

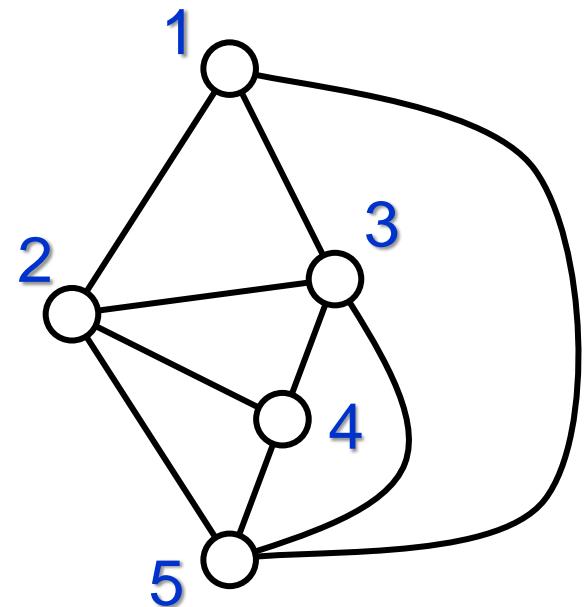


Network Thinking: Some Examples

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What Is Network Science?

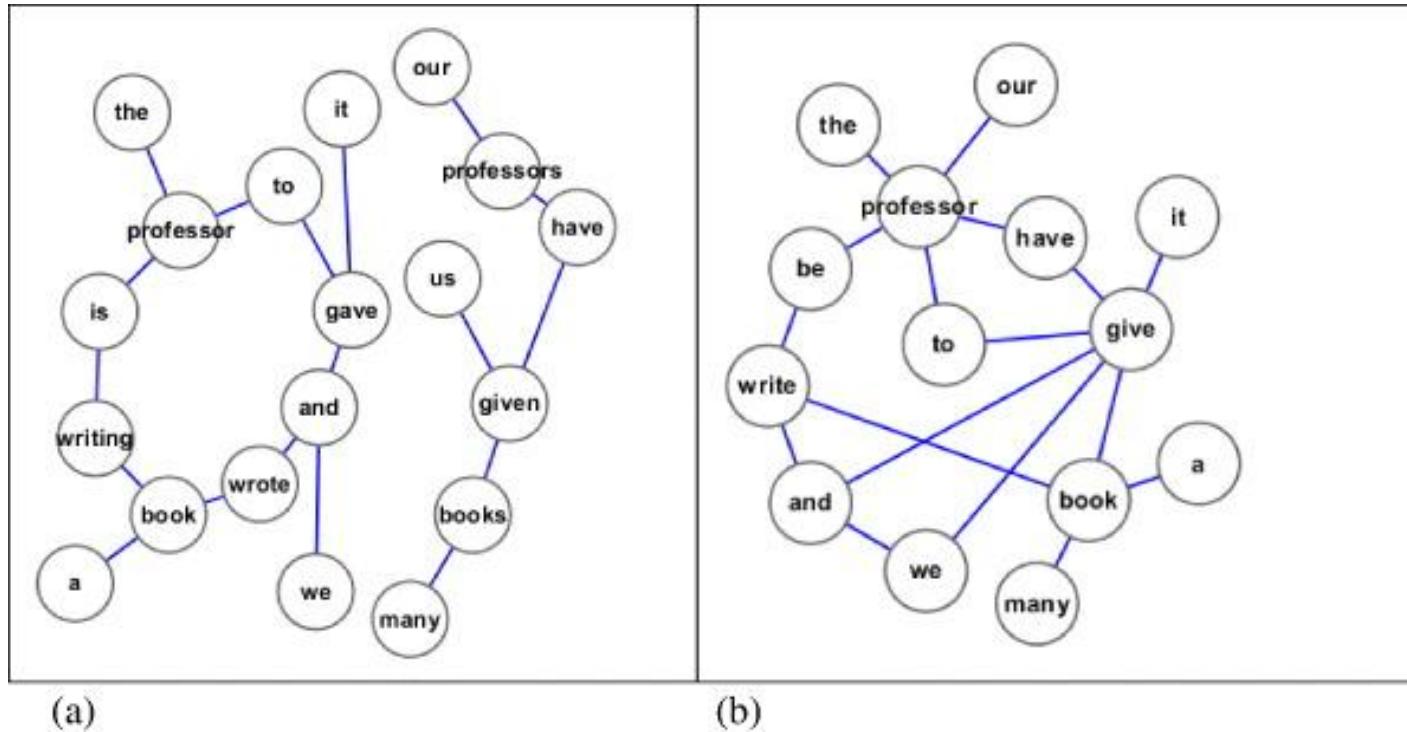
- **Data-driven science** that focuses on “*how things are related*”, rather than what things are in isolation
- **Interdisciplinary science** that draws upon concepts and methods taken from *mathematics, computer science, physics, social sciences, humanities, etc.*

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)



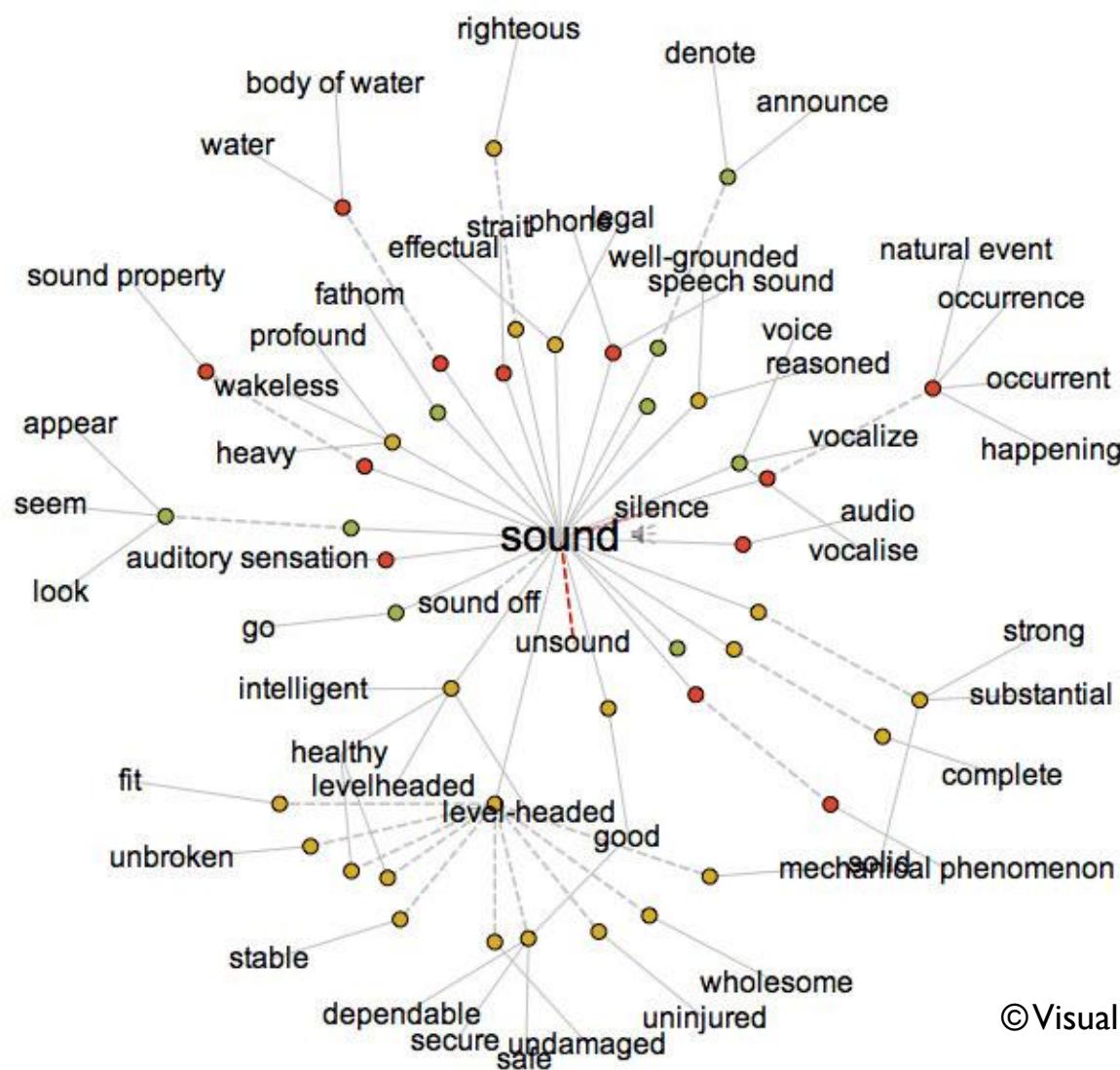
From Liu & Xu 2011; networks were generated from the following three sentences:

This professor is writing a book.

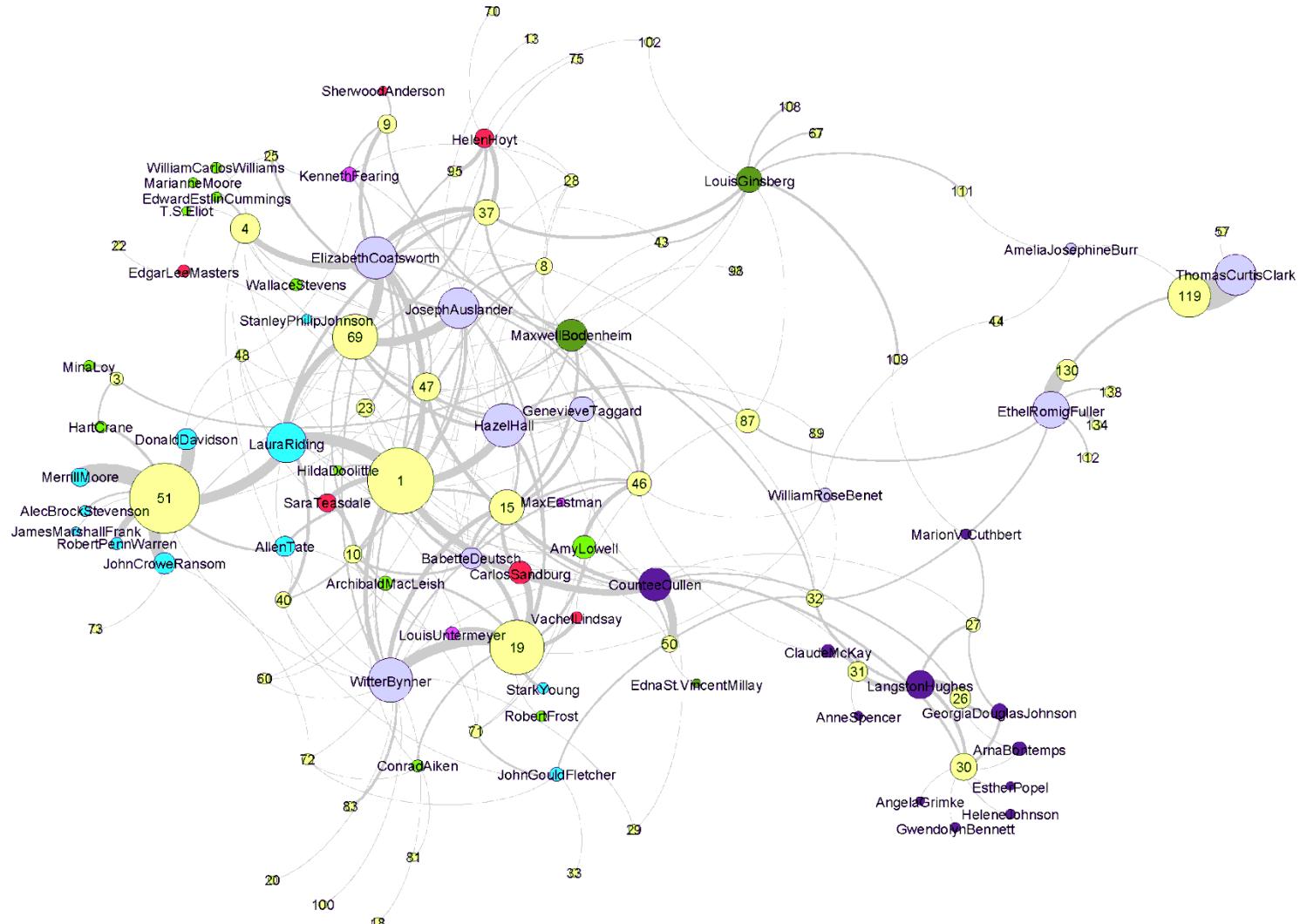
Our professors have given us many books.

