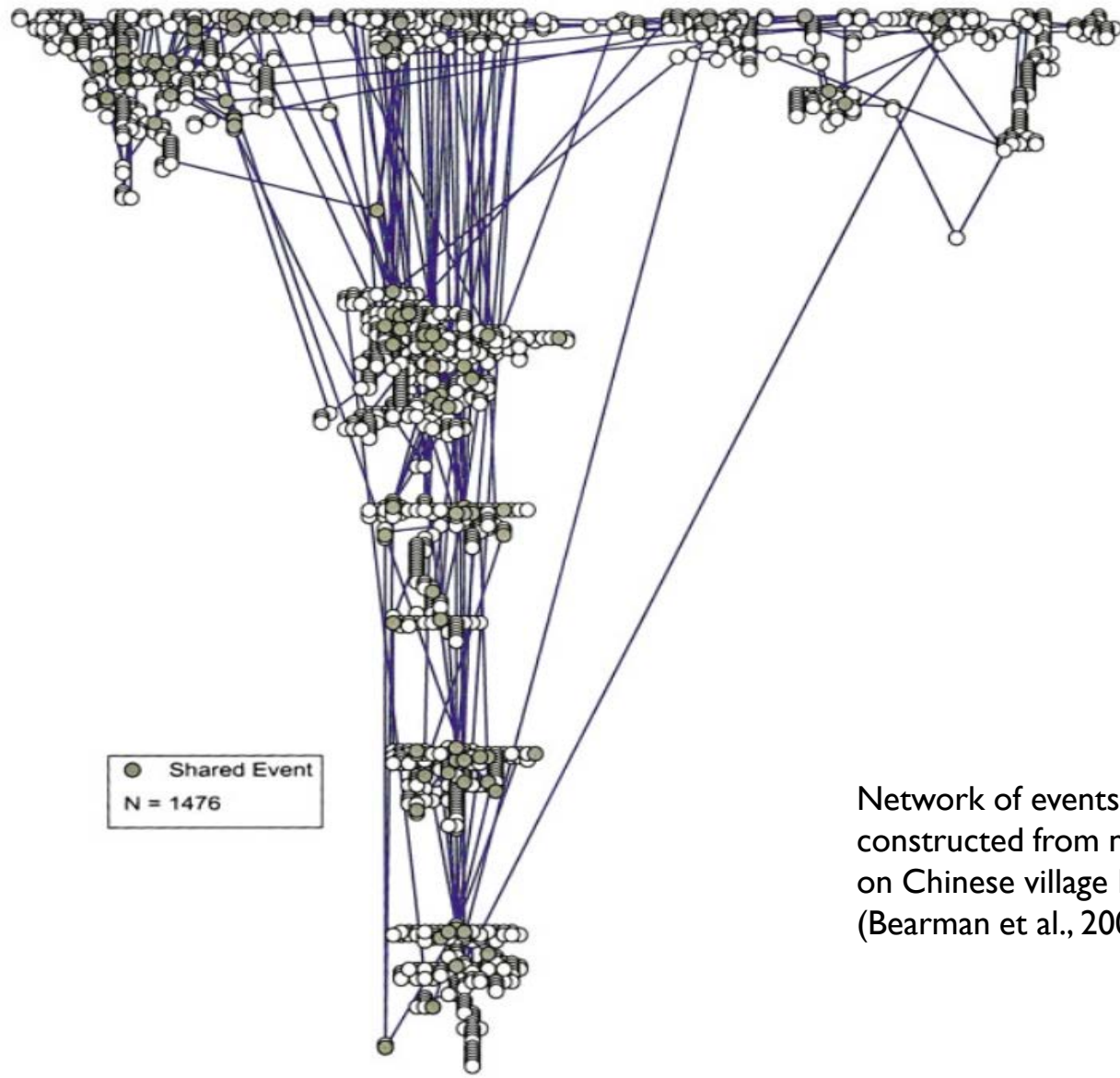


Network of Corporations



Vitali et al.,
2011

Network of Historical Events

