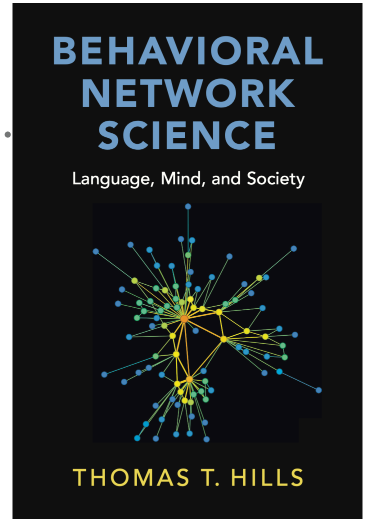
"I always dream of a pen that would be a syringe." — Jacques Derrida

BEHAVIORAL NETWORK SCIENCE

USING SOCIAL NETWORK ANALYSIS



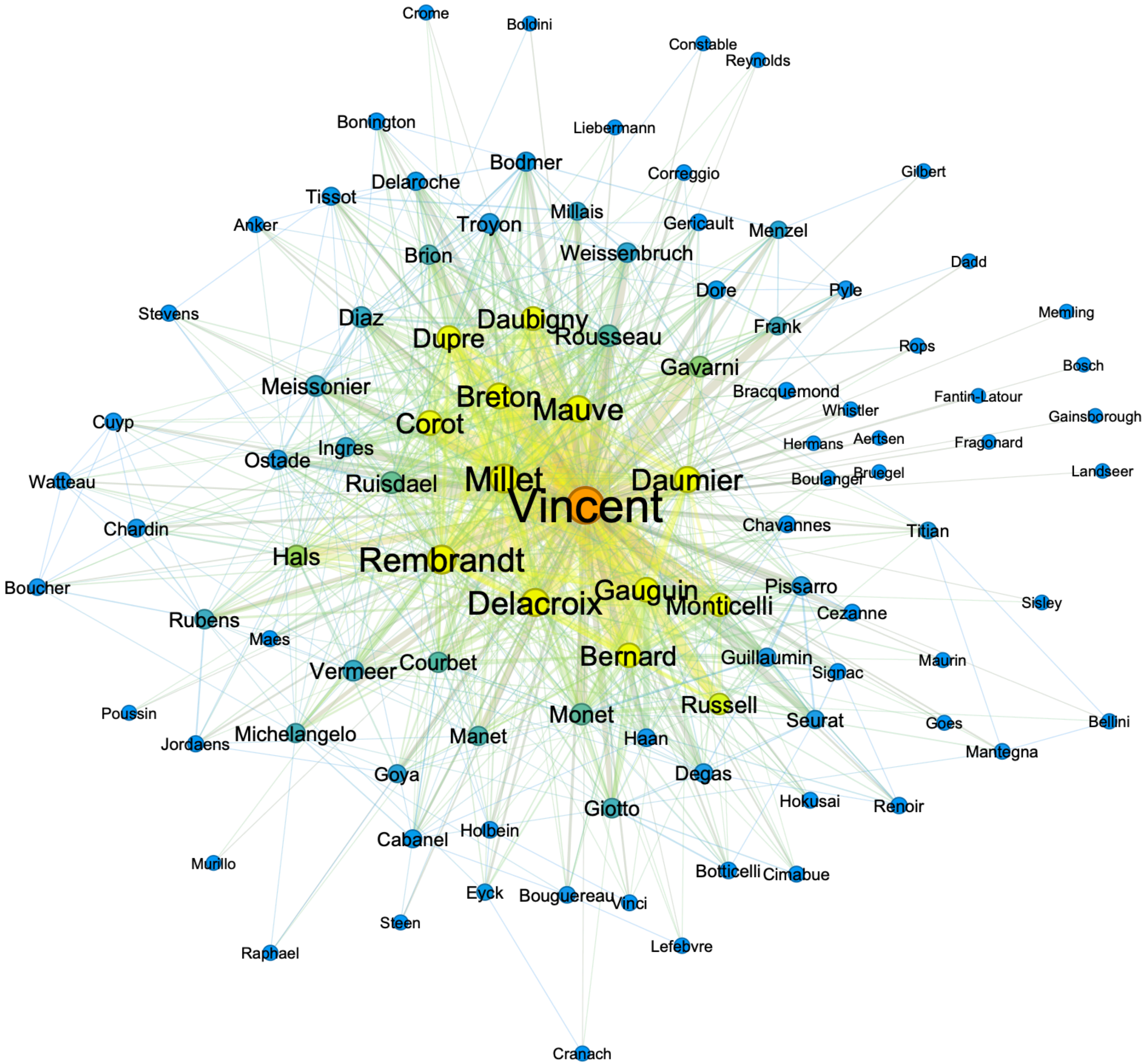
Thomas Hills
University of Warwick

PS941

WARWICK
THE UNIVERSITY OF WARWICK

The Alan Turing Institute

THE ROYAL SOCIETY



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Constable
Reynolds
Bonington
Liebermann
Bodmer
Correggio
Gilbert
Delaroche
Tissot
Millais
Anker
Troyon
Gericault
Menzel
Brion
Weissenbruch
Dadd
Dore
Pyle
Stevens
Diaz
Daubigny
Memling
Dupre
Rousseau
Frank
Rops
Gavarni
Bosch
Meissonier
Bracquemond
Fantin-Latour
Breton
Mauve
Whistler
Gainsborough
Cuyp
Corot
Aertsen
Fragonard
Hermans
Ingres
Ostade
Landseer
Bruegel
Watteau
Ruisdael
Millet
Daumier
Boulanger
Vincent
Chardin
Chavannes
Titian
Hals
Rembrandt
Boucher
Pissarro
Sisley
Gauguin
Delacroix
Monticelli
Cezanne
Rubens
Maes
Bernard
Guillaumin
Maurin
Courbet
Signac
Vermeer
Russell
Poussin
Monet
Seurat
Goes
Bellini
Michelangelo
Jordaens
Manet
Haan
Mantegna
Goya
Degas
Hokusai
Renoir
Giotto
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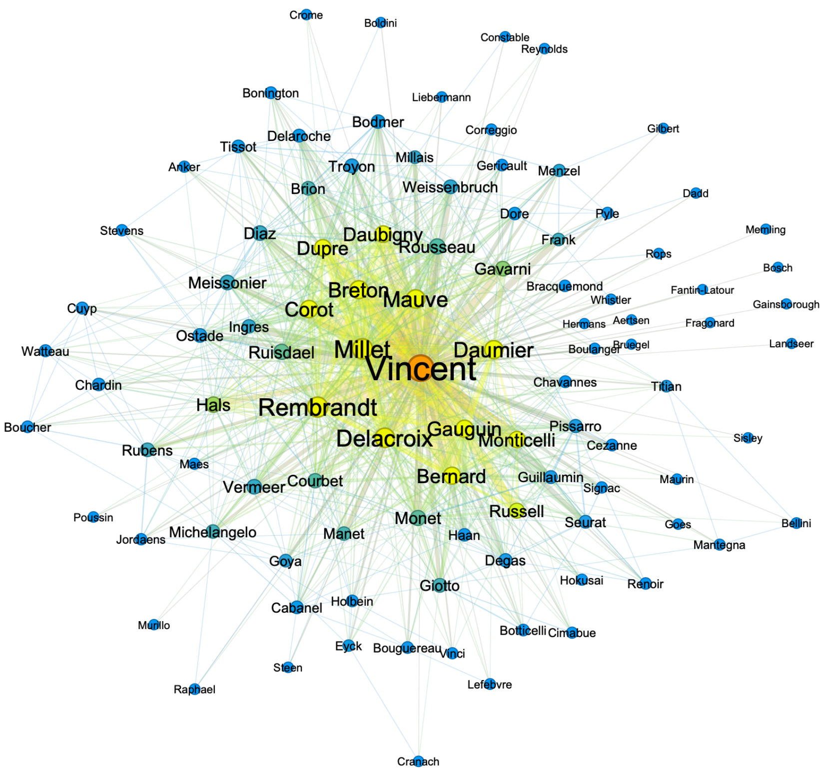
Cimabue
Eyck
Bouguereau
Vinci
Steen
Lefebvre
Raphael
Cranach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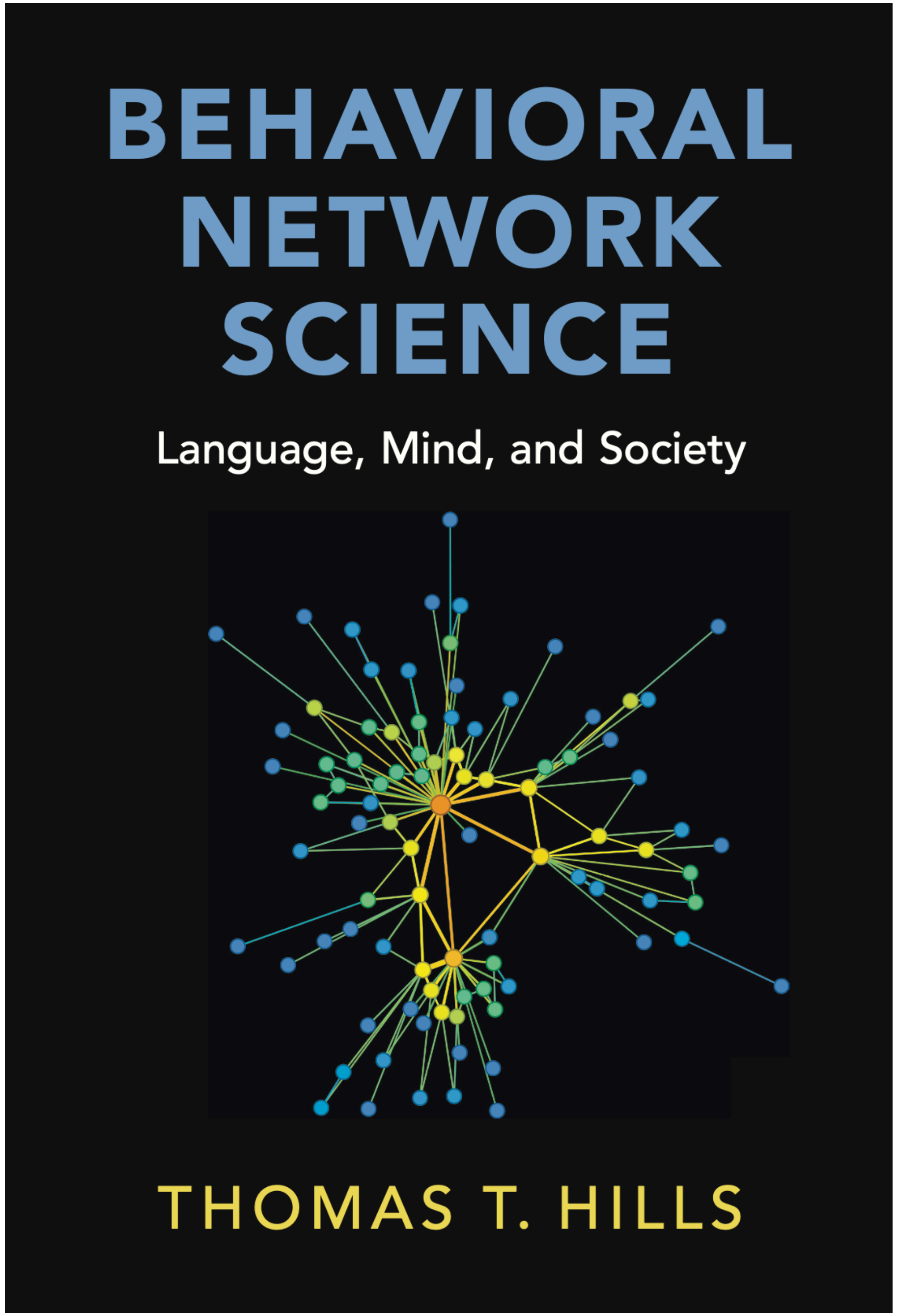