We wrote a book and gave it to the professor.

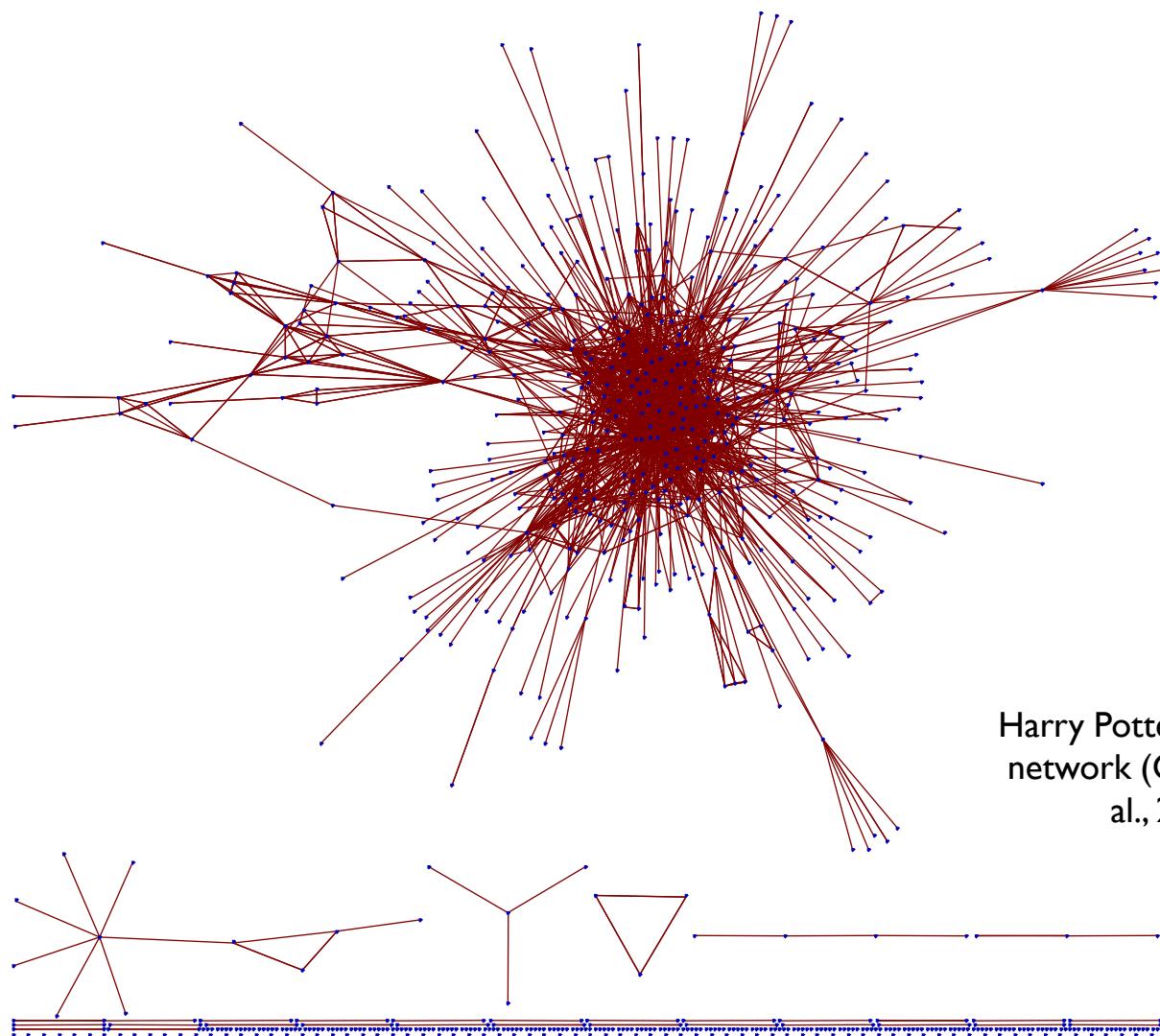
Network of Words (Semantic)



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

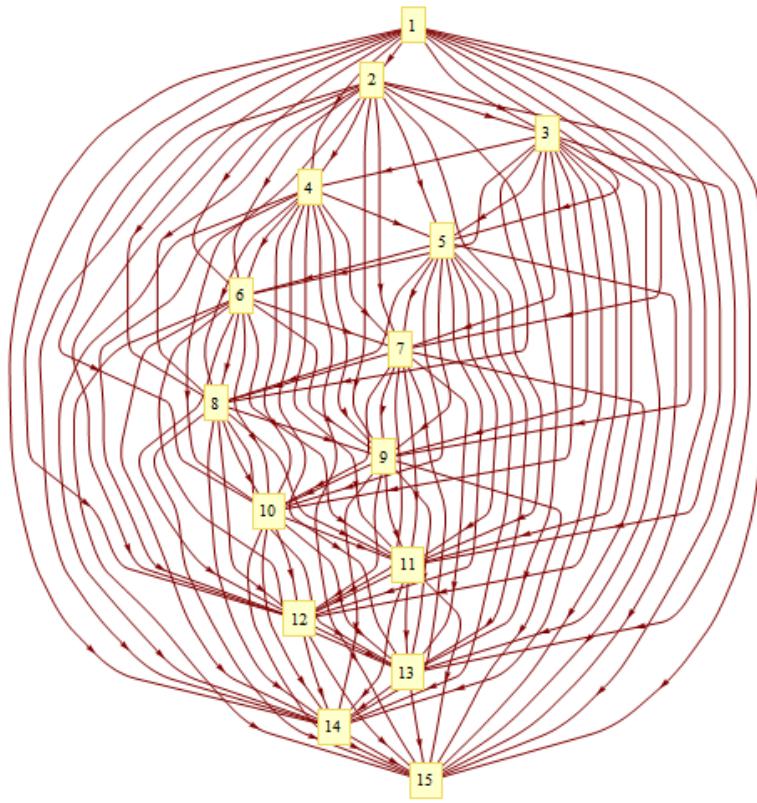


Network of Fictional Characters

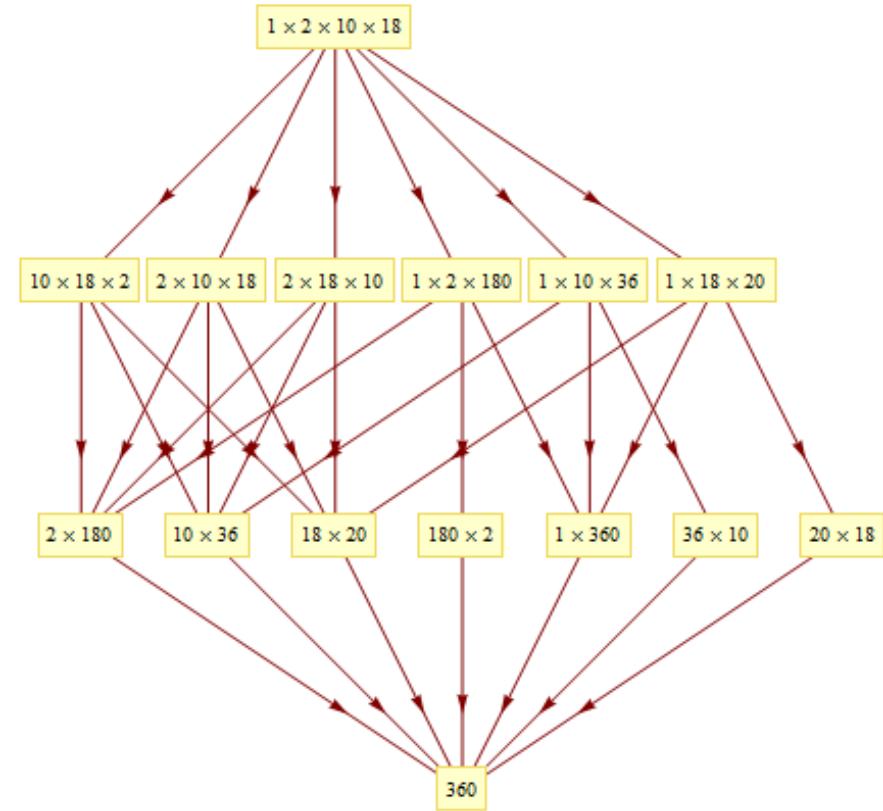


Networks in Math

Networks of Numbers (I)

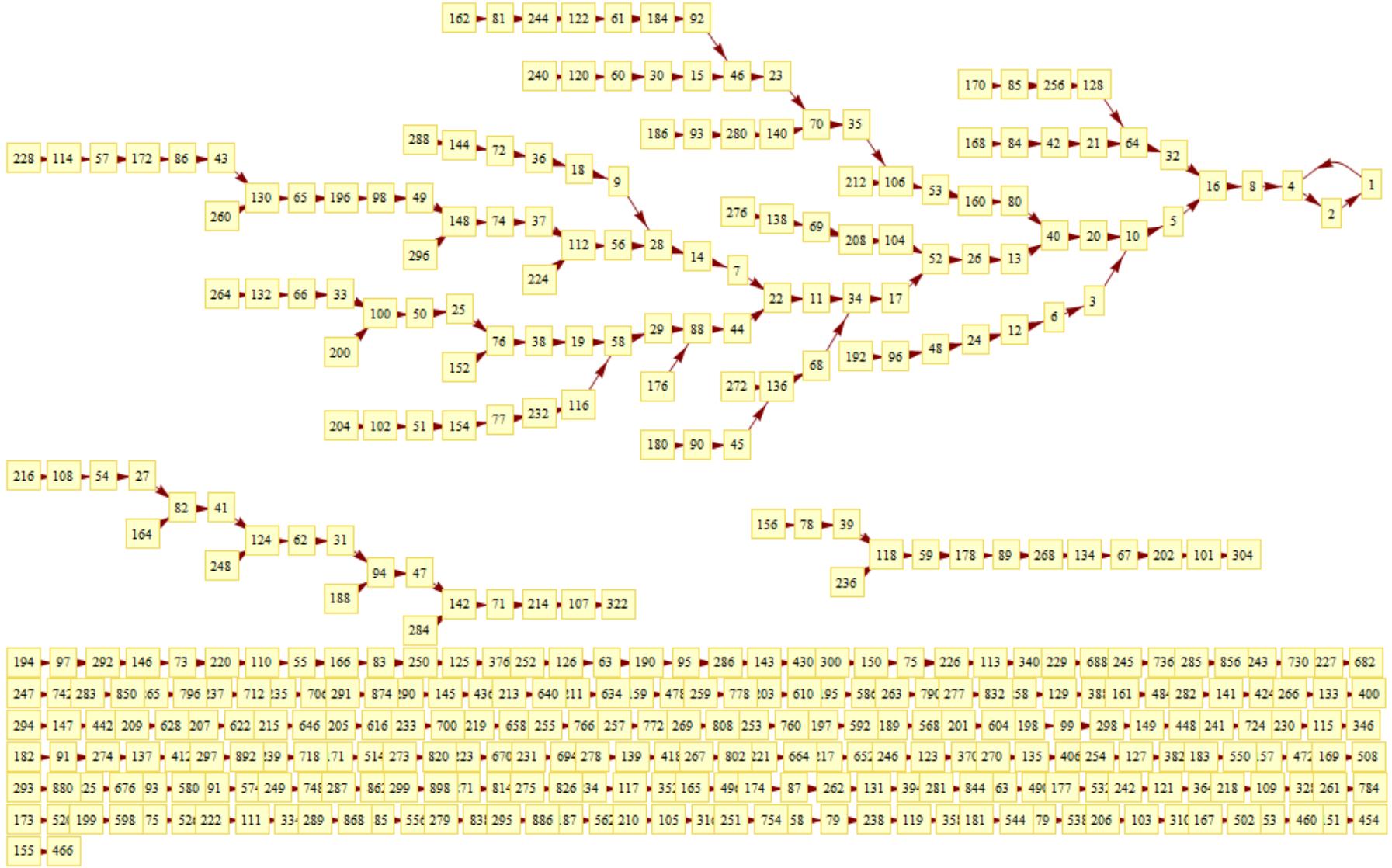


Transitivity network ($i \rightarrow j$ if and only if $i < j$)