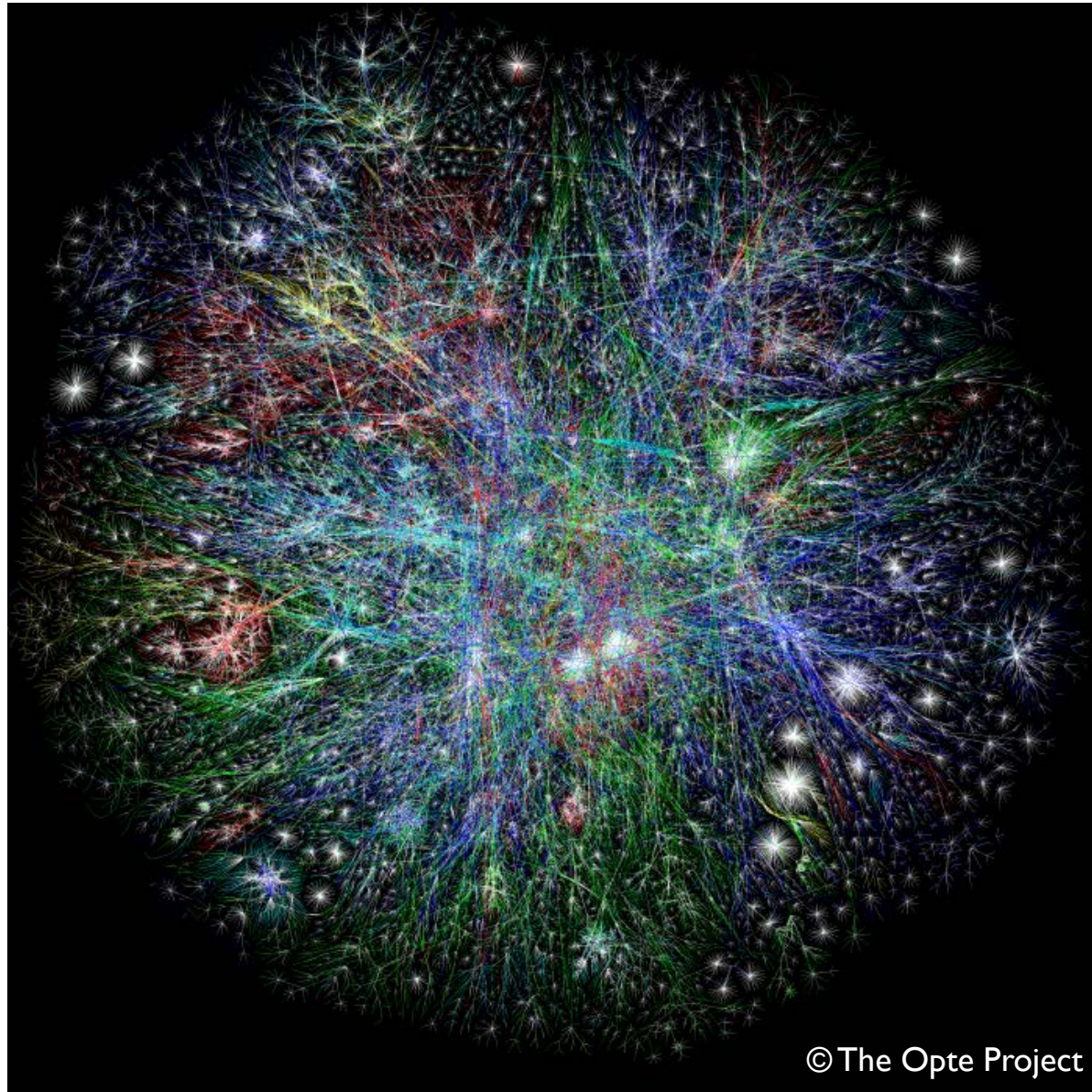


Network of events
constructed from narratives
on Chinese village Liu Ling
(Bearman et al., 2003)

