Overview of Complex Networks

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Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 6701, 6713, & a pretend number, 2023–2024| @pocsvox

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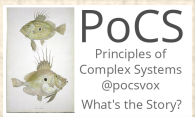
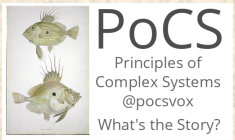
Computational Story Lab | Vermont Complex Systems Center
Santa Fe Institute | University of Vermont





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Outline


THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING BORDET YET MIRACULE
THE MISREADING OF THE BOOK OF SAND
THE MANY TALES OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POOLING DATA
THE CHARMS OF THE MANY WRING FAITH
THE DOORS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MANKS
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
It was the best of times,
THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
"I am the Monarch of the Sea."
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
CLASSIFIED PHOENIX BIO HAZARD
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
THE UNENDING PANDEMICS
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE RATIO OF GAIN
THE MECHANICS OF FAME
THE TALK OF FAME
THE STORIES CONTAGIOUS
THE JOHN DORY
THE ADJACENT NARRATIVES
THE STORYTELLERS
THE FATED OPTIMAL PATH
THE PATHS OF UNIVERSALITY
THE DEPENDENT PATHS
THE TROUBLES OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
THE LANDSCAPE OF FORKING PATHS
THE NETWORKS OF BLOOD
THE TREES OF REALITY
THE ORDERS OF STREAMS
THE LAWS OF BRANCHING
THE SCALING OF BROKEN HIERARCHIES
THE BRAID OR THE BRANCH
THE LAW OF OPTIMAL FORKS
THE CHURCH OF QUARTEROLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILL-SCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM SUM OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS
THE OVERCOMING OF CATASTROPHE
THE TROUBLES ILL-FORMED
THE NETWORKS OF MANY ILKS
THE CHAOS OF FETTERED CONTAGION
THE END
THE NETWORKS COMPLEX

Outline

net•work |ˈnetˌwərk|

noun

1 an arrangement of intersecting horizontal and vertical lines.

- a complex system of roads, railroads, or other transportation routes *: a network of railroads.*

2 a group or system of interconnected people or things *: a trade network.*

- a group of people who exchange information, contacts, and experience for professional or social purposes *: a support network.*
- a group of broadcasting stations that connect for the simultaneous broadcast of a program *: the introduction of a second TV network* | [as adj.] *network television.*
- a number of interconnected computers, machines, or operations *: specialized computers that manage multiple outside connections to a network* | *a local cellular phone network.*
- a system of connected electrical conductors.

verb [trans.]

connect as or operate with a network *: the stock exchanges have proven to be resourceful in networking these deals.*

- link (machines, esp. computers) to operate interactively : [as adj.] (**networked**) *networked workstations.*
- [intrans.] [often as n.] (**networking**) interact with other people to exchange information and develop contacts, esp. to further one's career *: the skills of networking, bargaining, and negotiation.*

Thesaurus deliciousness:

network

noun

1 *a network of arteries* WEB, lattice, net, matrix, mesh, crisscross, grid, reticulum, reticulation; Anatomy plexus.

2 *a network of lanes* MAZE, labyrinth, warren, tangle.

3 *a network of friends* SYSTEM, complex, nexus, web, webwork.

Ancestry:

From Keith Briggs's excellent etymological investigation:

- Opus reticulatum:
- A Latin origin?

[http://serialconsign.com/2007/11/we-put-net-network]

Ancestry:

First known use: Geneva Bible, 1560

‘And thou shalt make unto it a grate like networke of brass (Exodus xxvii 4).’