BEHAVIORAL NETWORK SCIENCE
Language, Mind, and Society
THOMAS T. HILLS

Outline for Day 1

- Why should we care about structure? Network insights
- Network basics

Some of my latest work

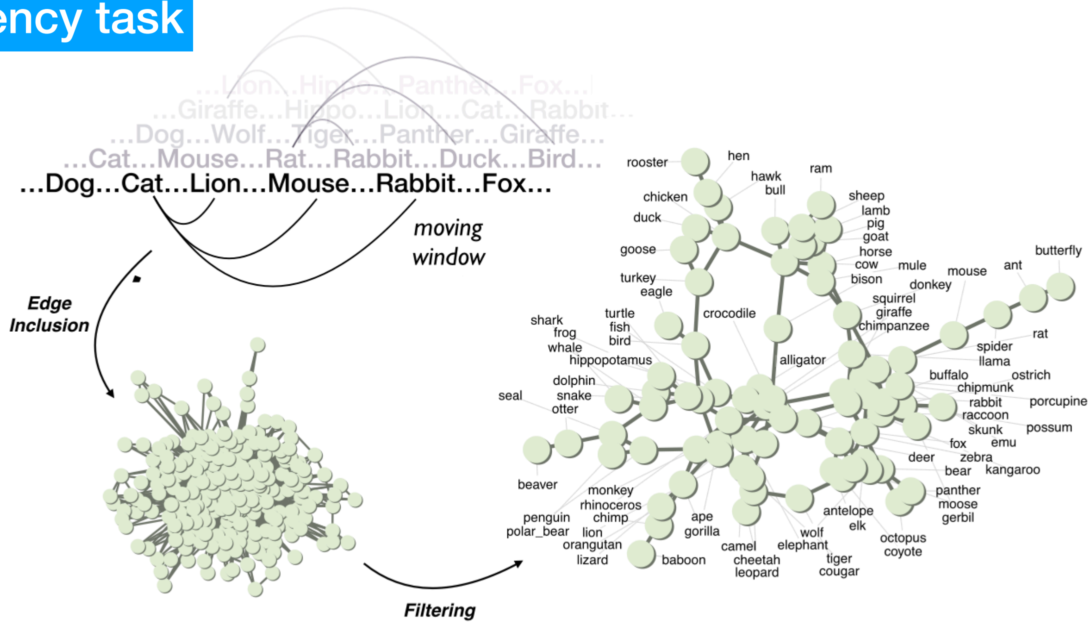
scientific reports

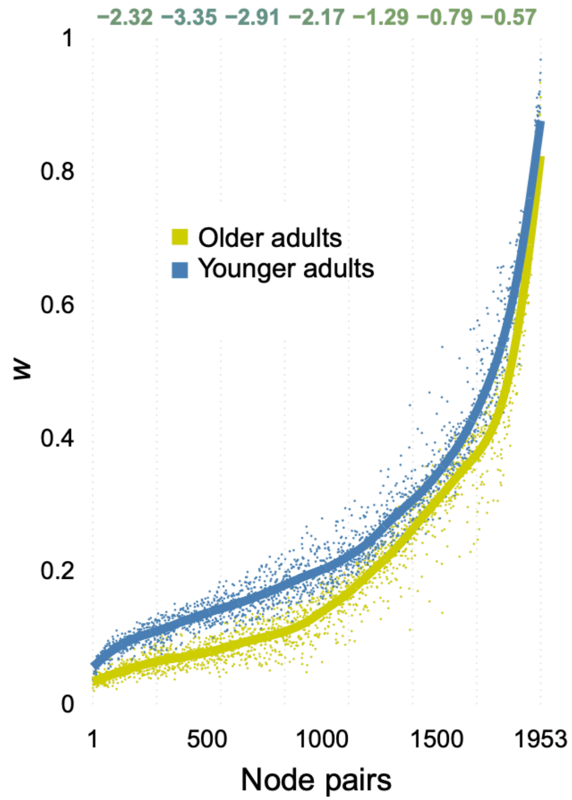
OPEN

Structural differences in the semantic networks of younger and older adults

Dirk U. Wulff[1,2], Thomas T. Hills[3] & Rui Mata[1,2]

Fluency task





Infer that older adult memory is less well connected. Specifically, relationships between words are weaker.

Some recent work

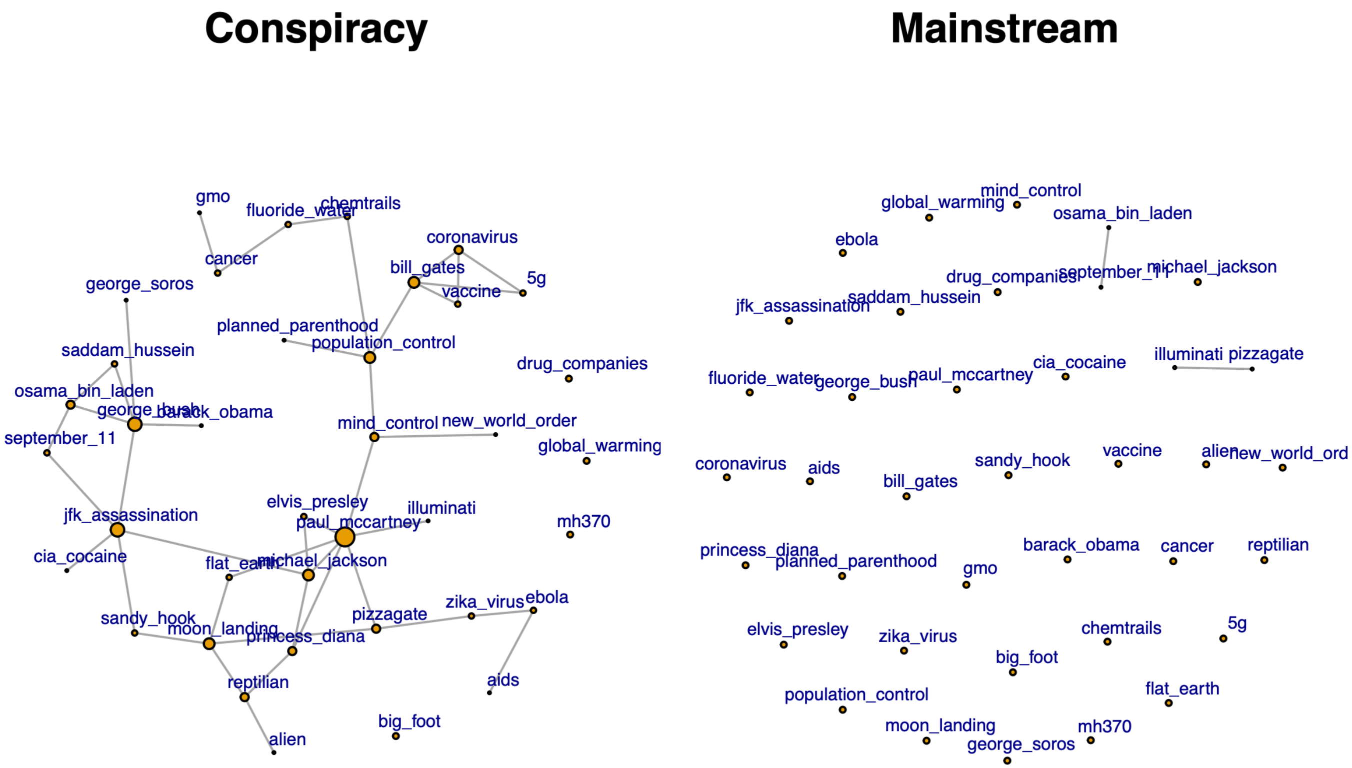
SCIENCE ADVANCES | RESEARCH ARTICLE

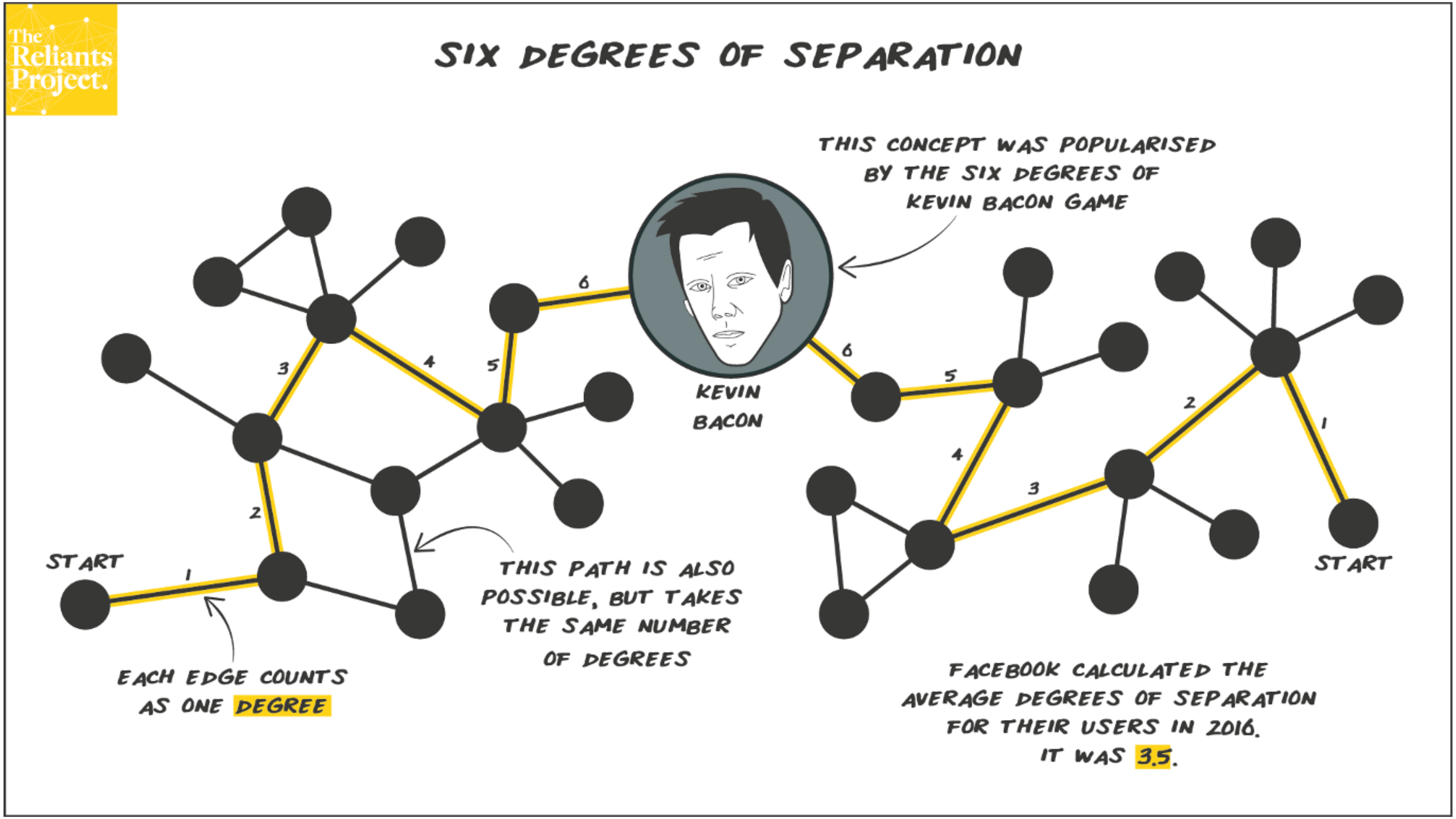
NEUROSCIENCE

Interconnectedness and (in)coherence as a signature of conspiracy worldviews

Alessandro Miani[1]*, Thomas Hills[2,3], Adrian Bangerter[1]

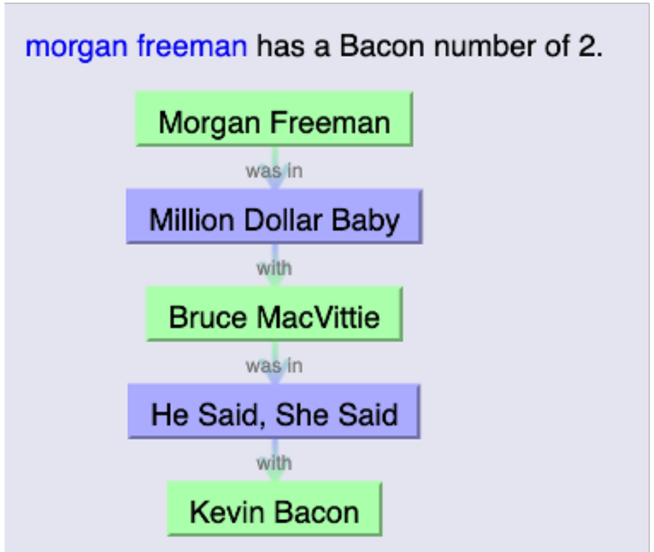
Conspiracy theories may arise out of an overarching conspiracy worldview that identifies common elements of subterfuge across unrelated or even contradictory explanations, leading to networks of self-reinforcing beliefs. We test this conjecture by analyzing a large natural language database of conspiracy and nonconspiracy texts for the same events, thus linking theory-driven psychological research with data-driven computational approaches. We find that, relative to nonconspiracy texts, conspiracy texts are more interconnected, more topically heterogeneous, and more similar to one another, revealing lower cohesion within texts but higher cohesion between texts and providing strong empirical support for an overarching conspiracy worldview. Our results provide inroads for classification algorithms and further exploration into individual differences in belief structures.