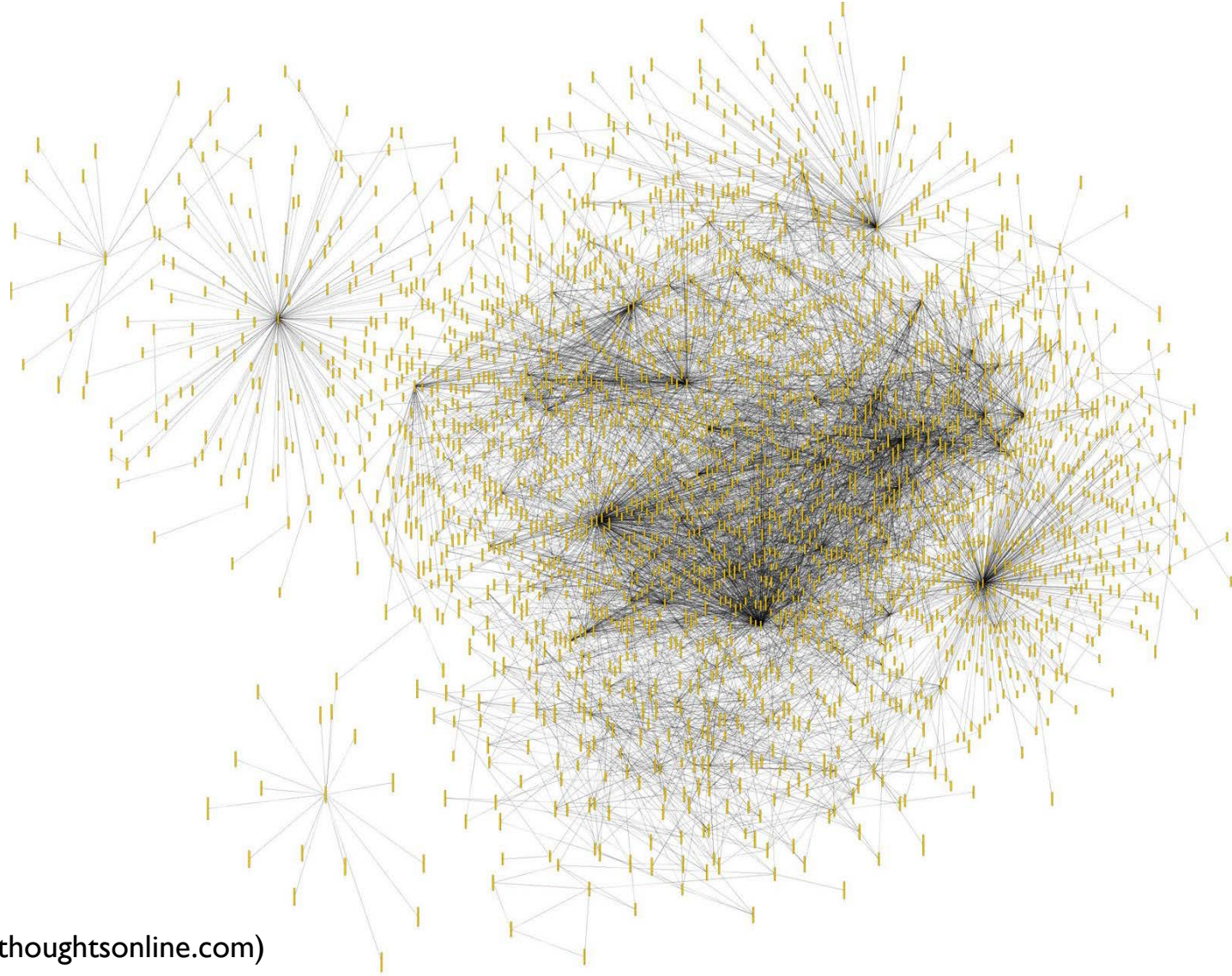


Networks in Technical Education

The Internet