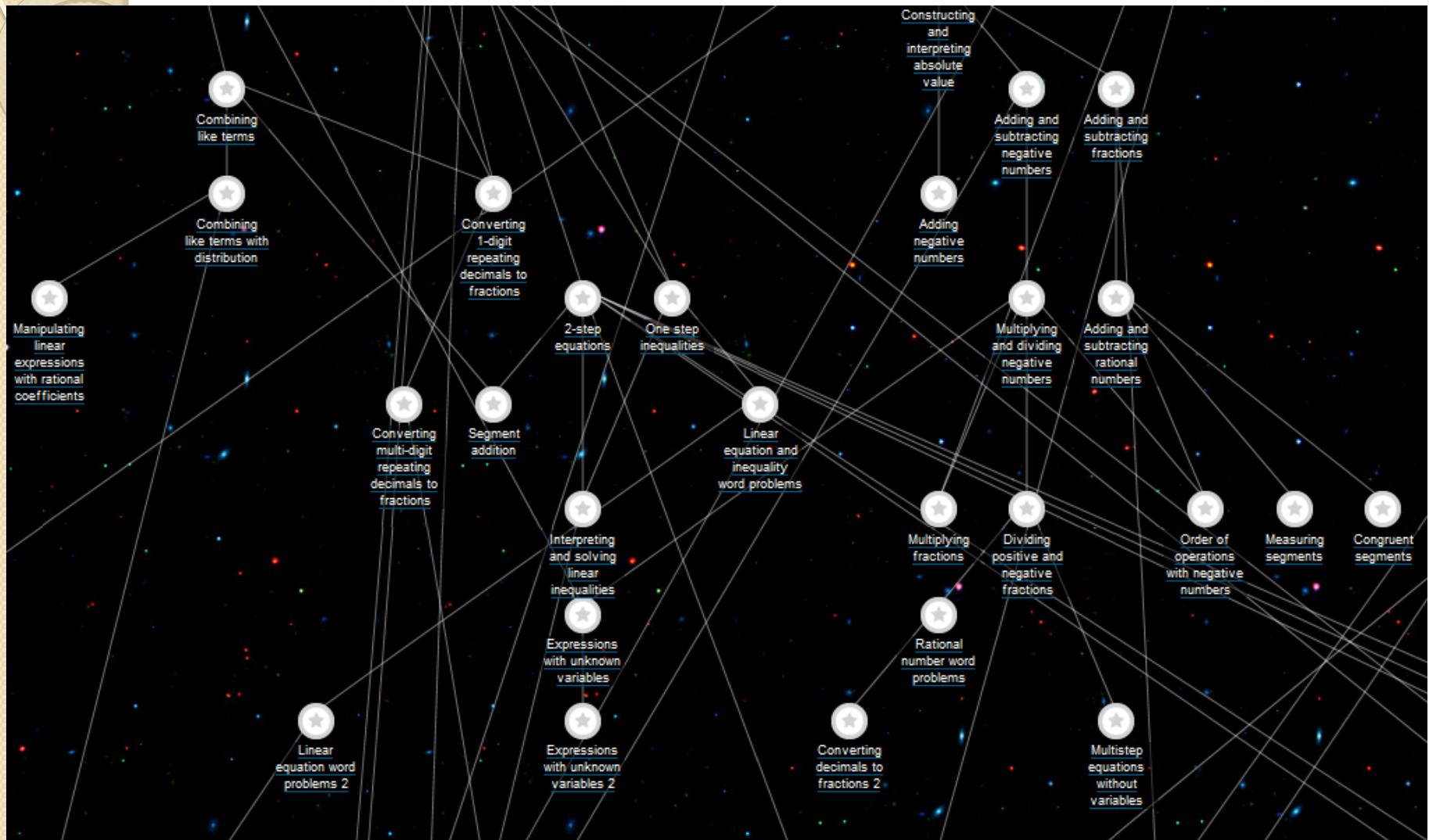
Associativity network (about multiplication)

Networks of Numbers (2)



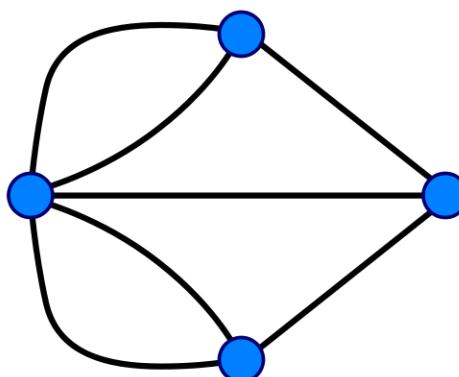
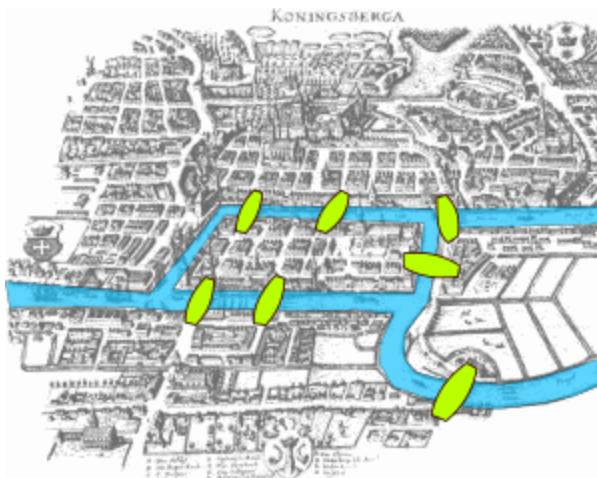
Collatz sequence ($x \rightarrow y ; y = x/2$ if x is even, or $3x+1$ otherwise)

Network of Concepts

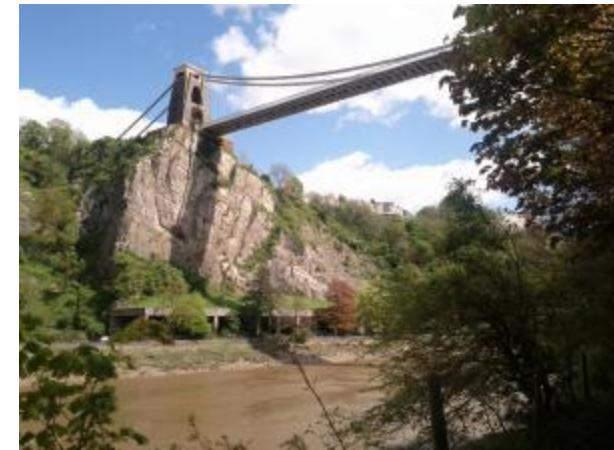


Knowledge Map (from Khan Academy)

Networks in Math Puzzles



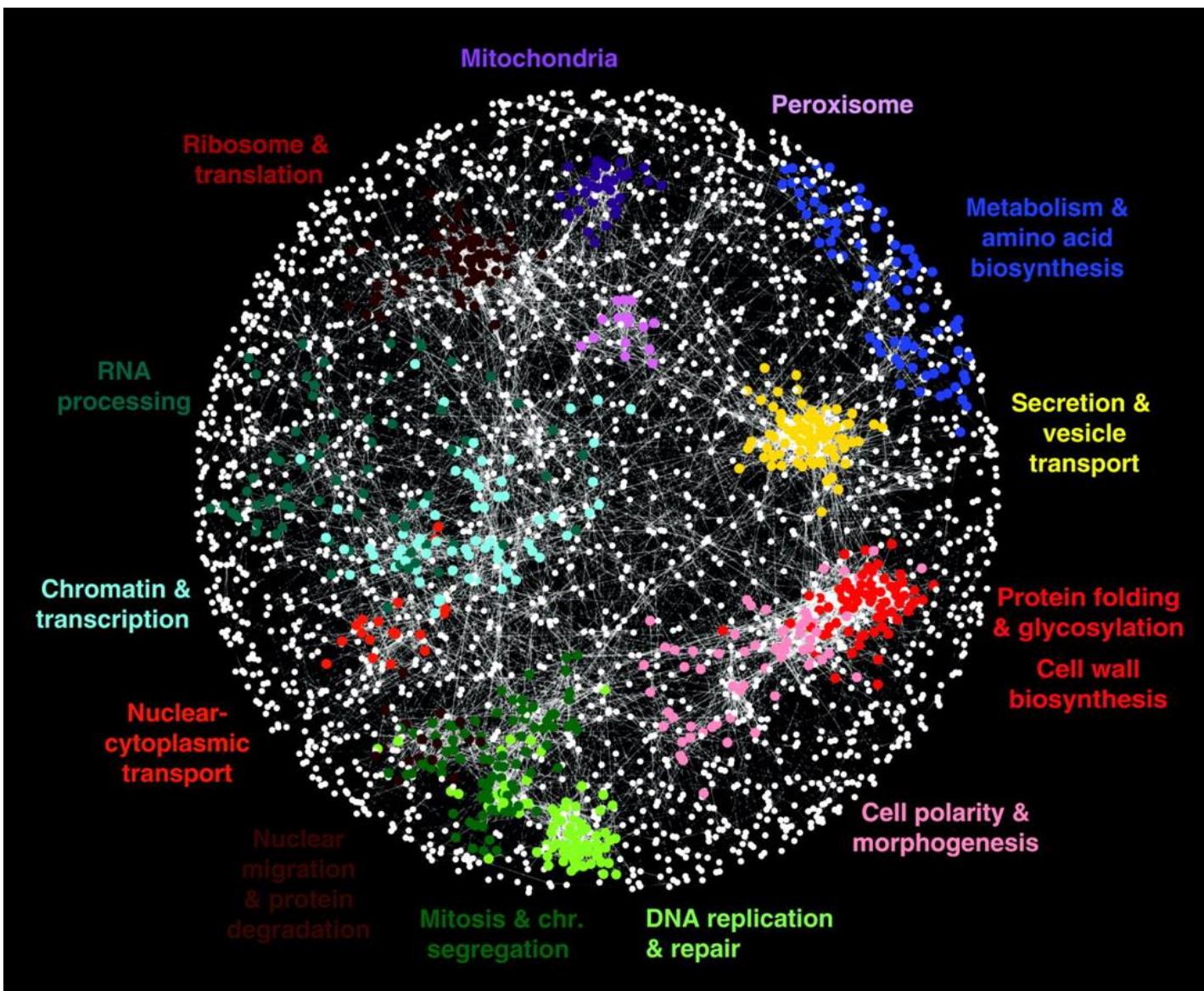
Seven bridges of Königsberg
(images from Wikipedia)