Oracle of Bacon

What's my Bacon number?



https://oracleofbacon.org/movielinks.php

58	4	"Can We All Become Geniuses?"	September 20, 2016	0.332[65]

Morgan Freeman says, "The Kodály method teaches children to think of music as a three-dimensional space."

Philo Farnsworth invented television.

Richard T. James invented the Slinky.

Stochastic resonance can boost weak signals. Freeman says that the dorsolateral prefrontal cortex (DL-PFC) "plays a key role in problem solving."

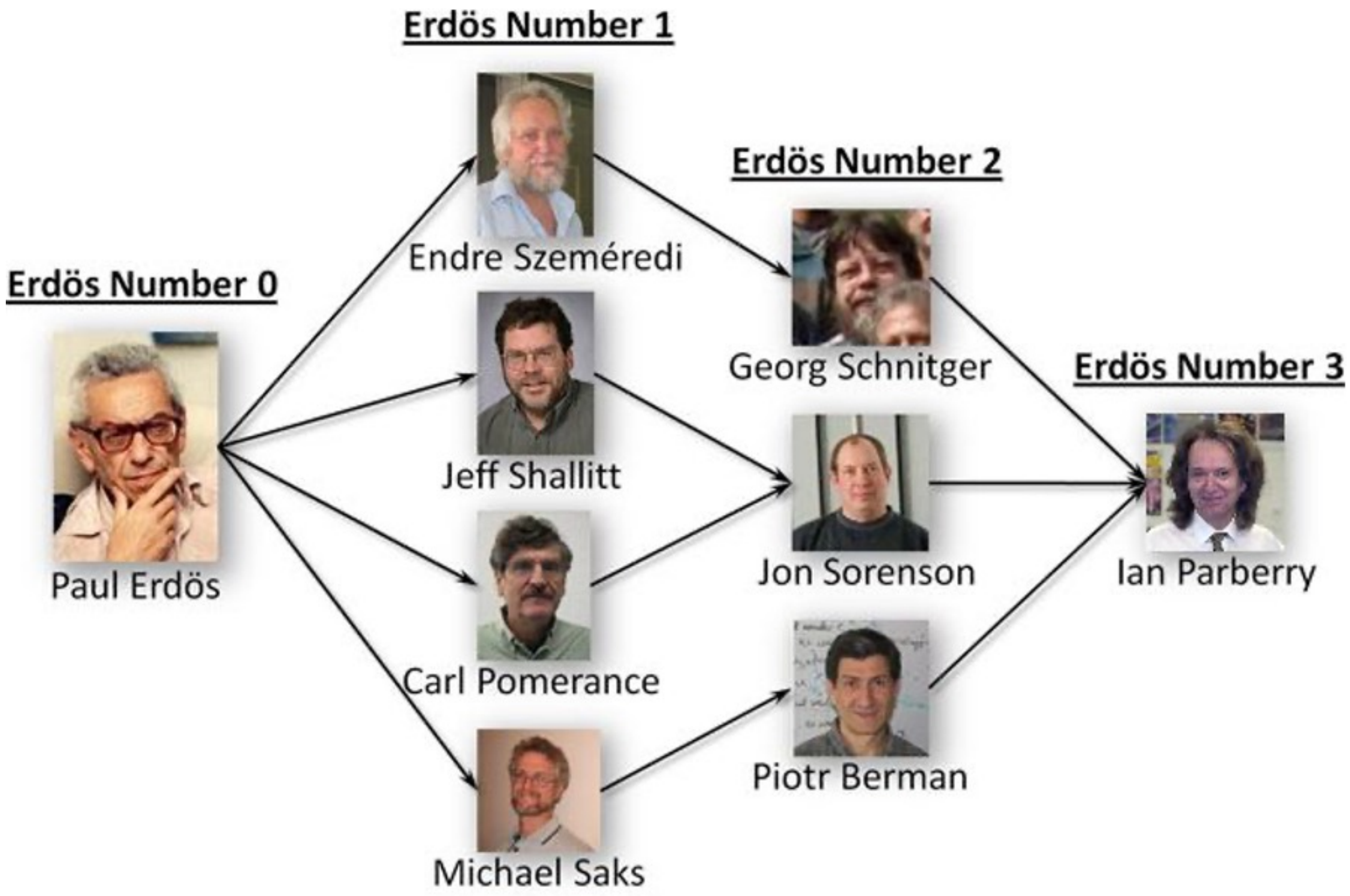
Freeman says that PDE4B has a detrimental effect on memory formation.

- Interviewed experts: Jason Padgett (see Berit Brogaard#Cognitive neuroscience), Martin F. Gardiner, John Kounios, Roi Cohen Kadosh, John Georgiou in Toronto, Thomas Hills at the University of Warwick, Theodore W. Berger at the University of Southern California.

Erdös Number

Citation network path with Paul Erdös

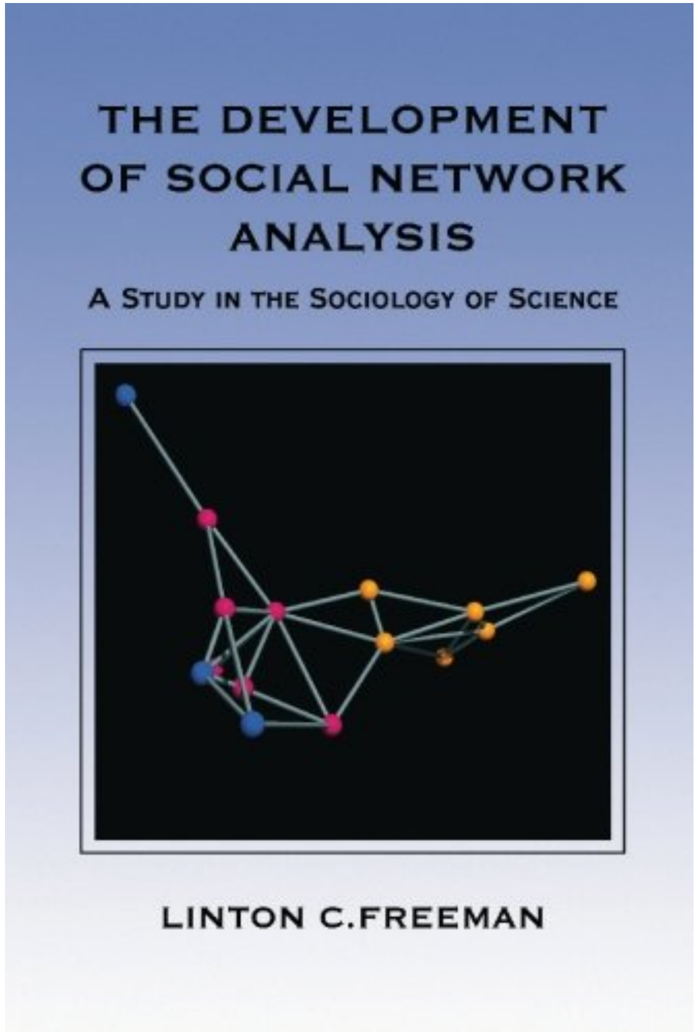
Paul Erdös wrote 1500 math papers, one of which is about Erdös-Renyi random graphs, which we will discuss tomorrow. Mathematicians like to compute their Erdös number.



We can apply network science to anything with structure (not just social networks)

A HISTORY OF SOCIAL NETWORK ANALYSIS

- "Motivated on structural intuition based on ties linking social actors"
- "Grounded in systematic empirical data"
- "Draws heavily on graphic imagery"
- "Relies on use of mathematical and computational models"

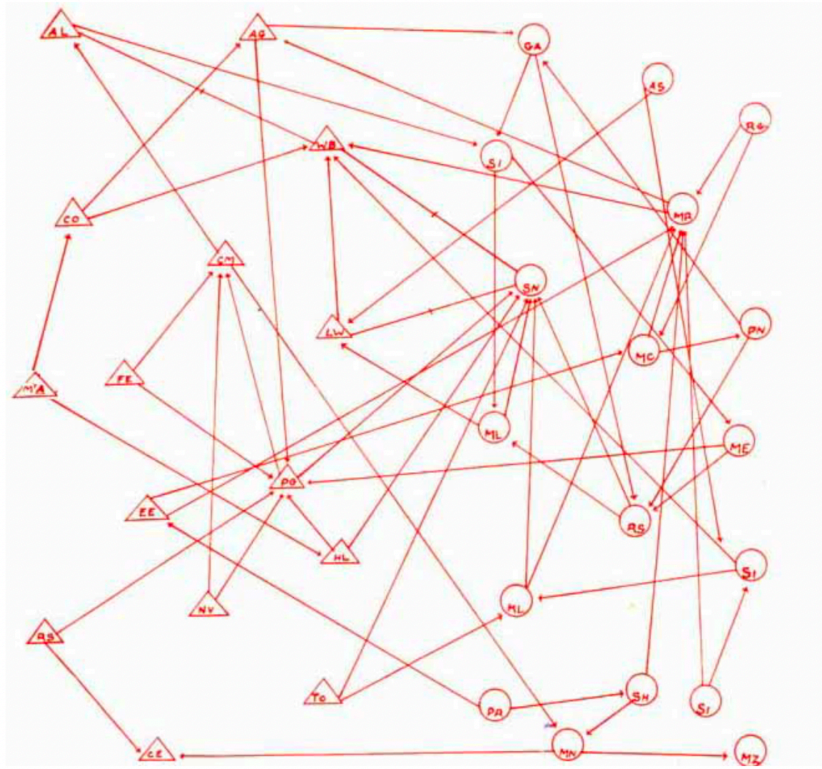


Network science originated in sociology and mathematics independently — which often means we have multiple names for the same thing (nodes/vertices, edges/links)

JACOB LEVY MORENO'S SOCIOGRAMS (WITH HELEN HALL JENNINGS)

Moreno, J. L. (1934). *Who shall survive?: A new approach to the problem of human interrelations.* Nervous and Mental Disease Publishing Co.

Introduction to sociometry… introduced the term "network" in the sense used today…"effects beyond the two persons and the immediate group"…

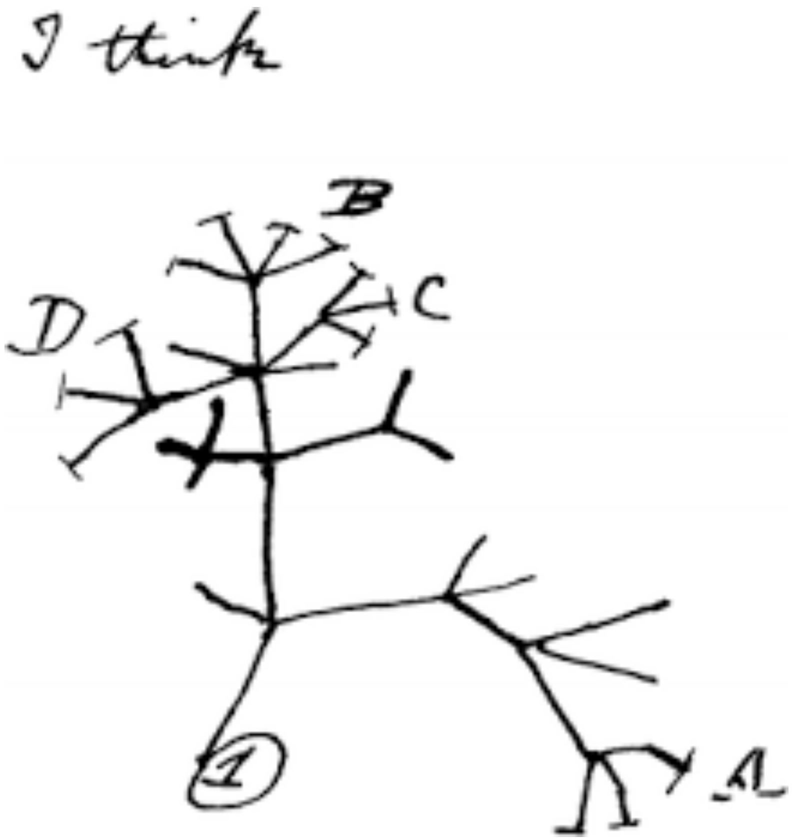


STRUCTURE OF A KINDERGARTEN

15 boys and 18 girls. *Unchosen* 9, RS, NV, FE, MA, TO, AS, RG, SI, PR; Pairs 3, AL-WB, WB-SN, SN-LW; *Stars,* (Centers of Attractions), PG, SN, MR; *Chains* (of relationships), 0; *Triangles,* 0; *Inter-sexual Attractions,* 19.