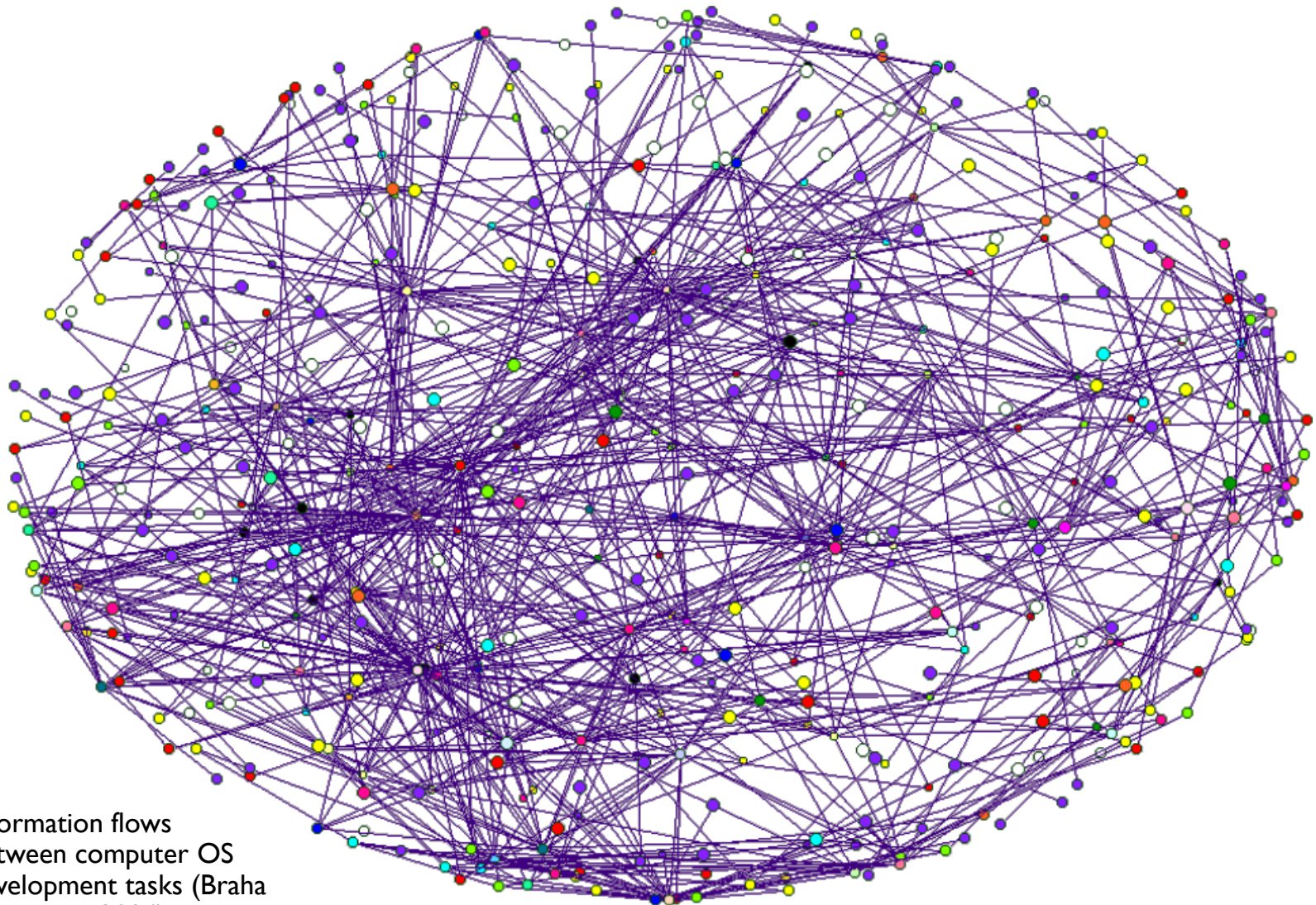
Network of Java Classes



Cavlin, 2012

(from simplethoughtsonline.com)