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

Networks in Science

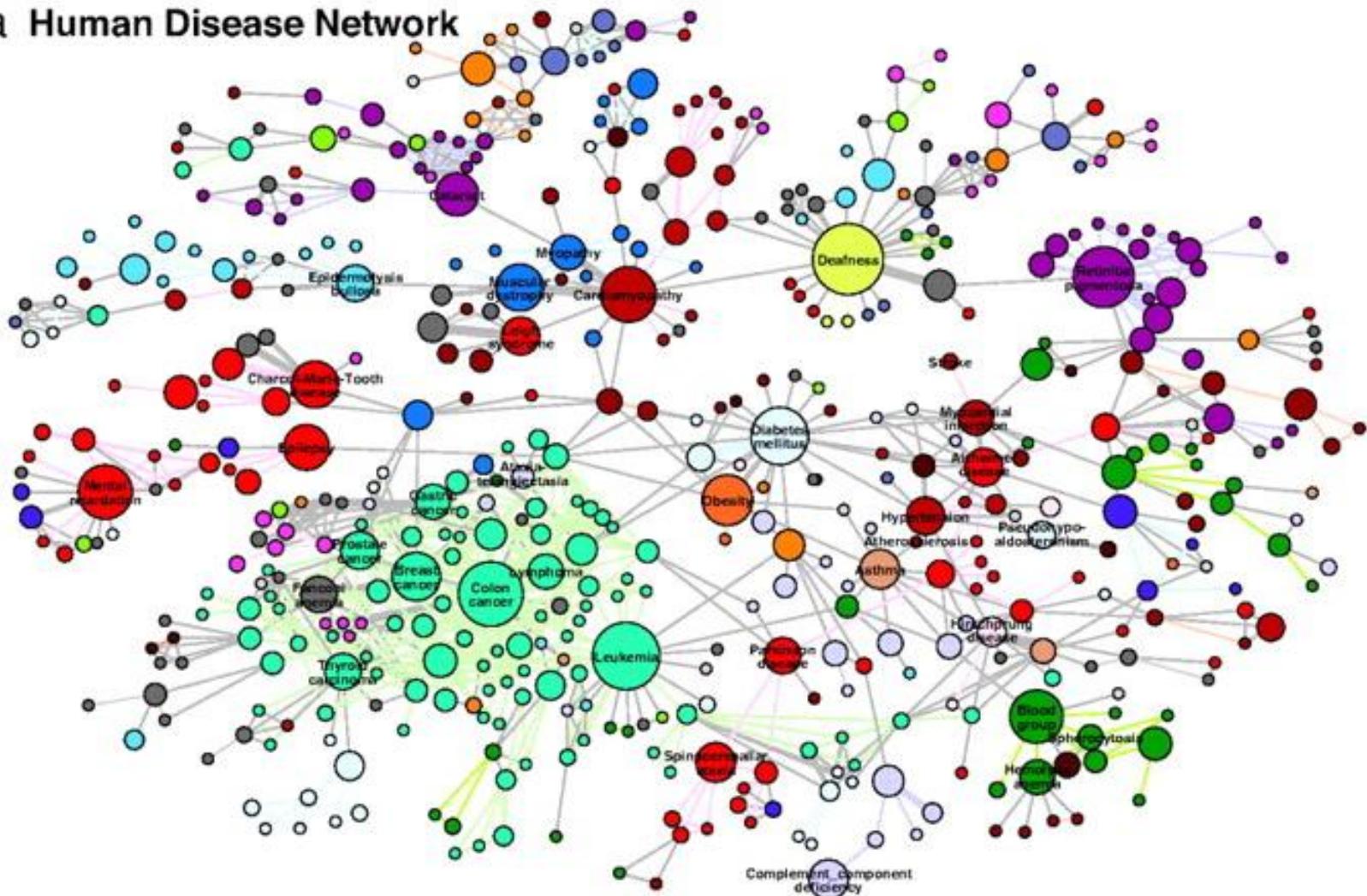
Network of Genes



Costanzo
et al., 2010

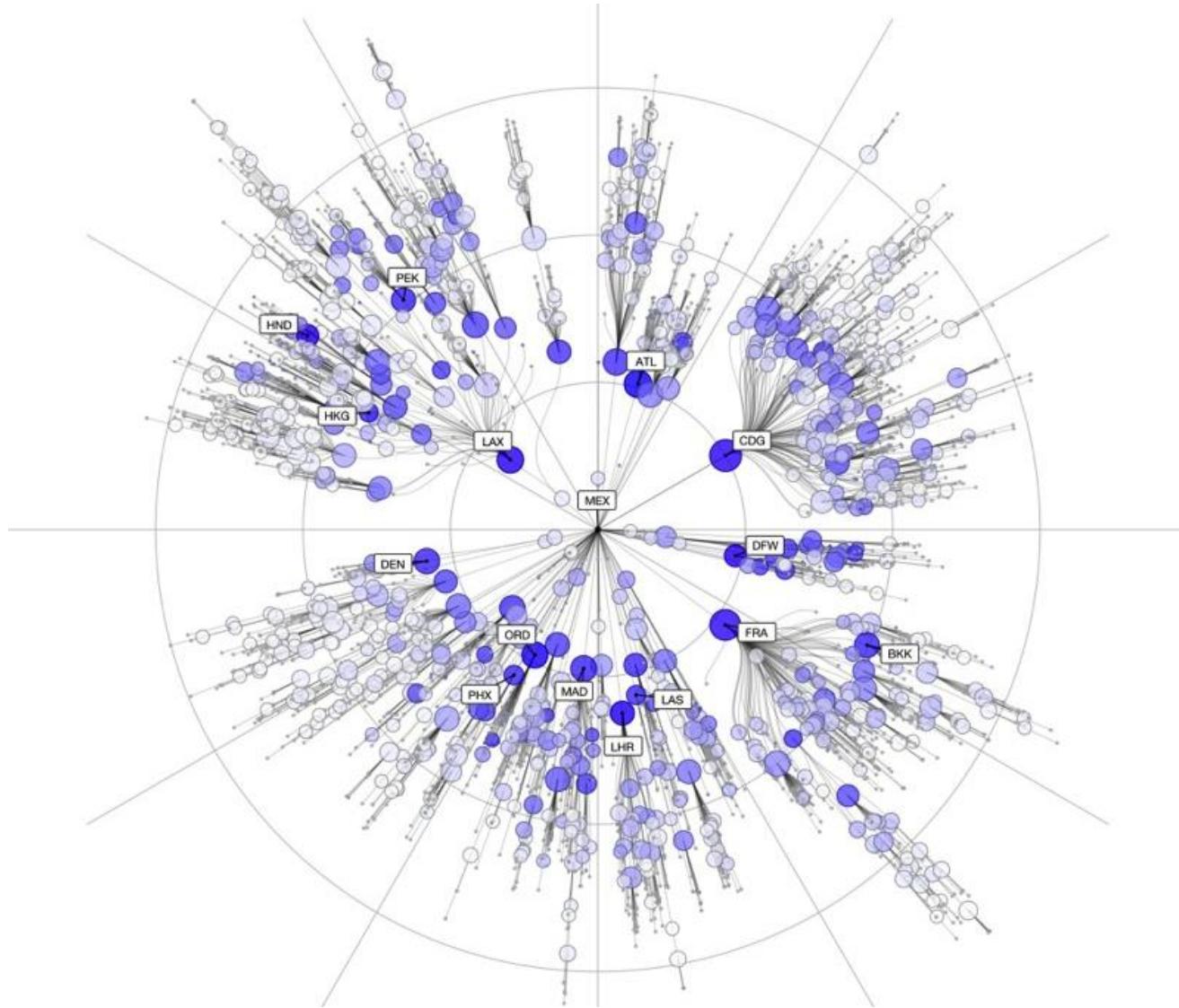
Network of Diseases

a Human Disease Network



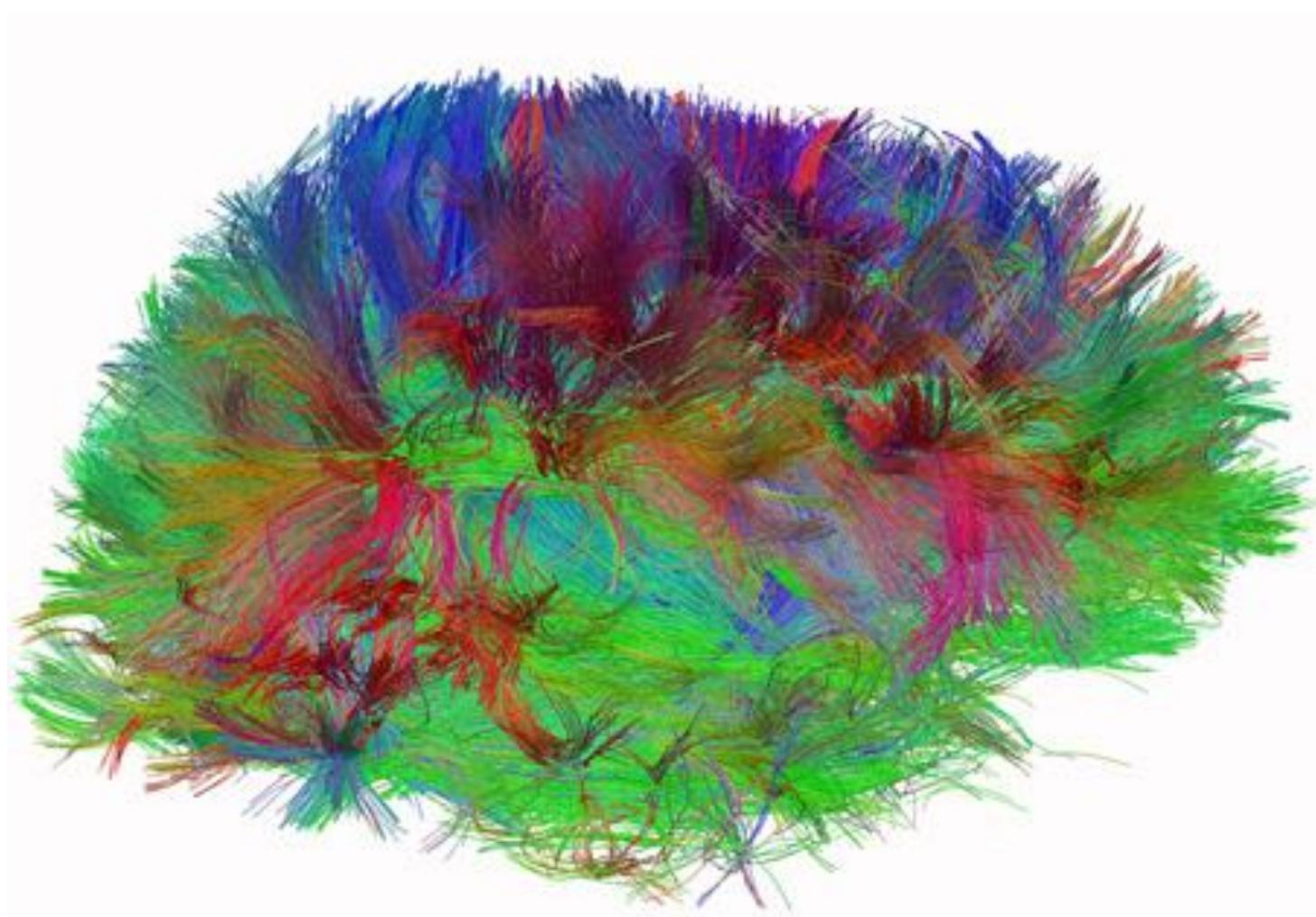