DARWIN

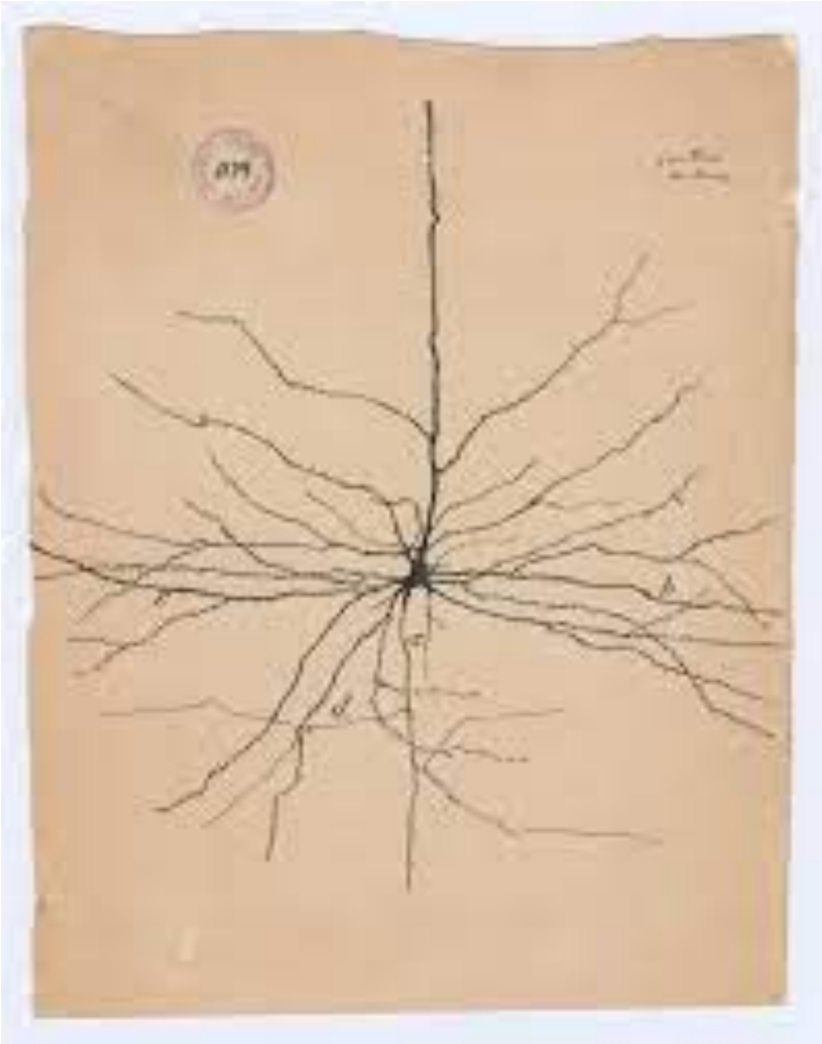
Biology/Relatedness

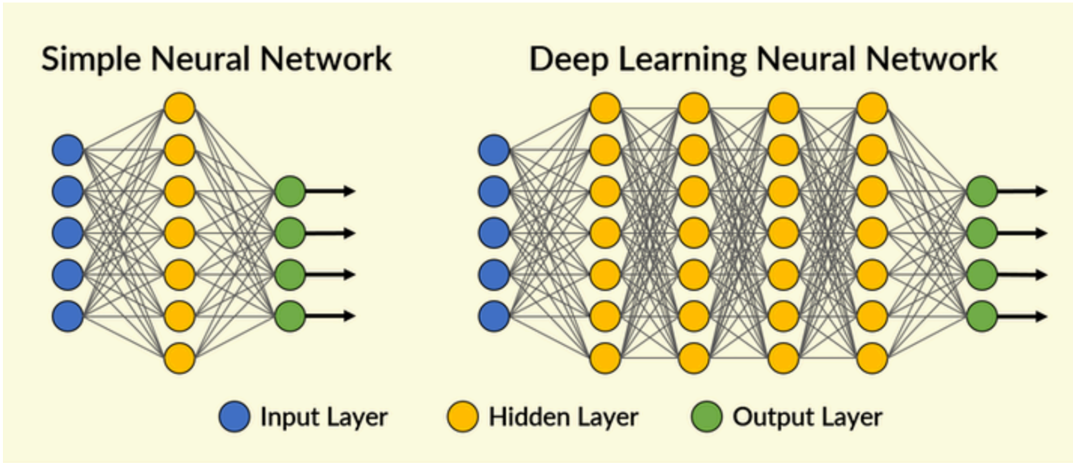


Theodosius Dobzhansky: "Nothing in biology makes sense except in the light of evolution."

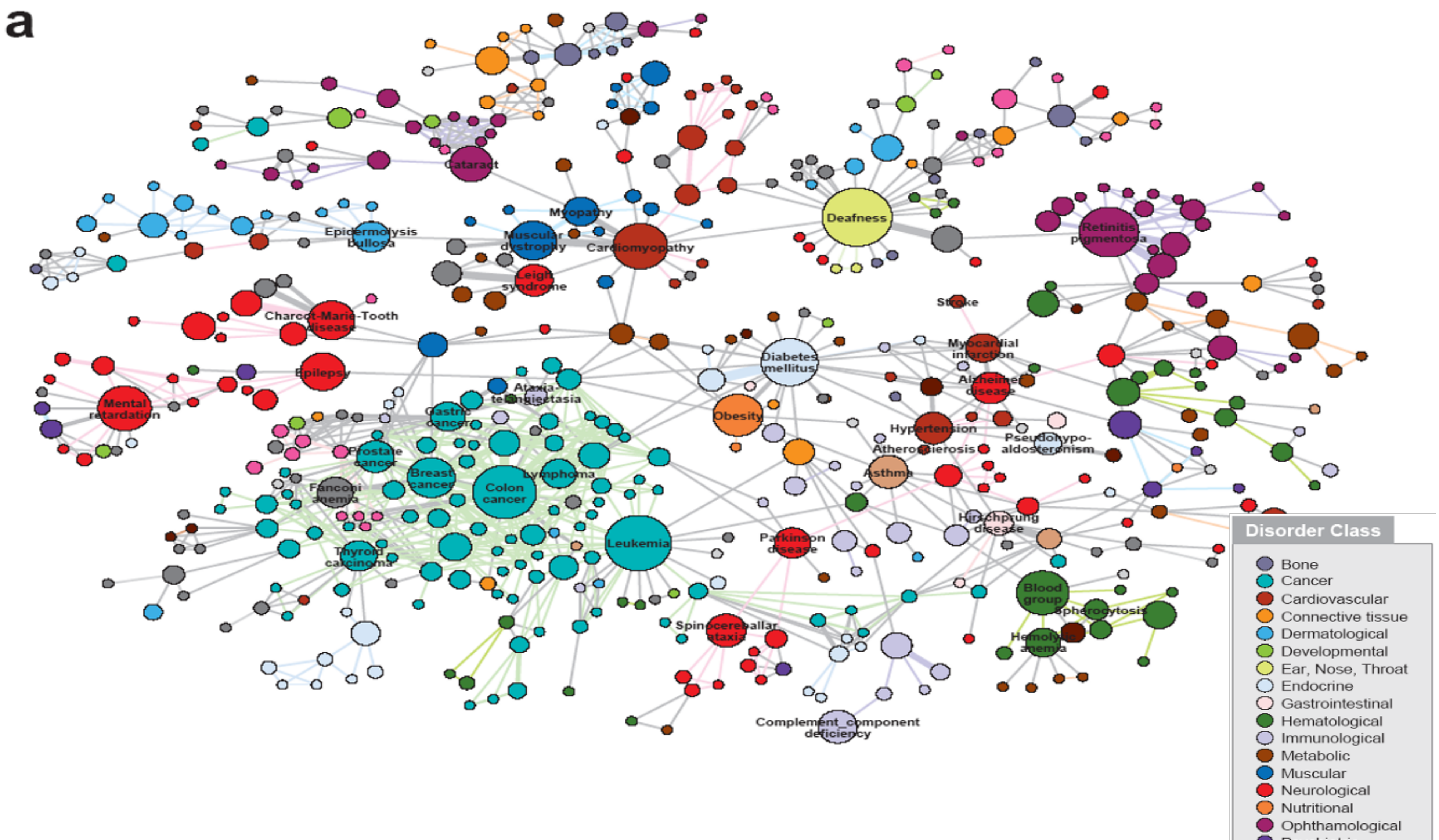
RAMON Y CAJAL

With repeated learning, such networks encode information in their structure





HUMAN DISEASE NETWORKS BASED ON SHARED GENES



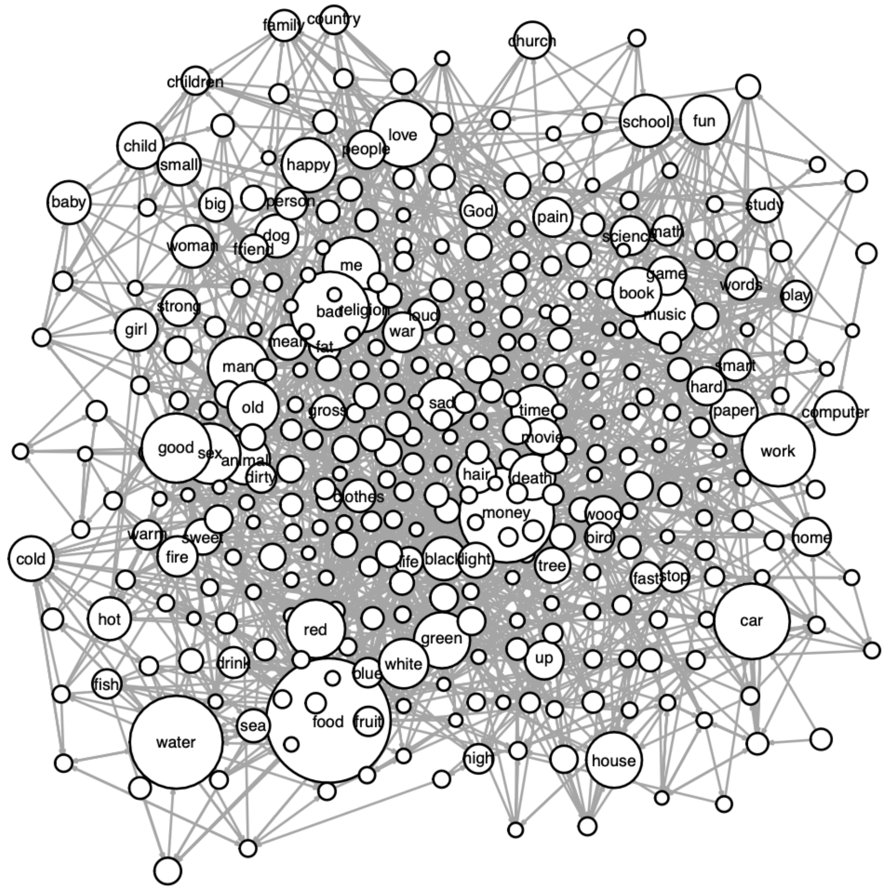
The size of each node is proportion to the number of genes contributing to the disease and the width of the edge represents shared genes

FERDINAND DE SAUSSURE

Linguistics/language/associations/concepts/beliefs

- Relationality: signs just gain their meaning from their relations with other terms

John Firth: “You shall know a word by the company it keeps.”



Some examples of why we should care about structure?

Structure can tell us what kinds of systems we’re dealing with.

Why is this social network so disconnected?

- Krebs (2002) mapped the network structure of the 9/11 terrorist cells---identifying each individual and the relationships among them.

- What he observed was peculiar for a social network. The 19 hijackers had sparsely interacted. This is rare among social networks. Our friends' friends tend to become our friends. Close-knit groups form from like-minded individuals. And coordinated groups need coordinated communication.