Network of Product Design



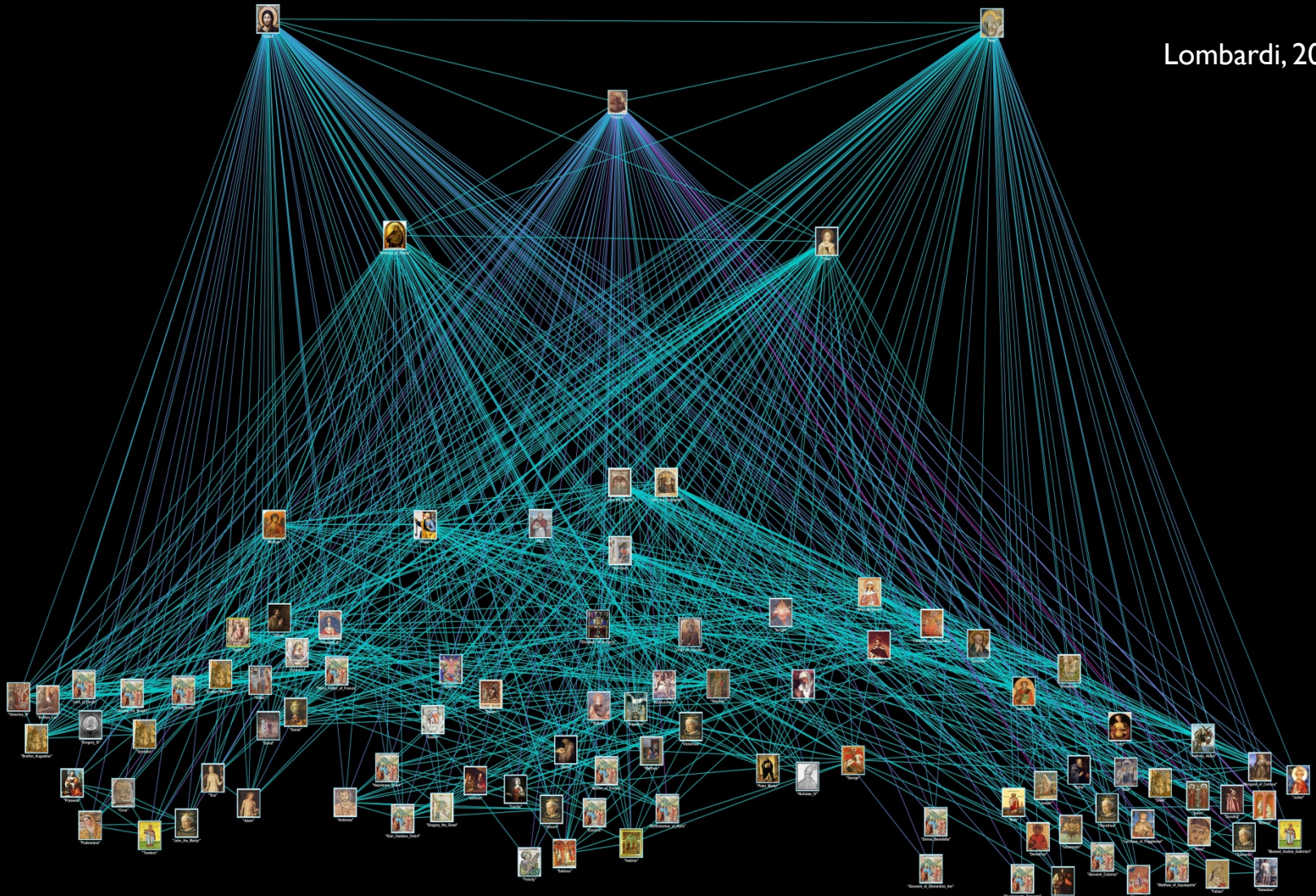
Information flows
between computer OS
development tasks (Braha
& Bar-Yam, 2004)