Goh et al., 2007

Network of Disease Propagation



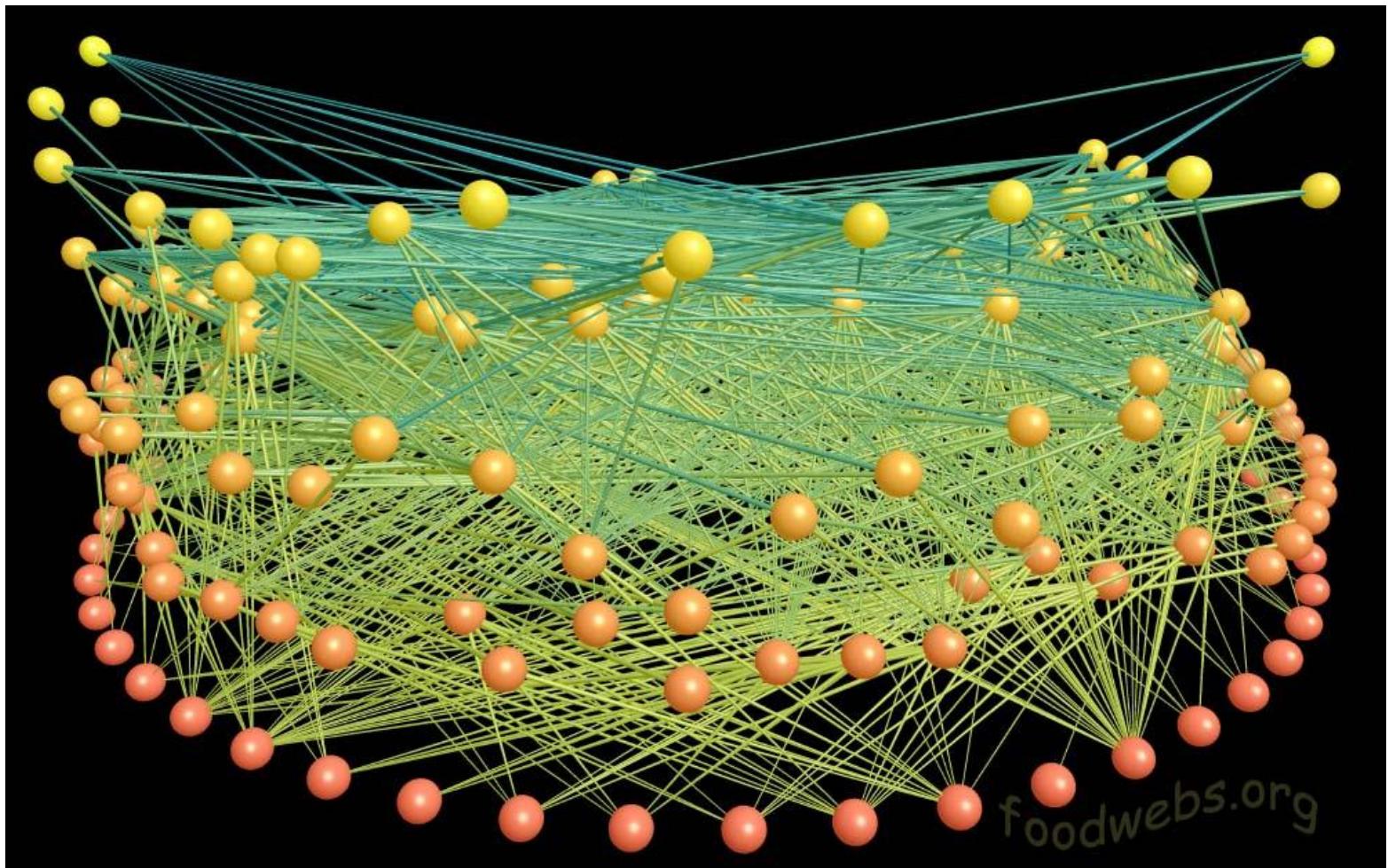
HINI activities illustrated according to distance from MEX airport (Brockmann, 2013)

Network of the Brain



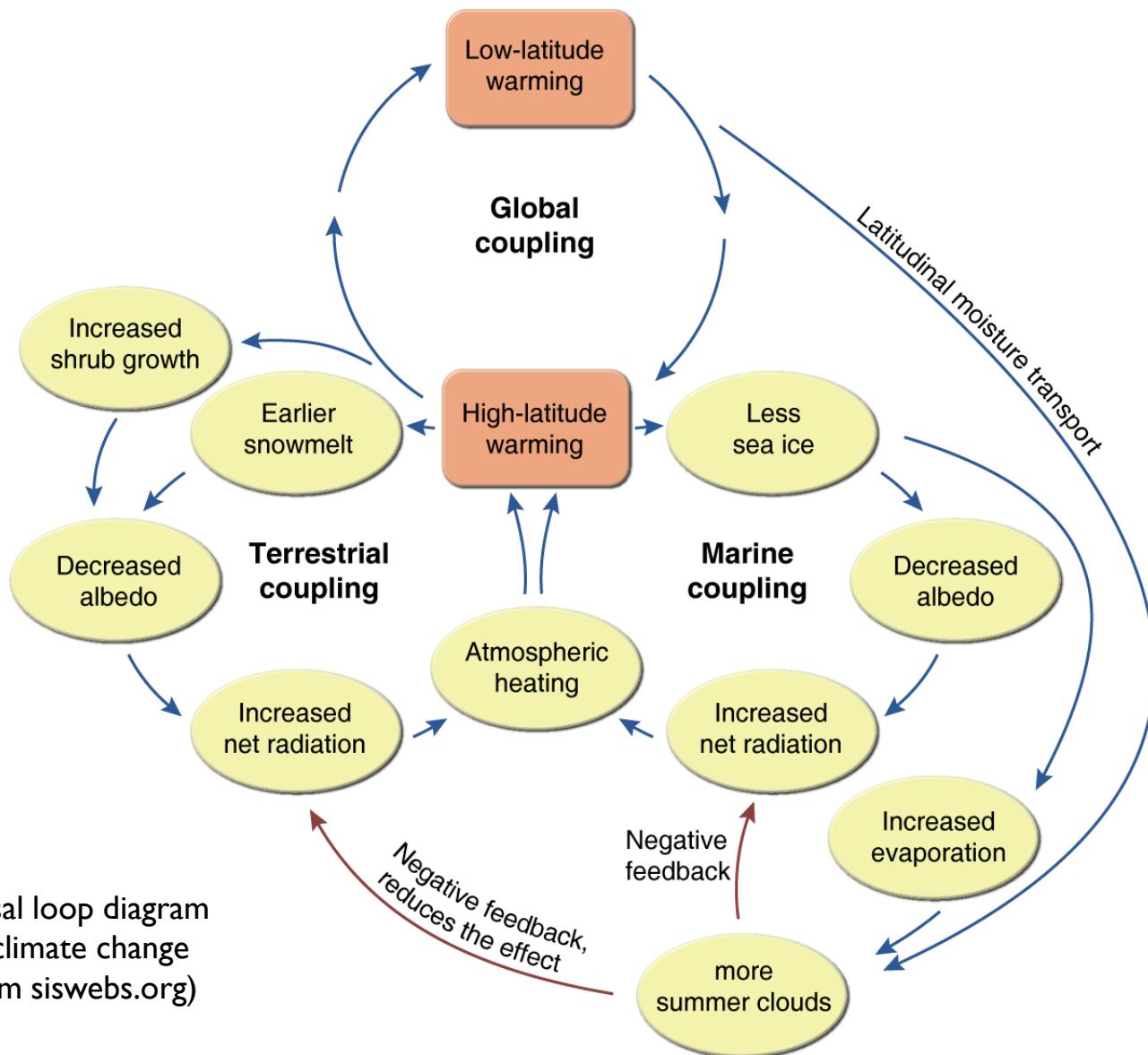
Van J. Wedeen, M.D., MGH/Harvard U.