- On the face of it, the structure of the terrorist cells lacked these features. Why?

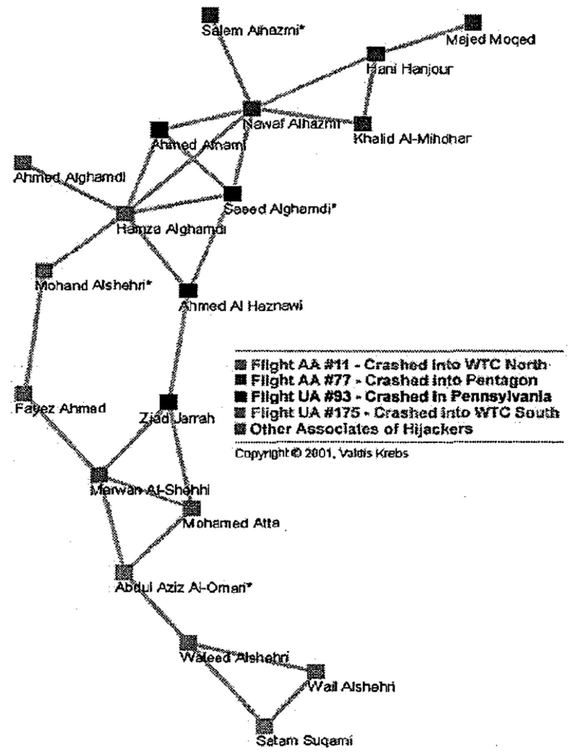


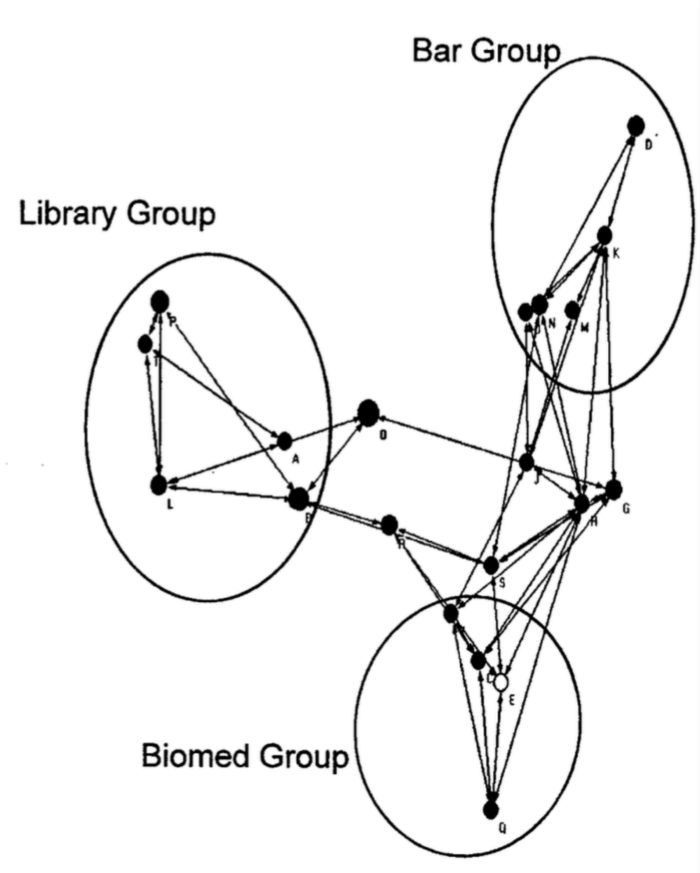
Figure 2 Trusted Prior Contacts

Social networks have a Behavioral Immune System

Structure can help us understand how to make systems better

How to successfully overwinter at the South Pole

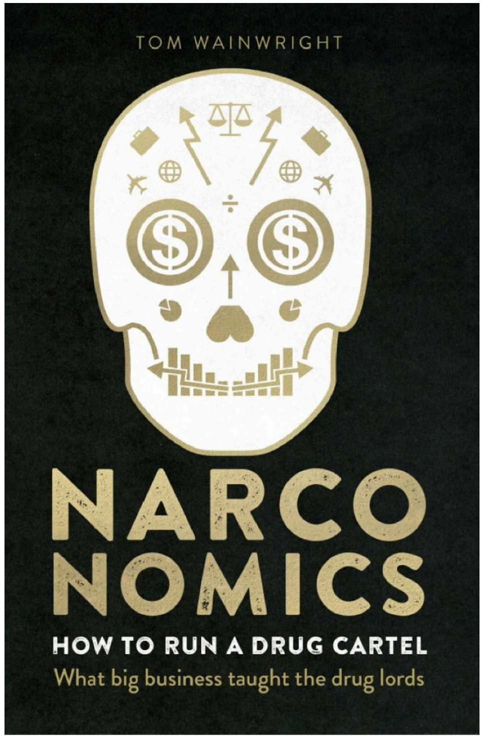
- Johnson et al. (2003)'s pioneering research on overwintering teams in the South Pole.
- These teams stayed 9 months inside small spaces with one another under harsh conditions.
- What holds communities together?
- Expressive leaders—coordinated social interactions to help keep the communities connected.
- Positive deviant—i.e., the clown — violated social boundaries and therefore kept the communities connected.



Unhappy Group C: The lowest coherence and lowest agreed expressive leadership and positive deviants.

Structure can help us predict what’s important and why

What made Juarez the murder capital of the world from 2008-2011?

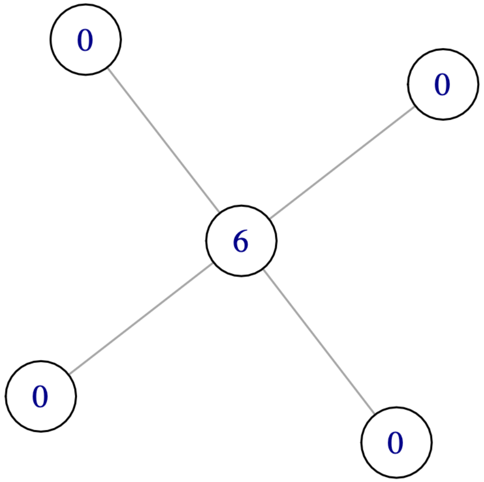


Why is this location important?

Betweenness

Drugs pass through Juarez. The Juarez and Sinaloa cartels began fighting over control of this border because President Calderon led a crackdown on cartels that destabilized the Juarez cartel, which in turn led El Chapo and the Sinaloa to try and take control.

What made Juarez the murder capital of the world from 2008-2011?



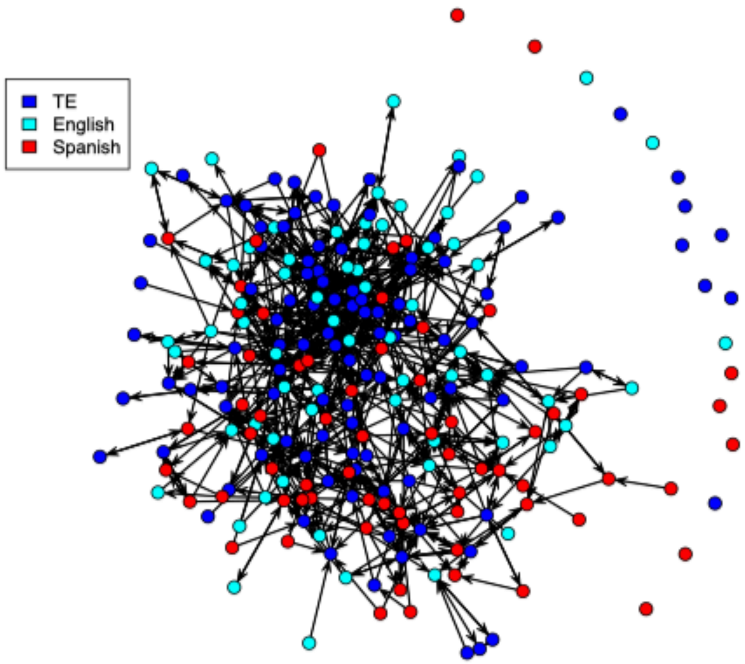
Why is this location important?

Betweenness

Drugs pass through Juarez. The Juarez and Sinaloa cartels began fighting over control of this border because President Calderon led a crackdown on cartels that destabilized the Juarez cartel, which in turn led El Chapo and the Sinaloa to try and take control.

Structure can help us understand process

How do bilingual first language learners learn languages?



Bilingual first language learners

TE: translational equivalent

Study of 181 bilingual first language learners learning two languages at once.

We developed a model to understand how monolingual language learners learned languages.

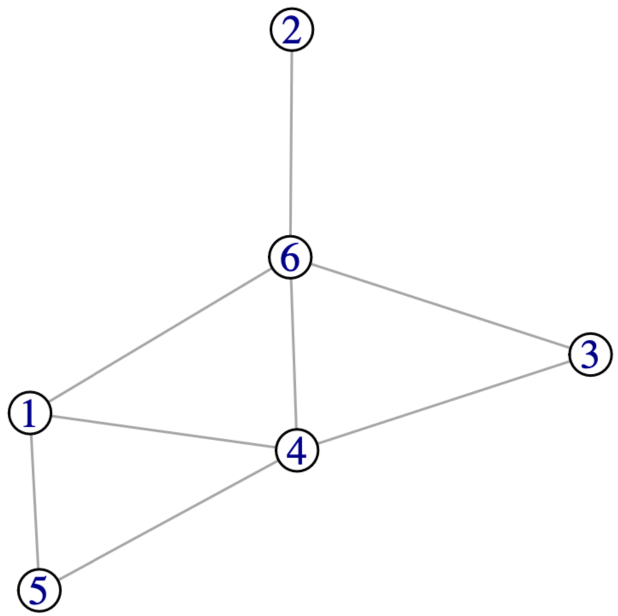
Then we asked how bilinguals were different from a monolingual learning two independent languages at once.

Result: Semantic facilitation

Bilson et al., 2015

Every structure has a process story

Network Basics



A basic network

Nodes and Edges

- What are nodes/vertices?
- What are edges/links?
- Think about this for a system that's important to you.

Some examples of nodes and edges

Table 1: Examples of cognitive networks and their cognitive application.

Cognitive Network	Nodes	Edges	Relevant research areas
Semantic network	Words	Semantic relationships, including free associations, shared features, taxonomic, cooccurrence, semantic roles	Language acquisition; cognitive aging; semantic priming; creativity/insight; cognitive search and navigation; semantic memory
Form similarity network	Words	Phonological or orthographic similarity	Lexical retrieval; production; speech errors; memory recall; word learning
Syntactic network	Words; phrases; sentences	Cooccurrence; parse trees; syntactic dependencies	Language acquisition; language evolution; syntactic learning
Concept network	Concepts; ideas	Cooccurrence; causal; feature similarity	Learning; memory; concept formation
Informational network	Shapes; pictures; any unit of information	Temporal cooccurrence; communication; transmission	Statistical learning of external structure; information transmission
Clinical, personality networks	Symptoms; personality traits; items on a questionnaire	Statistical relationship such as partial correlations; comorbidity	Clinical psychopathology; personality disorders
Social network	People	Friendship; followers on social media; face to face interactions	Collective problem solving; decision making; echo chambers; polarization

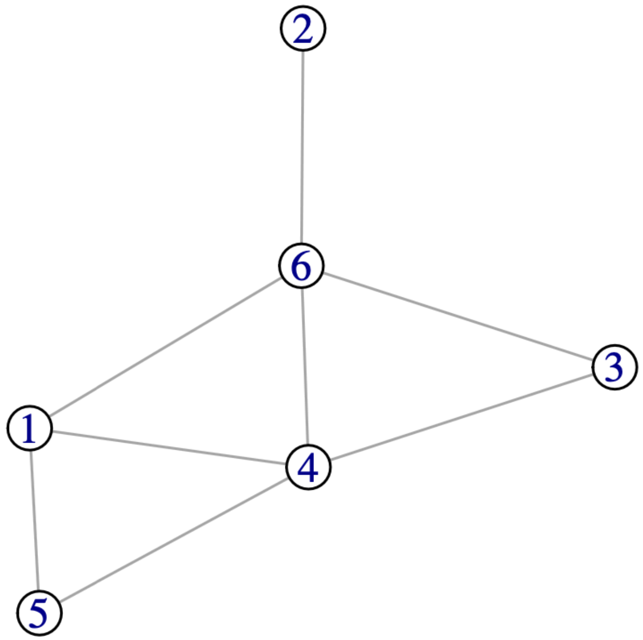
There are many more.