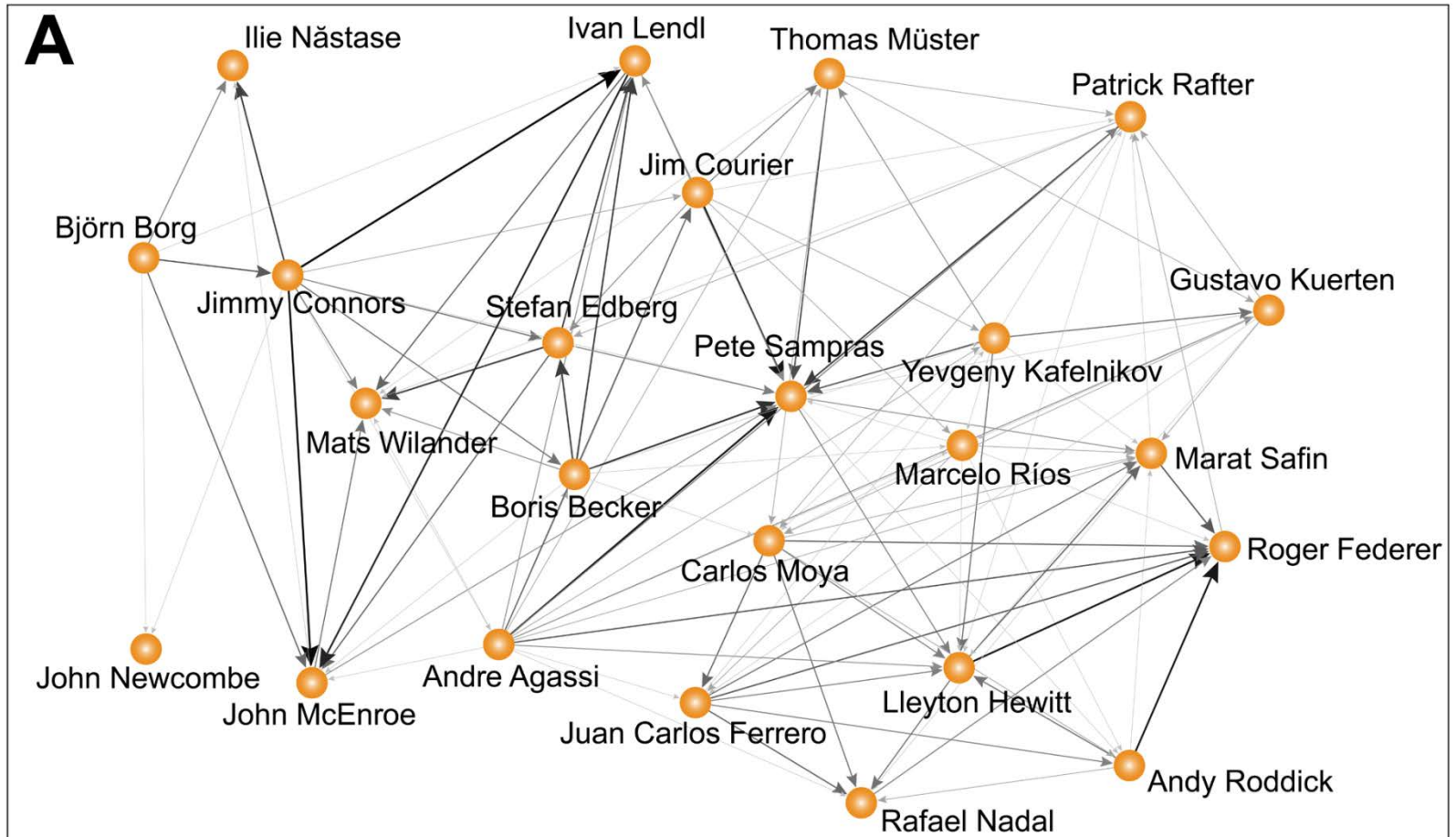
Networks in Other Subjects

Network of Saints in Iconography

Lombardi, 2013



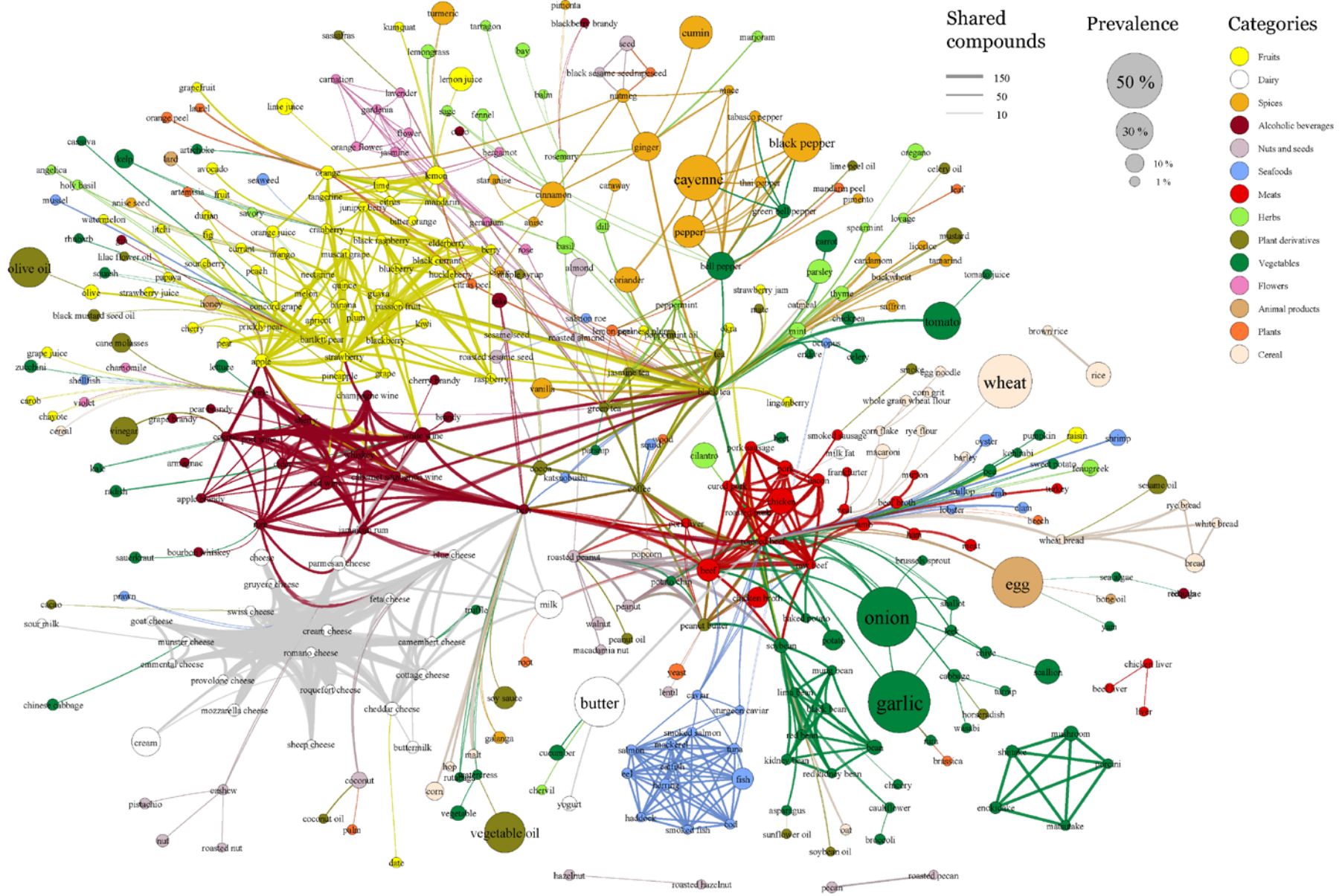
Network of Top Tennis Players



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

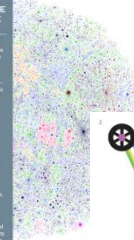
Essential Concepts and Core Ideas



NetSciEd

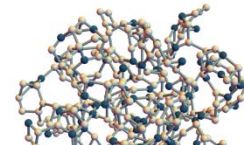
1 NETWORKS ARE EVERYWHERE

- The concept of networks is broad and general, and it describes how things are interconnected with other things in a system in many aspects of life.
- Networks exist in many forms: social, biological, technological, and abstract. They are everywhere, from the human brain to the Internet to the structure of a molecule.
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2 NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- Networks describe how things connect and interact. They are a way of representing the relationships between different parts of a system.
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7 THE STRUCTURE OF A NETWORK CAN INFLUENCE ITS STATE AND VICE VERSA

- The structure of a network can influence its state and vice versa. This means that the way things are connected can affect how they behave, and how they behave can affect how they are connected.