Food Webs



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

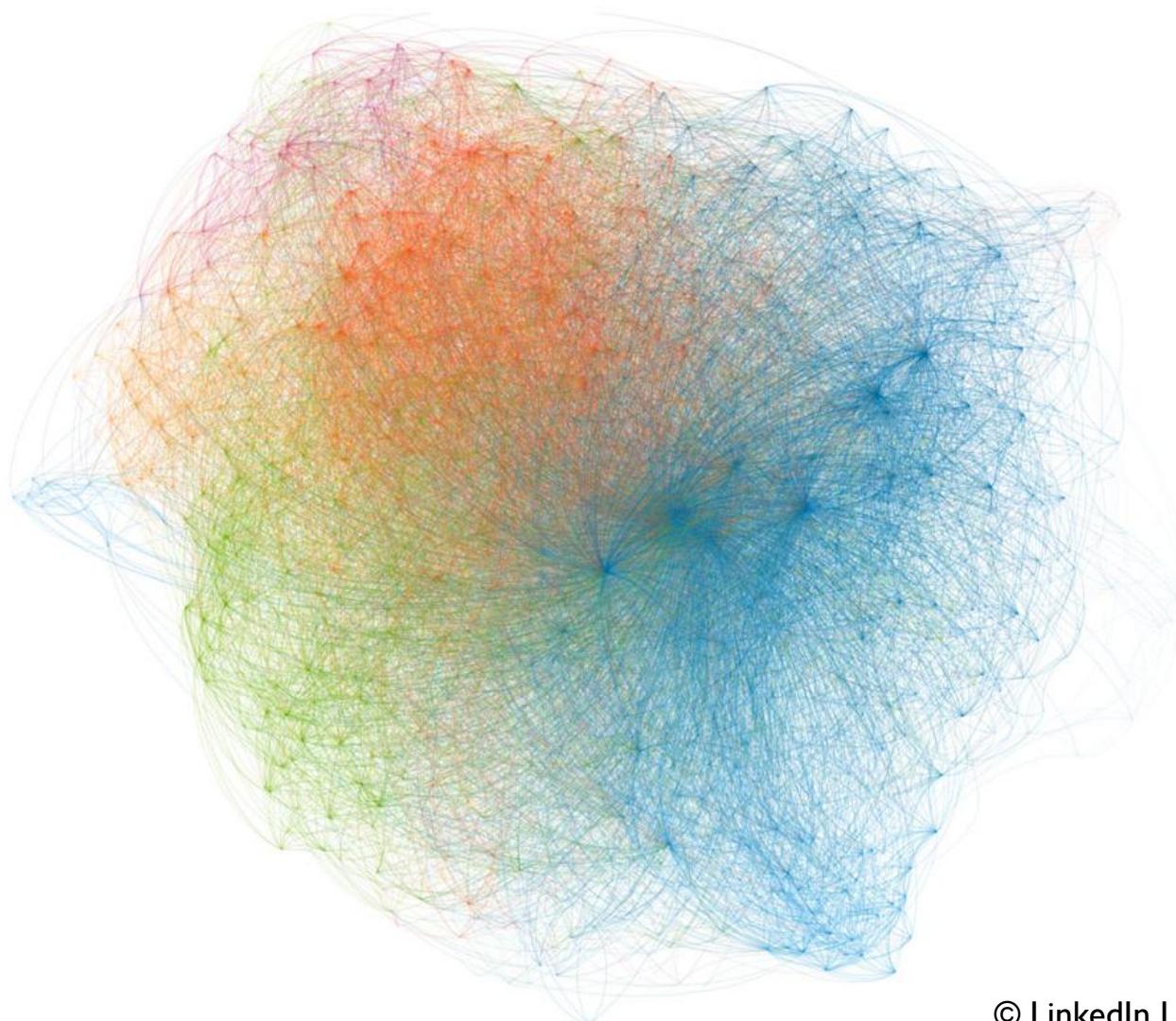
Causal Loop Diagram





Networks in Social Studies

Network of People Around You



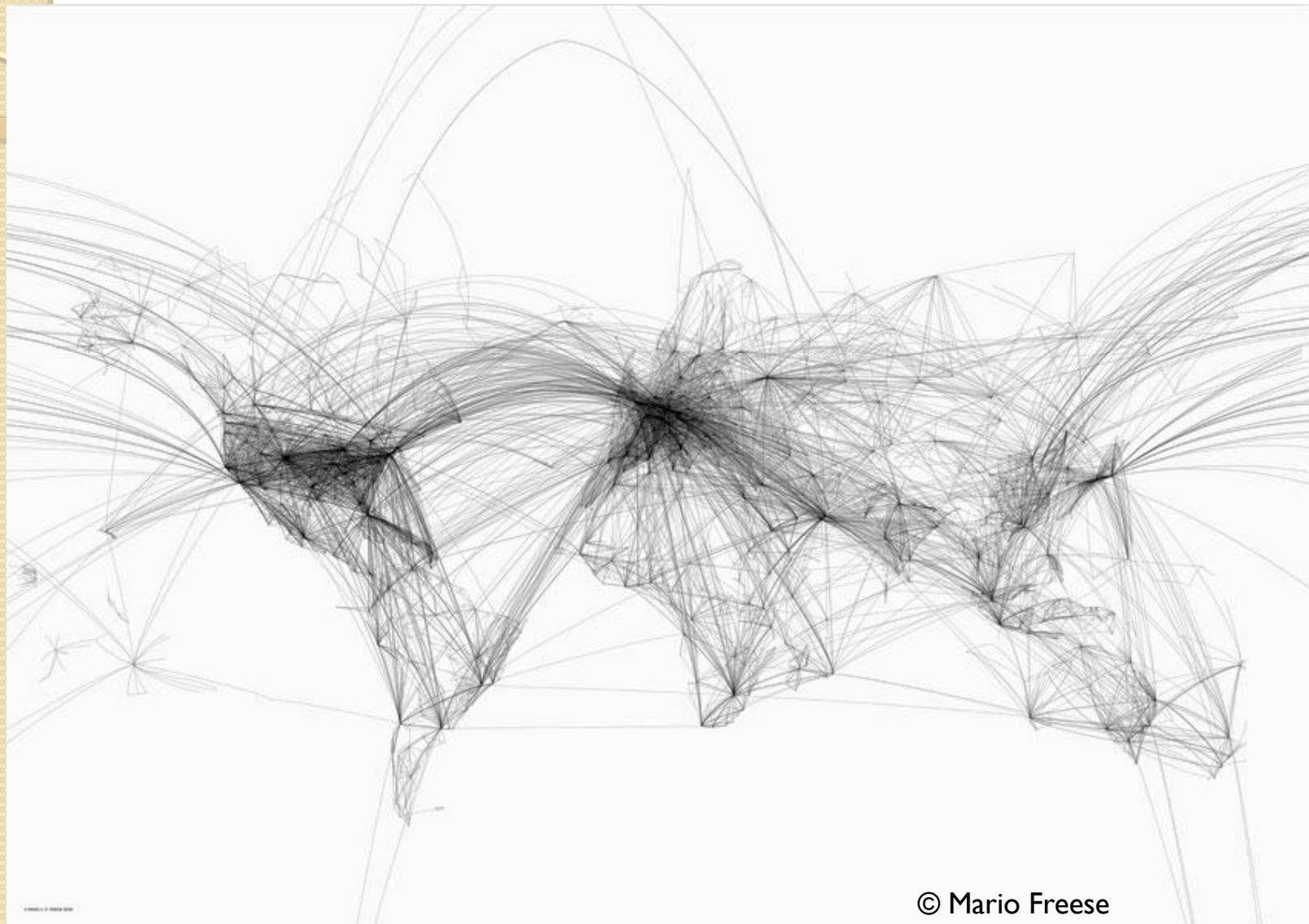
© LinkedIn Labs

Network of Human Migration

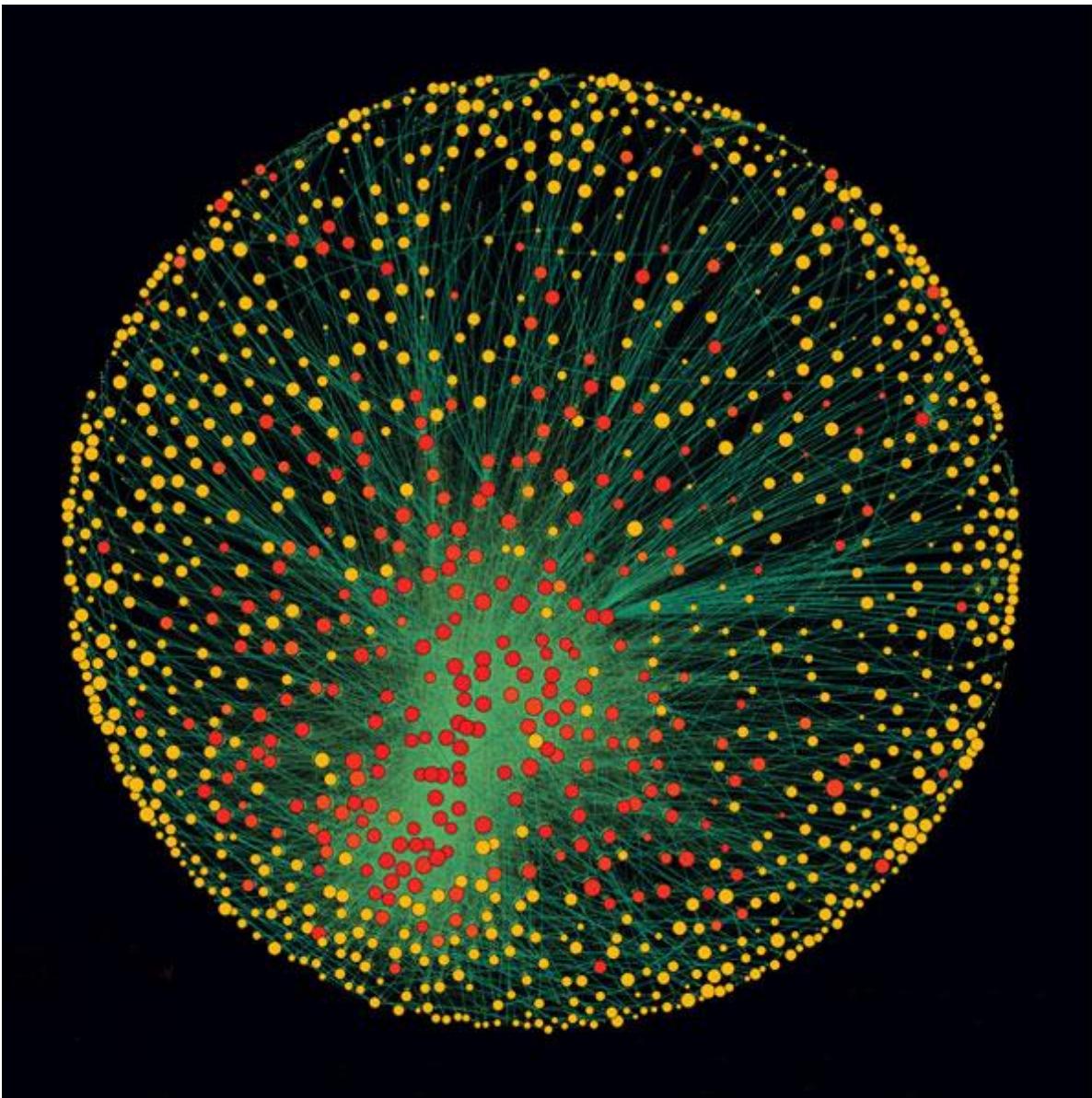


Davis et al., 2013

Network of Transportations