Siew et al., 2019

Representing a simple network

Edge list

V1	V2
1	4
3	4
1	5
4	5
1	6
2	6
3	6
4	6



Representing a simple network

Edge list

V1	V2
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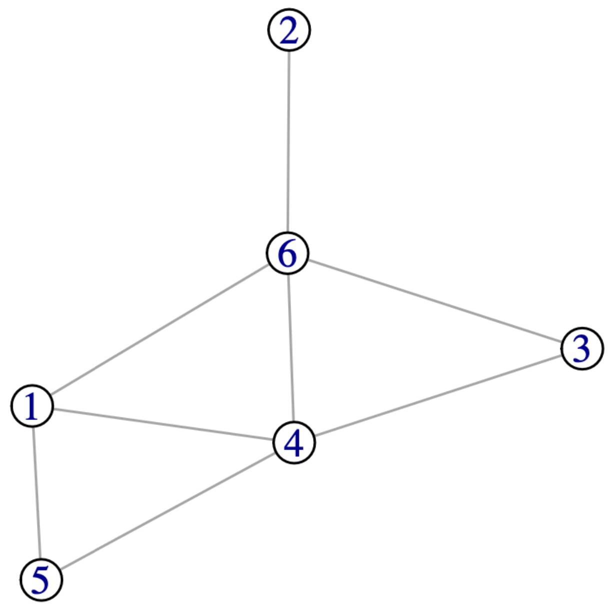
3	4
1	5
4	5
1	6
2	6
3	6
4	6



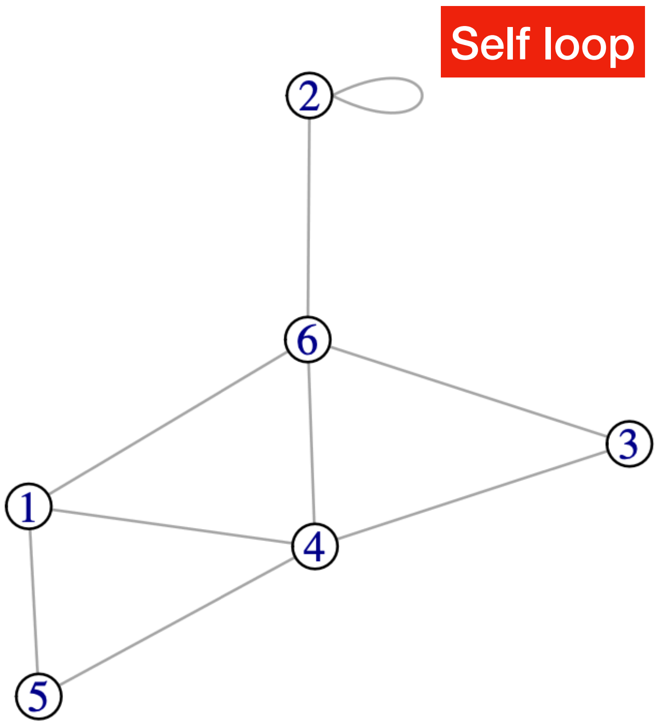
Adjacency Matrix

	1	2	3	4	5	6
1	0	0	0	1	1	1
2	0	0	0	0	0	1
3	0	0	0	1	0	1
4	1	0	1	0	1	1
5	1	0	0	1	0	0
6	1	1	1	1	0	0

These both contain all the information we need to construct this network.

Self-loops

Self-loops are connections from a node to itself



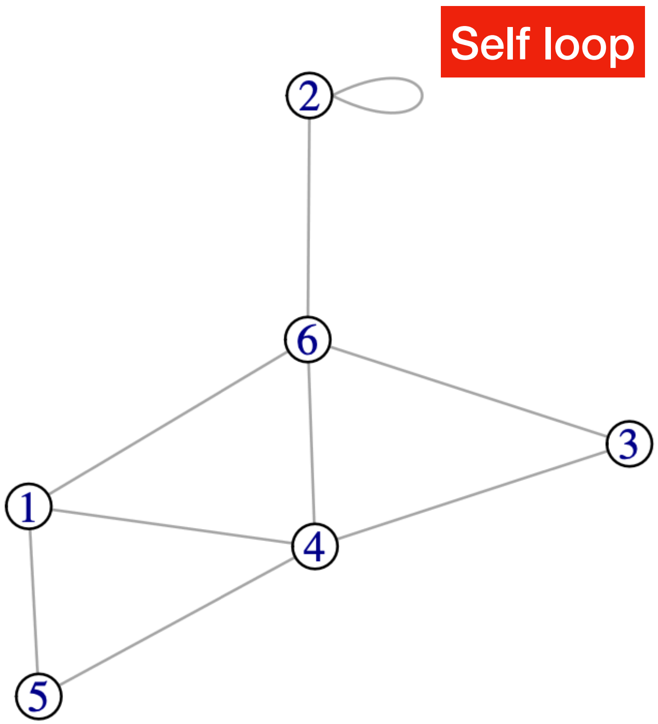
	1	2	3	4	5	6
1	0	0	0	1	1	1
2	0	1	0	0	0	1
3	0	0	0	1	0	1
4	1	0	1	0	1	1
5	1	0	0	1	0	0
6	1	1	1	1	0	0

Diagonal

What might self-loops be good for?

Self-loops

Self-loops are connections from a node to itself



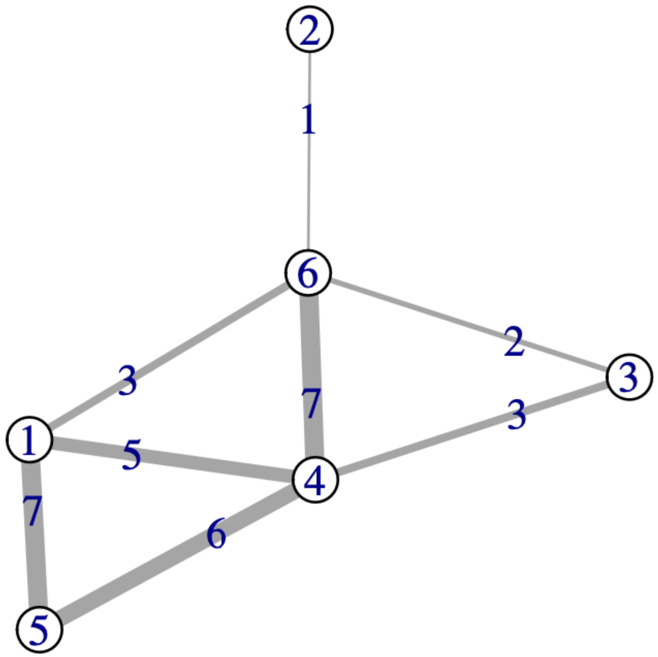
	1	2	3	4	5	6
1	0	0	0	1	1	1
2	0	1	0	0	0	1
3	0	0	0	1	0	1
4	1	0	1	0	1	1
5	1	0	0	1	0	0
6	1	1	1	1	0	0

Diagonal

What might self-loops be good for?

Imagine we all bring cake to share, but some people eat their own cake.

Weighted Networks



Adjacency Matrix

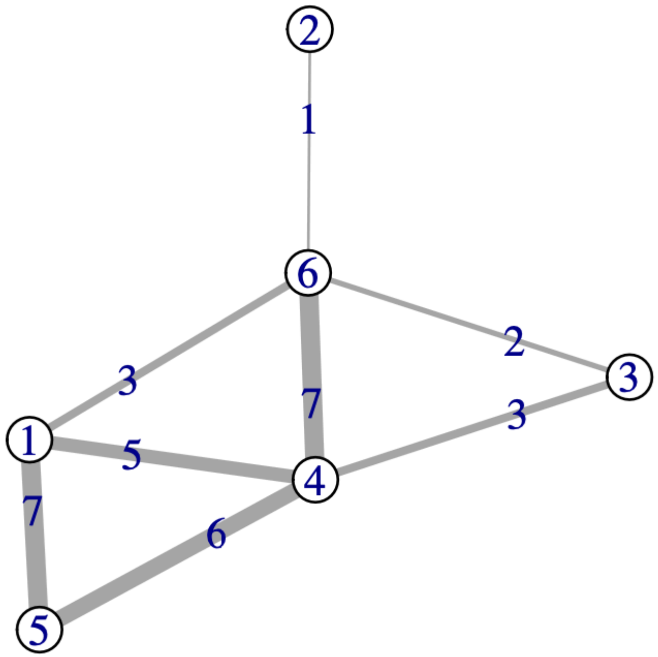
	1	2	3	4	5	6
1	0	0	0	5	7	3
2	0	0	0	0	0	1
3	0	0	0	3	0	2
4	5	0	3	0	6	7
5	7	0	0	6	0	0
6	3	1	2	7	0	0

Edge list

V1	V2	weight
1	4	5
3	4	3
1	5	7
4	5	6
1	6	3
2	6	1
3	6	2
4	6	7

What can weights represent?

Weighted Networks



Adjacency Matrix

	1	2	3	4	5	6
1	0	0	0	5	7	3
2	0	0	0	0	0	1
3	0	0	0	3	0	2
4	5	0	3	0	6	7
5	7	0	0	6	0	0
6	3	1	2	7	0	0

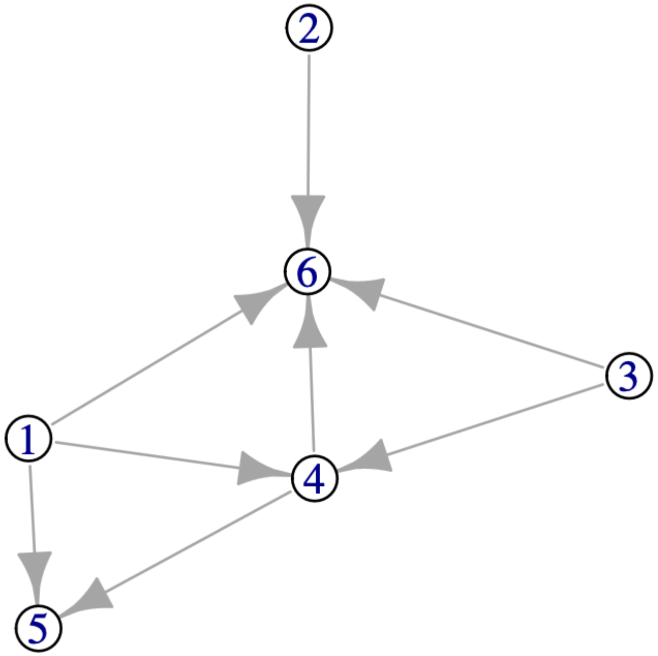
Edge list

V1	V2	weight
1	4	5
3	4	3
1	5	7
4	5	6
1	6	3
2	6	1
3	6	2
4	6	7

What can weights represent?

How similar are two nodes. How old is the relationship. What is the relationship strength.