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6 NETWORKS HELP YOU TO COMPARE A WIDE VARIETY OF SYSTEMS

- Networks help you to compare a wide variety of systems. By looking at the structure of a network, you can see how it is similar to or different from other networks.
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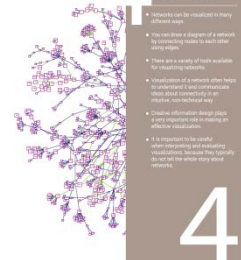
3 NETWORKS CAN HELP REVEAL PATTERNS

- Networks can help reveal patterns. By looking at the structure of a network, you can see how it is similar to or different from other networks.
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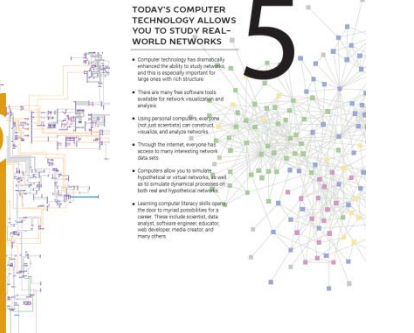
4 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

- Visualizations can help provide an understanding of networks. By looking at a visualization of a network, you can see how it is similar to or different from other networks.
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5 TODAY'S COMPUTER TECHNOLOGY ALLOWS YOU TO STUDY REAL-WORLD NETWORKS

- Today's computer technology allows you to study real-world networks. This means that you can now look at the structure of a network and see how it is similar to or different from other networks.
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<http://tinyurl.com/networkliteracy>