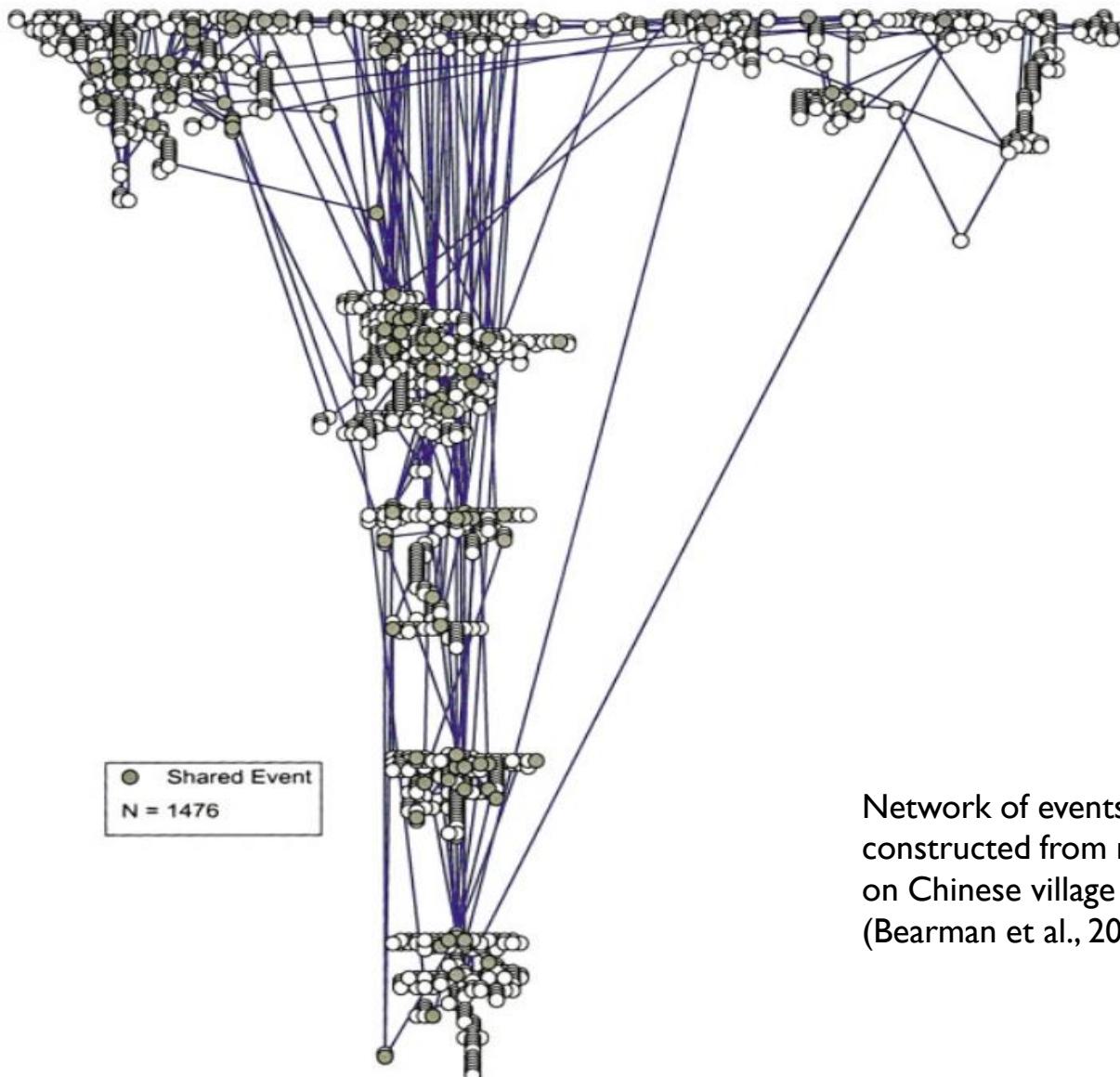


Network of Corporations



Vitali et al.,
2011

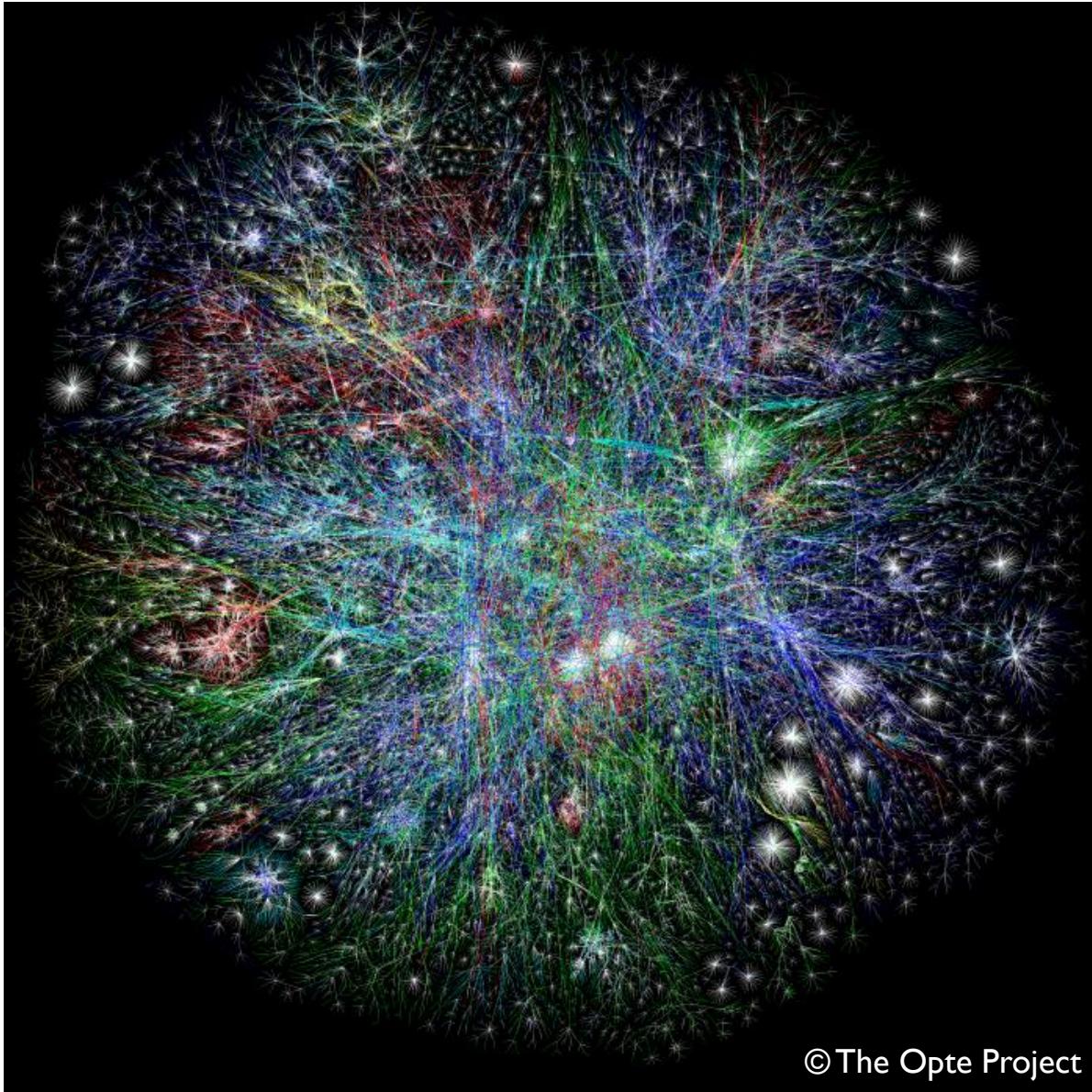
Network of Historical Events



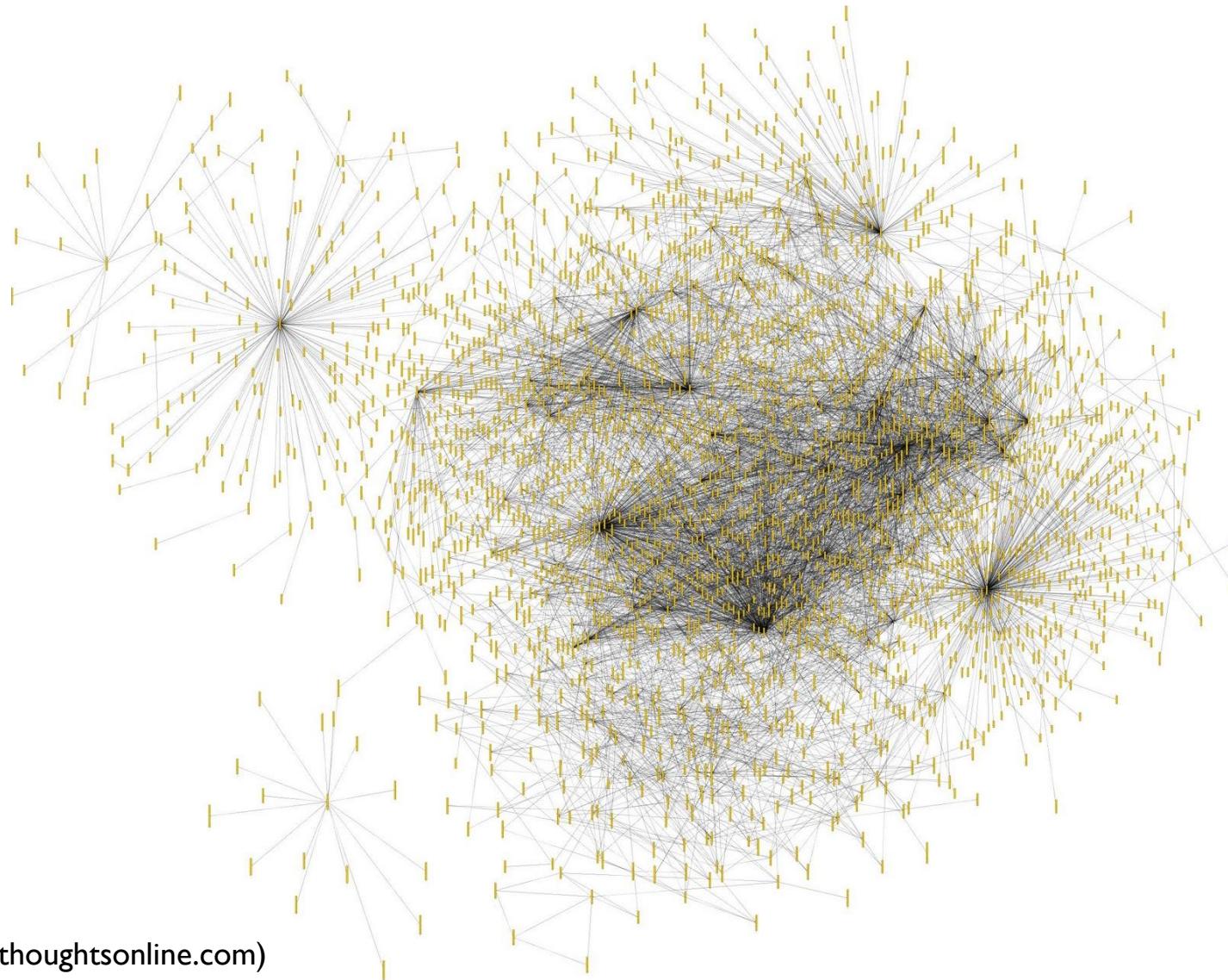


Networks in Technical Education

The Internet



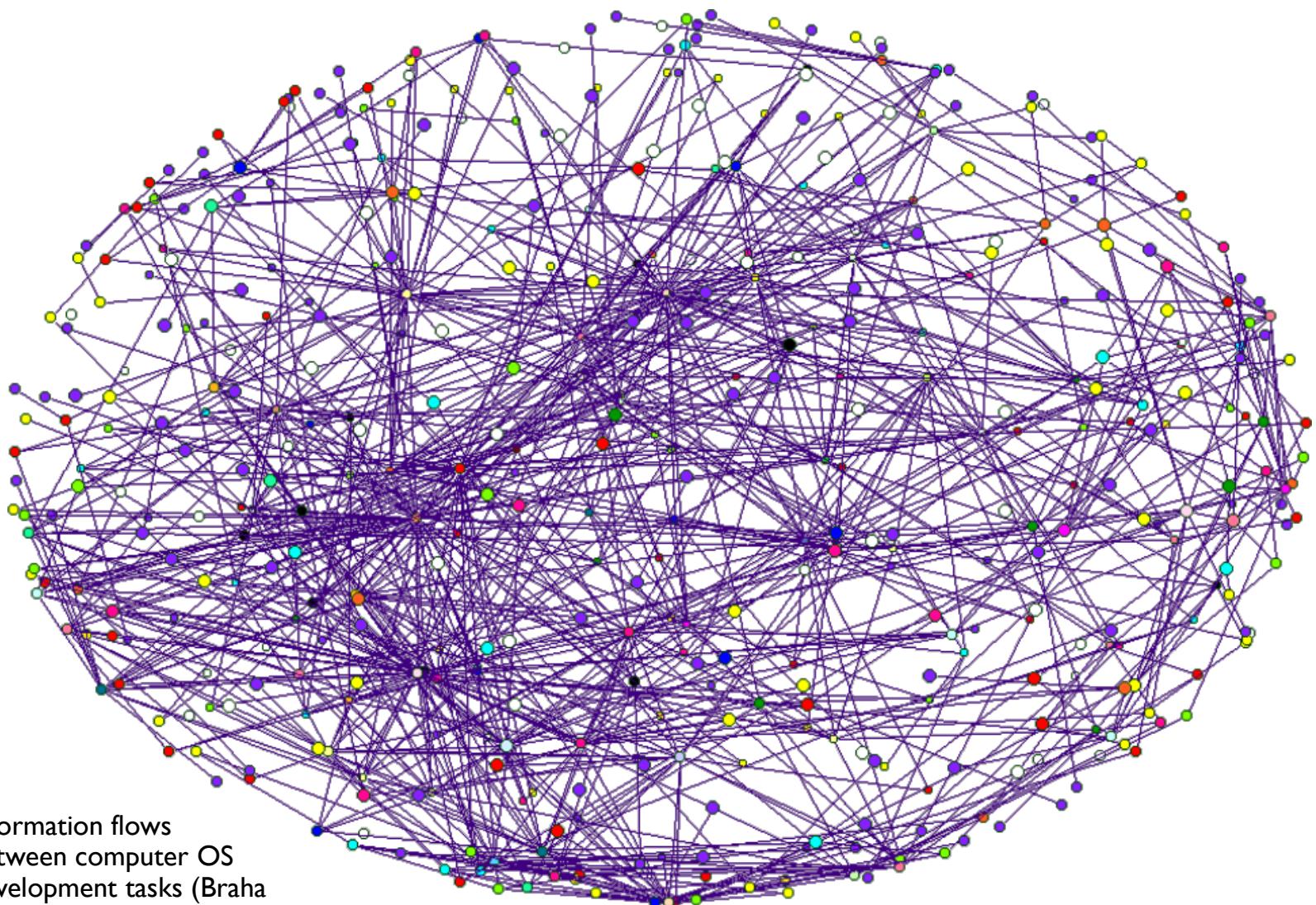
Network of Java Classes



Cavlin, 2012

(from simplethoughtsonline.com)