Directed Networks



Adjacency Matrix

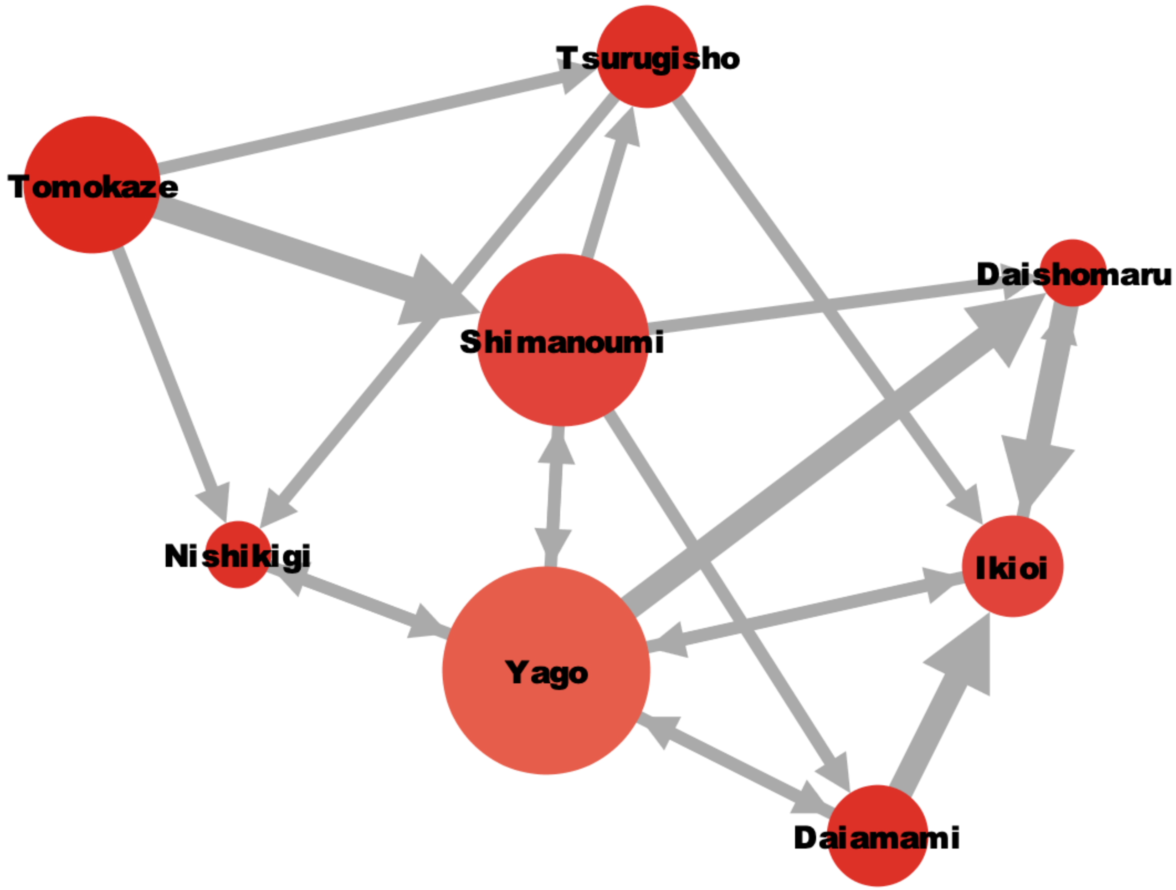
	1	2	3	4	5	6
1	0	0	0	1	1	1
2	0	0	0	0	0	1
3	0	0	0	1	0	1
4	0	0	0	0	1	1
5	0	0	0	0	0	0
6	0	0	0	0	0	0

Edge list

V1	V2
1	4
3	4
1	5
4	5
1	6
2	6
3	6
4	6

Why does the directed edge mean?

Application of directed network

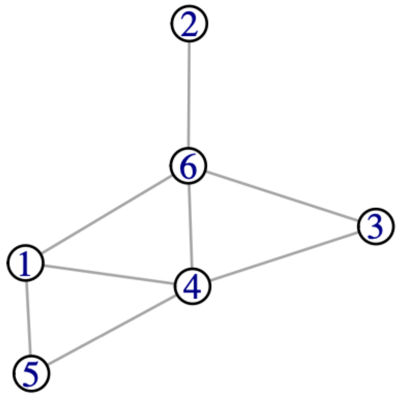


Arrows go from losers to winners

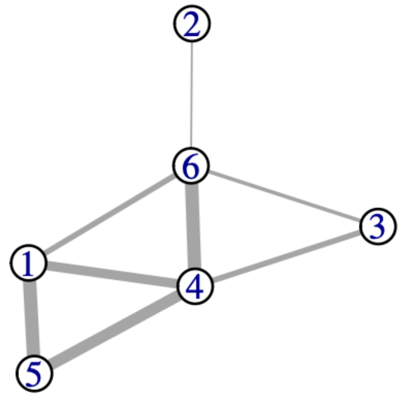
Data from Data.World Sumo Matches 2019

4 kinds of Networks

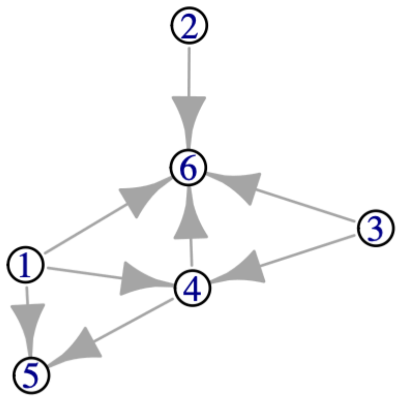
Simple: Unweighted, Undirected



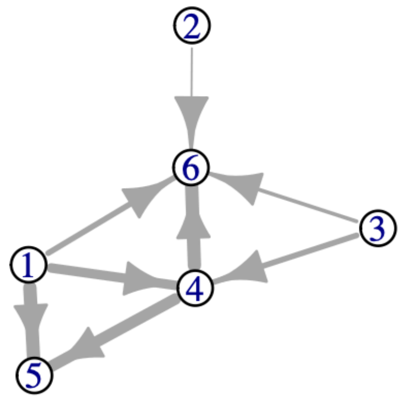
Weighted, Undirected



Directed, Unweighted



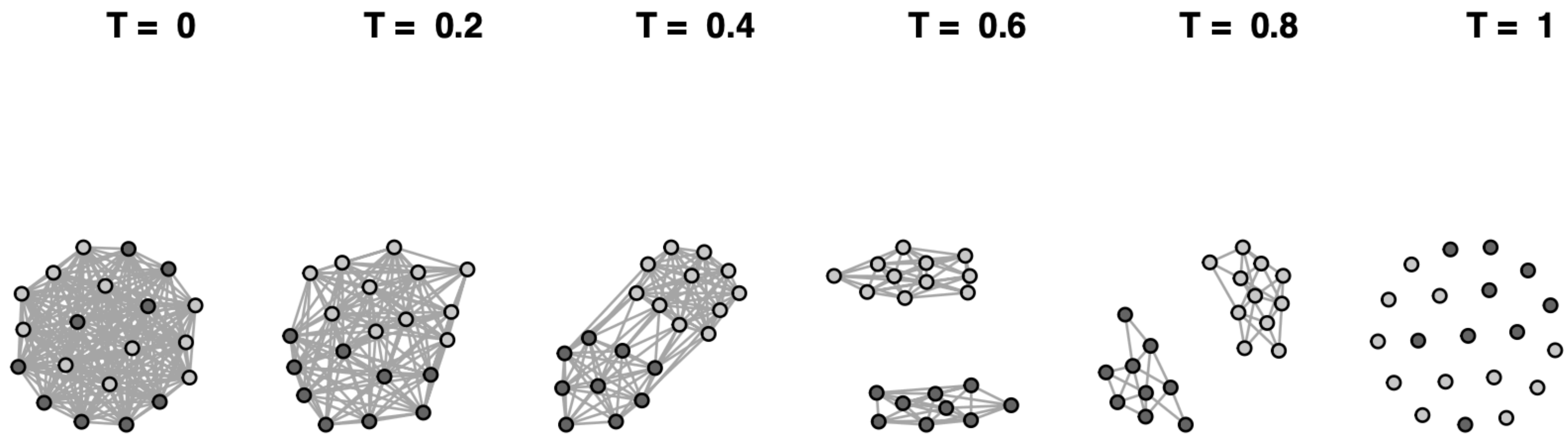
Weighted, Directed



- Often basic (undirected and unweighted) networks are easier to deal with.
- How can we transform a weighted and/or directed network into an unweighted and undirected network?

How to get a basic network from weighted data

- Apply a moving threshold. Keep edges above threshold.



Application of moving threshold to aging networks

- Apply a moving threshold. Keep edges above threshold.

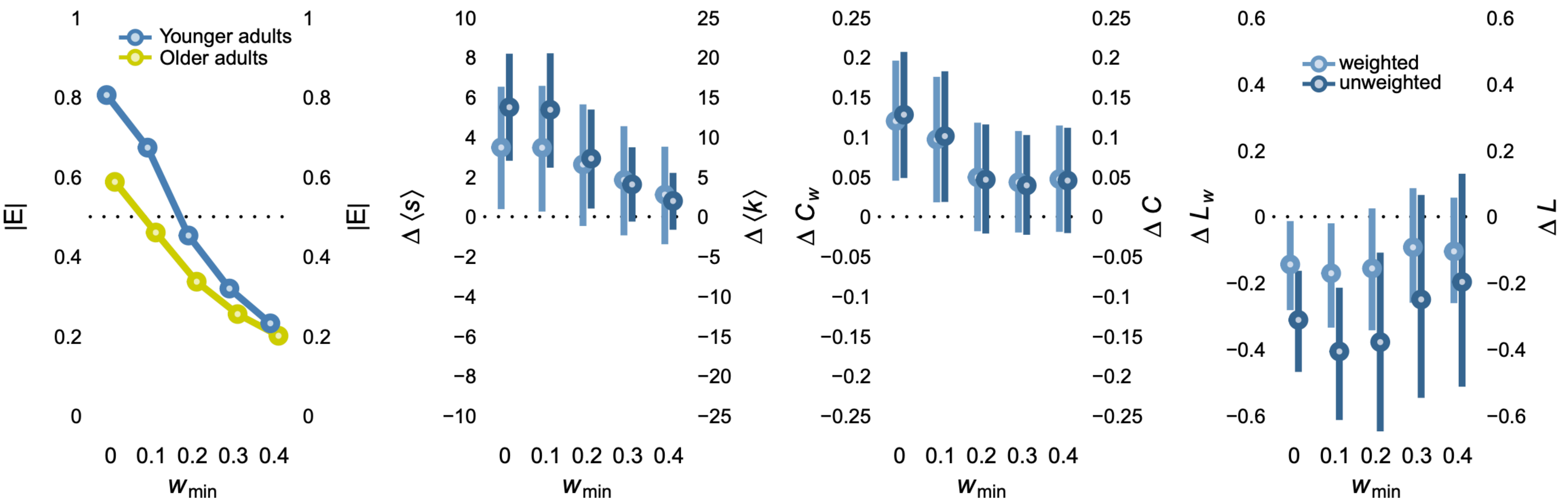


Figure 5. Differences in the macroscopic structure of younger and older adults' similarity rating networks. Blue and yellow circles, in panel 1, correspond to younger and older adults, respectively. In panels 2 to 4, light blue circles and dark blue circles correspond to differences between the younger and older adults' networks derived from weighted and unweighted networks, respectively. Error bars show 95% bootstrapped confidence intervals. Note: $|E|$ - Proportion of edges relative to fully-connected graph; $\Delta\langle s\rangle$, $\Delta\langle k\rangle$ - Differences in average strengths/degrees (unweighted); ΔC_w, ΔC - Difference in average clustering coefficients of weighted/unweighted networks; ΔL_w, ΔL - Difference in average shortest path lengths of weighted/unweighted networks.

How to get a simple network from a directed network

- Keep all edges or only reciprocal edges

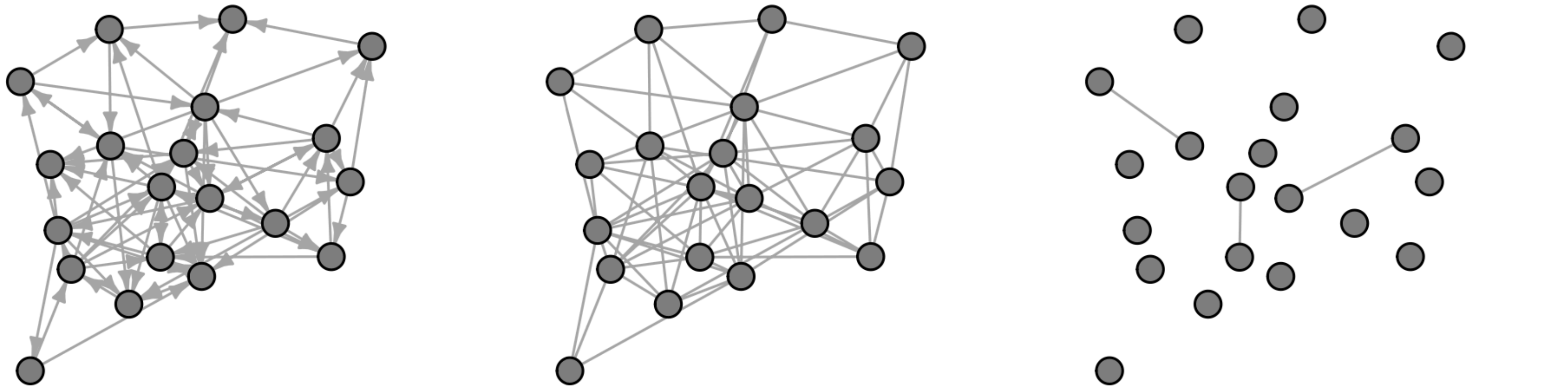
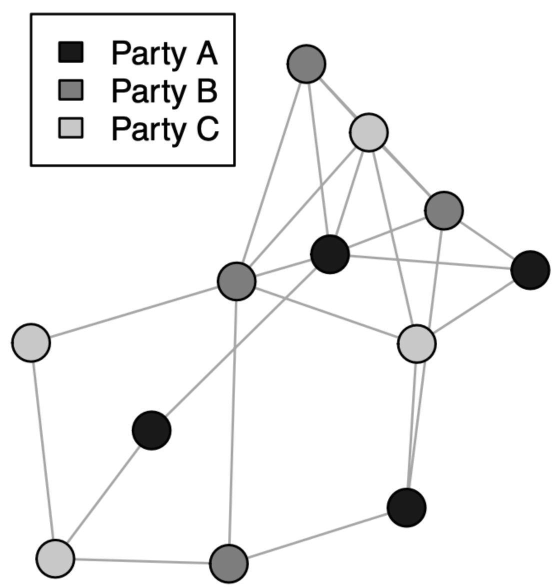


Figure 6: Thresholding directed networks. The network on the left shows the full directed network. The middle network transforms this into a simple, undirected network, making an edge wherever at least one node has a directed edge to the other. The network on the right only keeps reciprocal edges.

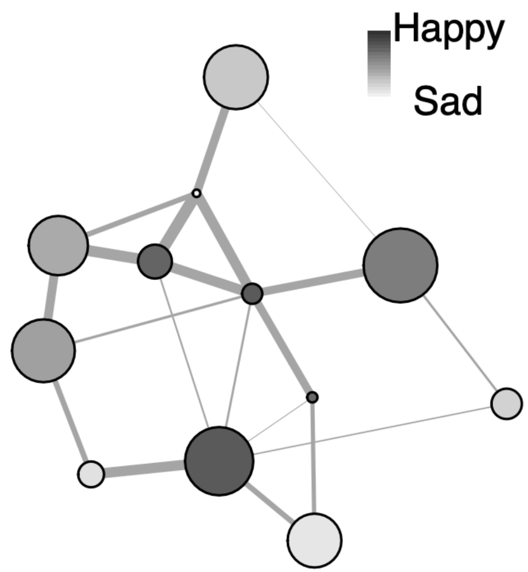
Node and edge attributes

Nodes and edges can have properties of their own

Political Party

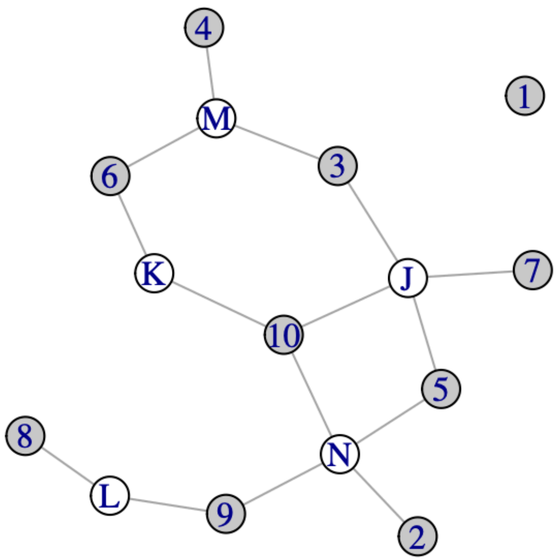


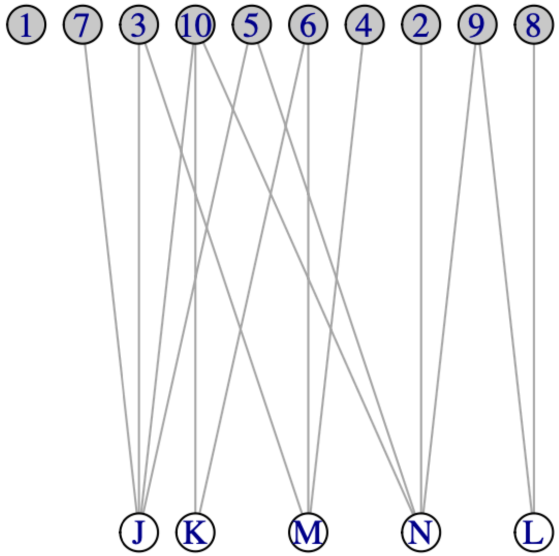
Age



Bipartite Networks

Bipartite networks have two kinds of nodes and nodes are only connected to nodes of other types.



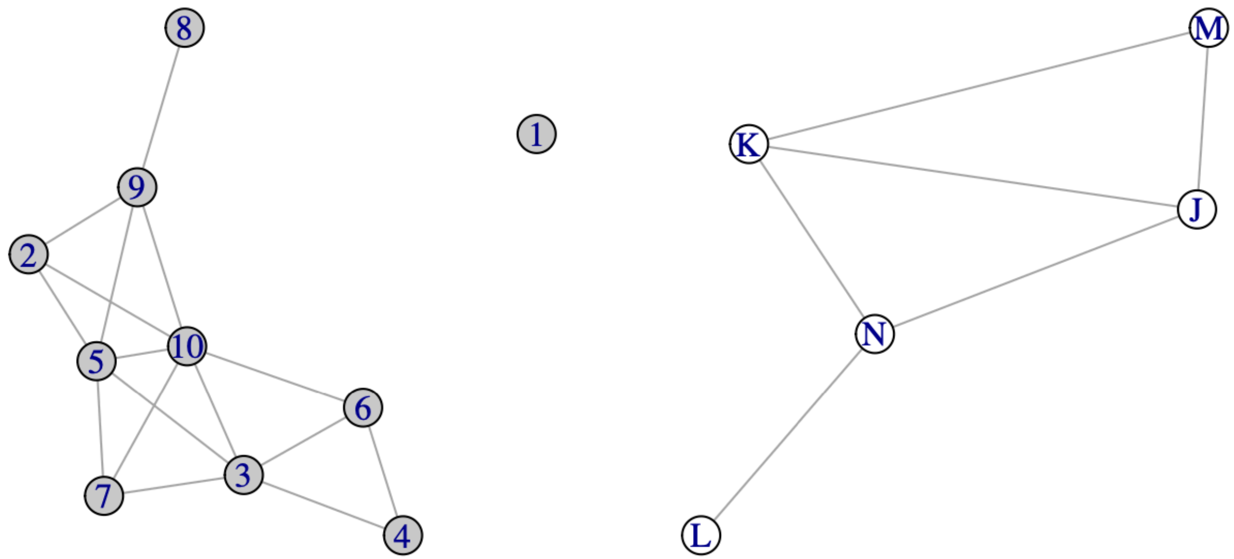


	J	K	L	M	N
1	0	0	0	0	0
2	0	0	0	0	1
3	1	0	0	1	0
4	0	0	0	1	0
5	1	0	0	0	1
6	0	1	0	1	0
7	1	0	0	0	0
8	0	0	1	0	0
9	0	0	1	0	1
10	1	1	0	0	1

Bipartite network

These two networks are the same (just visualized differently), and represented by the rectangular 'incidence' matrix on the right.

Bipartite Projections



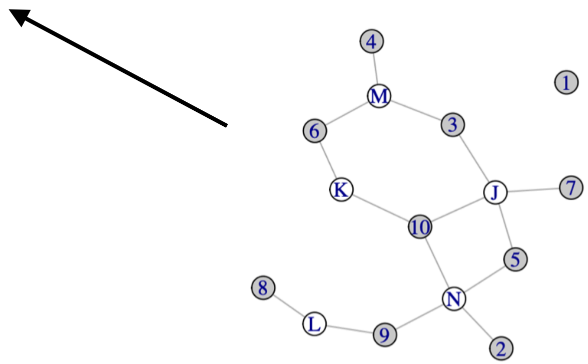


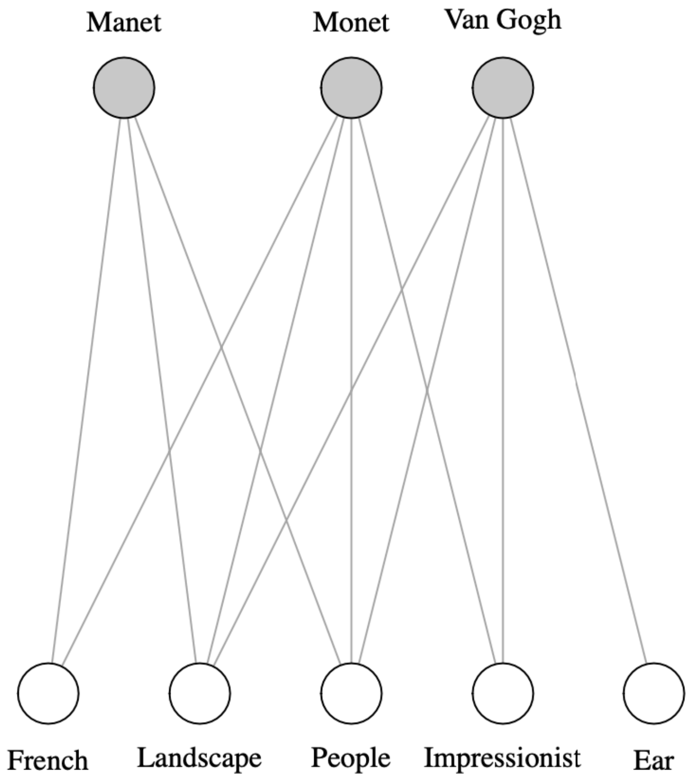
Figure 9: One-mode projections of the two-mode (bipartite) network.

Application of bipartite networks

Figure 1: Paintings from Manet (left), Monet (centre), Van Gogh (right)

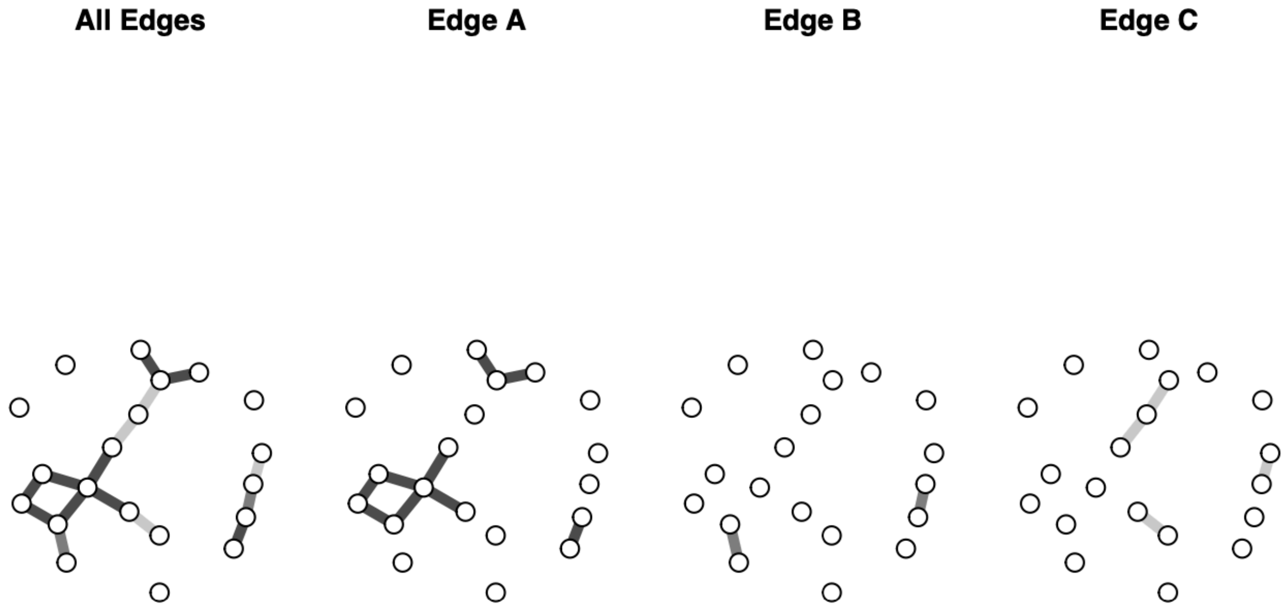
Table 1: A bipartite adjacency matrix with two node types: painters and features.

	French	Landscape	People	Ear	Impressionist
Manet	1	0.1	1.0	0	0
Monet	1	1.0	0.1	0	1
Van Gogh	0	1.0	0.1	1	1



Multiplex Networks

Contain edges of different kinds



Also called multilayer networks

Summary

- Structure matters in the behavioral sciences: Examples
- Network basics: How to turn data into networks, how to represent networks, different kinds of networks, how to simplify networks.