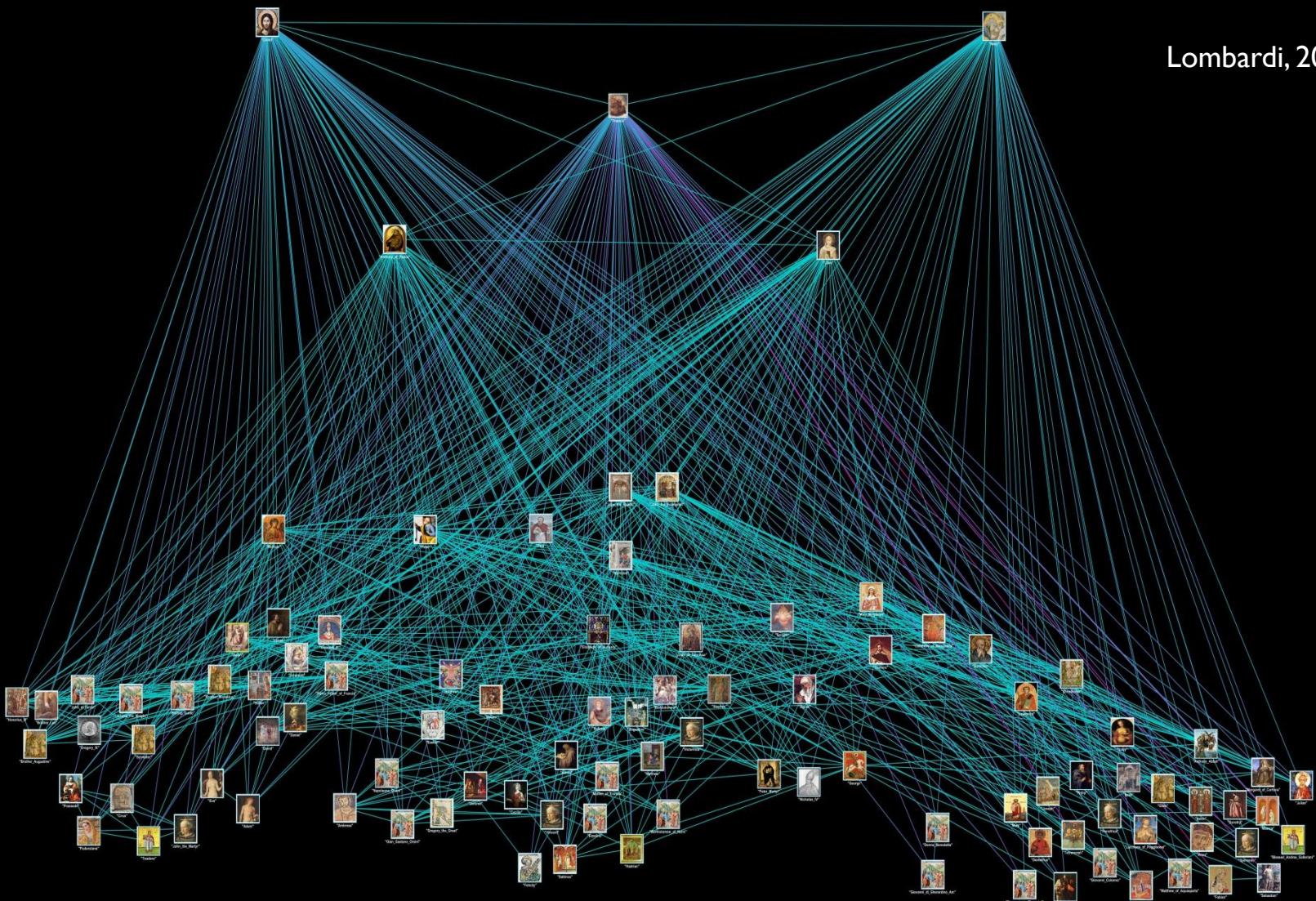
Network of Product Design



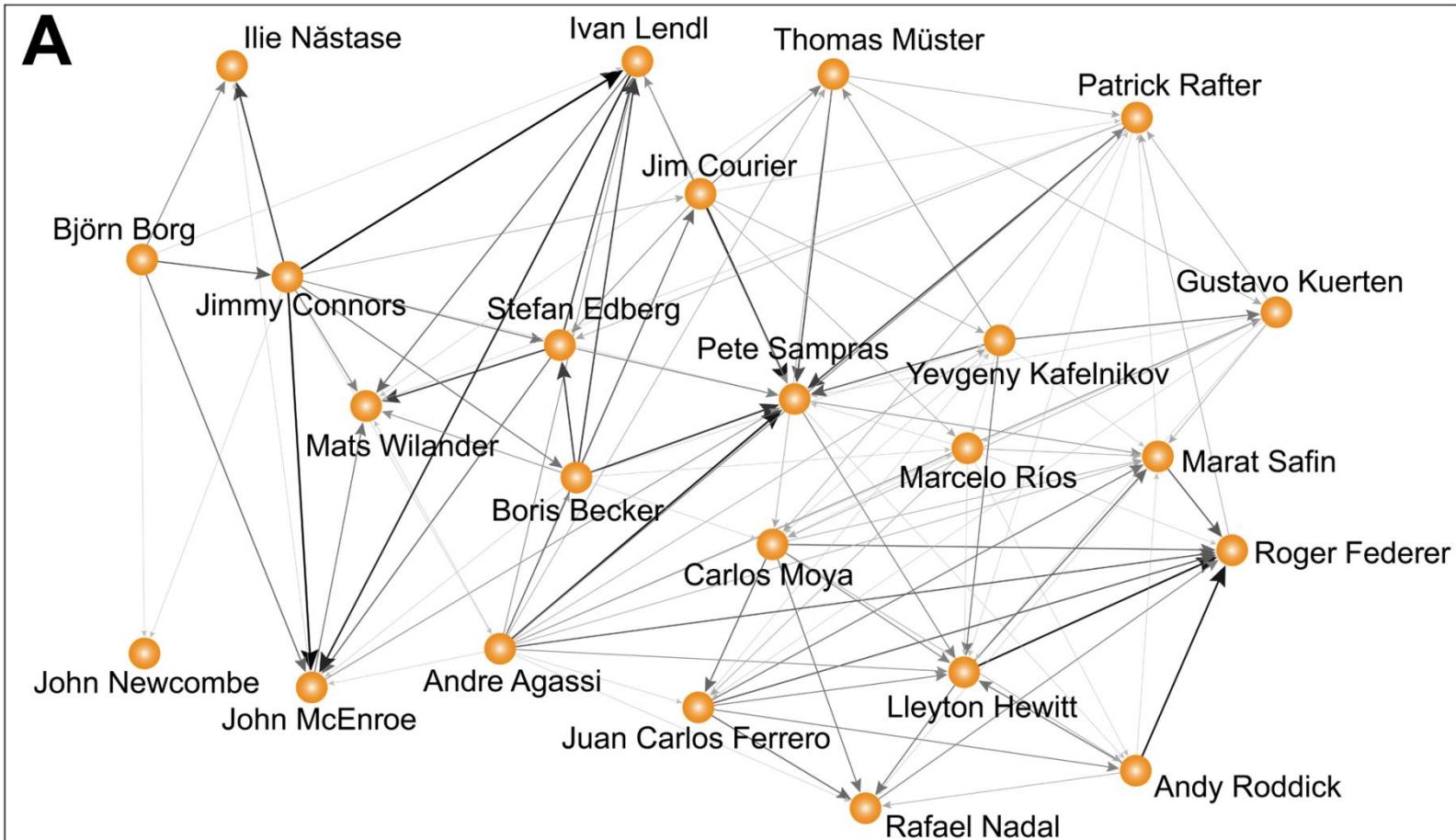
Networks in Other Subjects

Network of Saints in Iconography

Lombardi, 2013

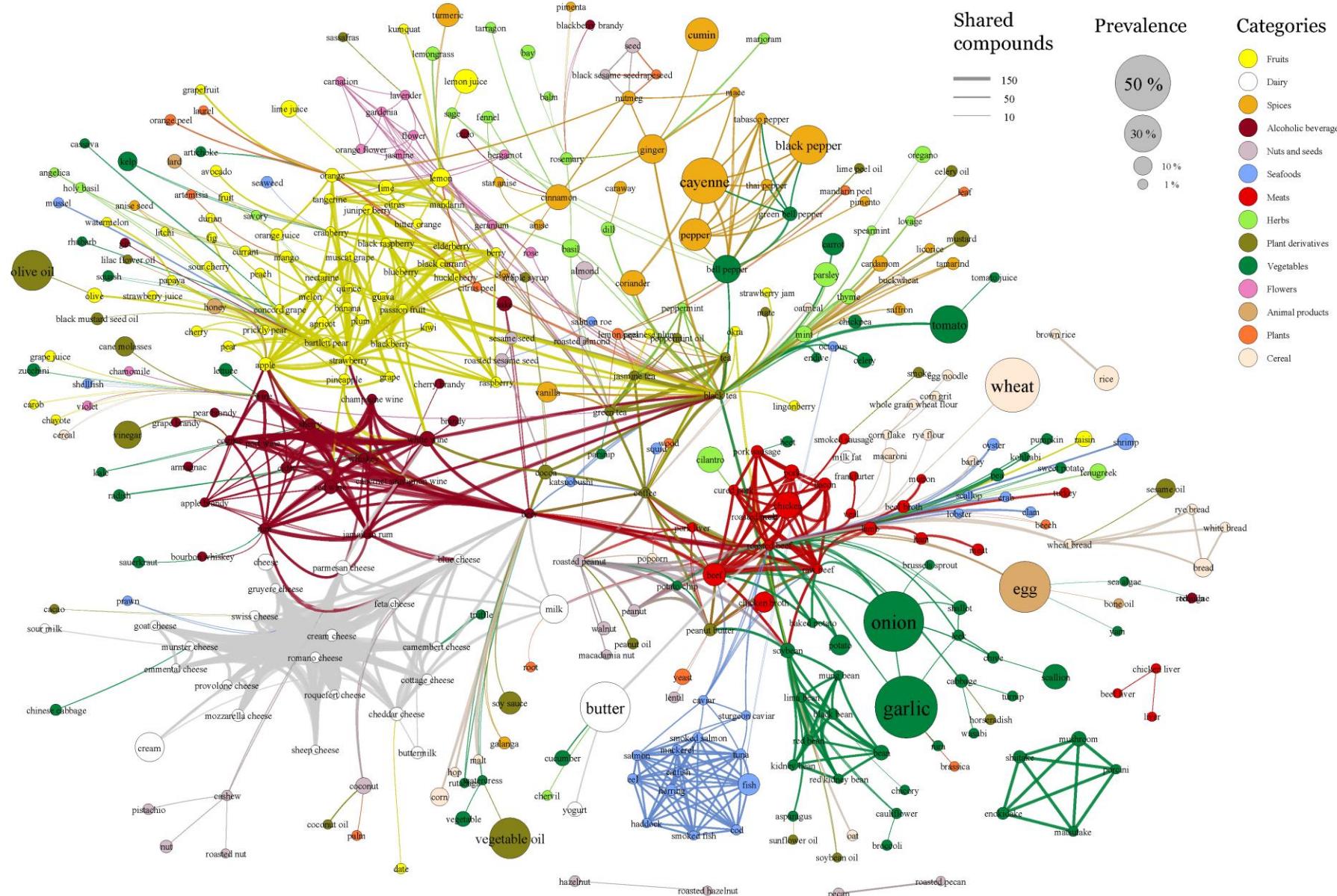


Network of Top Tennis Players



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/>).

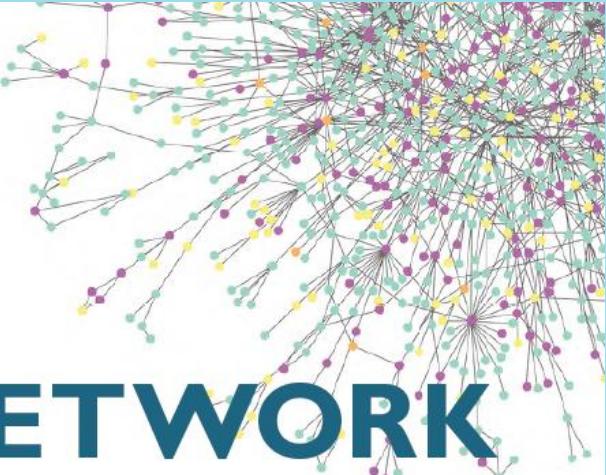
Take-Home Message

- 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



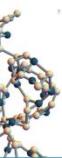
1 NETWORKS ARE EVERYWHERE

- The concept of networks is broad and general, and it describes how things are connected to one another. Networks are present in every aspect of life.
- There are networks that form the backbone of our society and economy, e.g., communication systems, transportation, commerce, governments, families, sports, the entire supply chain.
- There are social networks – e.g., families and friends, a workplace, neighborhoods, school, co-workers, Instagram, professional groups, etc.
- There are economic networks – e.g., trade, supply chains, financial markets, transportation, corporate partnerships, manufacturing, agriculture, etc.
- There are biological and ecological networks – e.g., food webs, gene regulatory networks, neural networks, patterns of disease spreading, language translation, art connected by style, interests, people connected by shared events, etc.
- Networks can exist at various spatial and temporal scales.



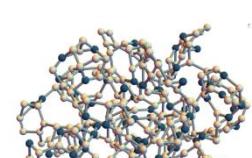
2 NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- There are many different ways that your actions in a network can affect others. These interactions can be represented mathematically as edges or ties.
- Connections are called links, edges, or ties. The vertices that are connected by a link are called nodes, nodes, vertices, or actors.
- Connections can be directed (one way) or undirected (two ways). They can also be weighted (communicate directed strength) or unweighted. They can also evaluate lots of different strengths, including positive, negative, or negative relationships.
- The number of connections of a node is called the degree of that node.



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

- Networks are connected in a network.
- Networks store information through their nodes and edges.
- Information can flow through a network over time.
- The time scale on which networks transition between states can be either similar or different.
- Network structure can influence the state of a network. Changes in network structure can lead to changes in network behavior. For example, a “falling” edge in social media can trigger a cascade of other edges made to address traffic jams.
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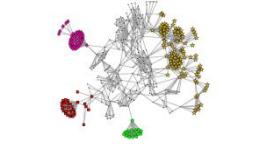
6 NETWORKS HELP YOU TO COMPARE A WIDE VARIETY OF SYSTEMS

- Various kinds of systems, such as social networks, power grids, and biological systems, share common mathematical properties that can be used to compare them.
- Networks help you to compare a wide variety of systems. These properties include the number of nodes, the number of edges, the degree distribution, and the clustering coefficient.
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- Science is conducted in different fields of study. Network literacy helps to achieve a holistic and more complete understanding of science.
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3 NETWORKS CAN HELP REVEAL PATTERNS

- In some networks, you find a few individuals who have much larger degrees than others. Such a network is said to be “scale-free,” and it is important to study it differently than other networks.
- In some networks, you find a group of nodes that all have similar degrees. Such a network is said to be “random,” and it is often studied using random-walk models.
- The properties of a network that are most important depend on what you are interested in studying.
 - If the degree distribution is important, then it is important to know the degree distribution.
 - If there are clusters, then it is important to know the size and density of clusters.
 - If there are hubs, then it is important to know the degree of the hubs.
 - If there are paths, then it is important to know the length of the shortest path.
- Using these findings, you can make predictions about future events, or you can make predictions about current events in the network.



4 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

- Networks can be visualized in many ways. By connecting nodes to each other, we can see the overall structure of the network.
- There are a variety of tools available for creating network visualizations.
 - Network visualization tools help to understand it and communicate its properties to others.
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- Creating informative design plays an important role in effective communication.
- It is important to understand and evaluate network visualizations, because they typically do not capture every aspect of networks.