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- 1914–: wireless broadcasting networks

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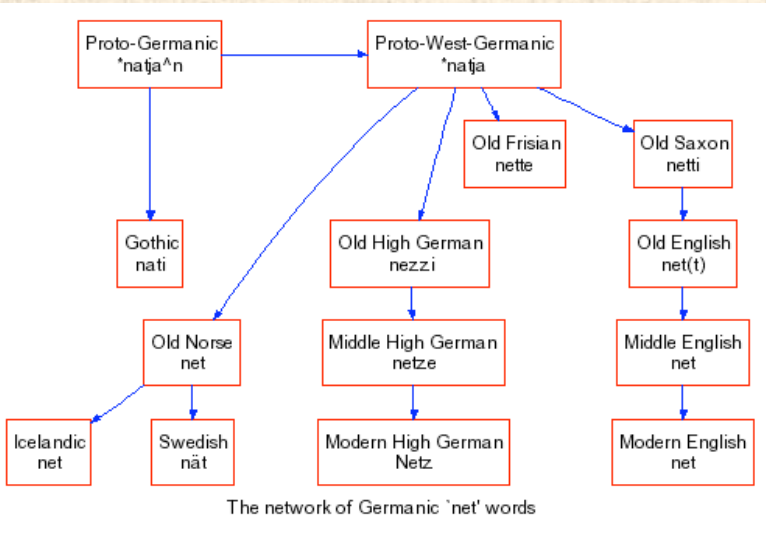
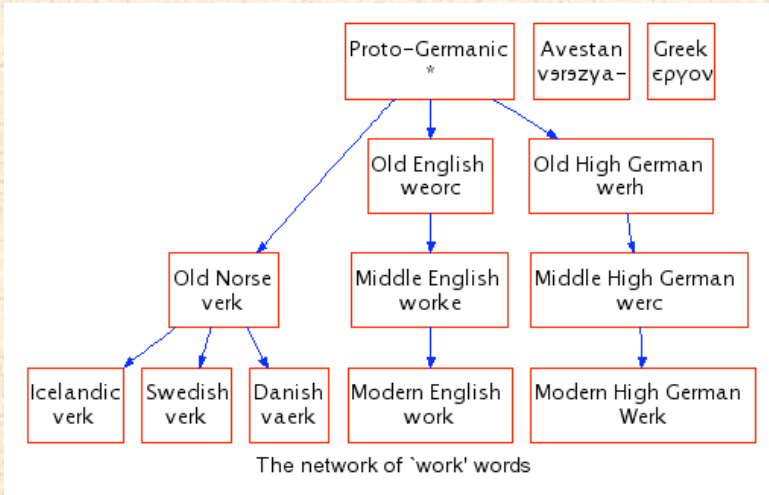
Net and Work are venerable old words:

- ‘Net’ first used to mean spider web (King Ælfréd, 888).
- ‘Work’ appear to have long meant purposeful action.



The network of Germanic `net' words



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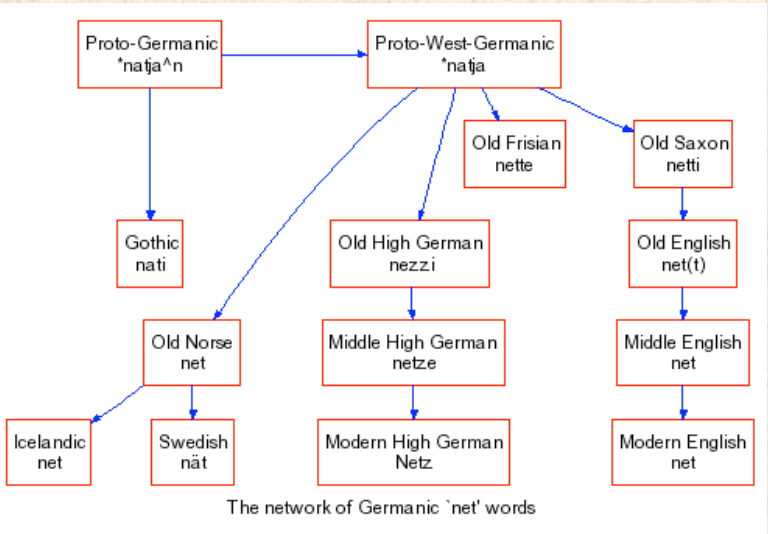

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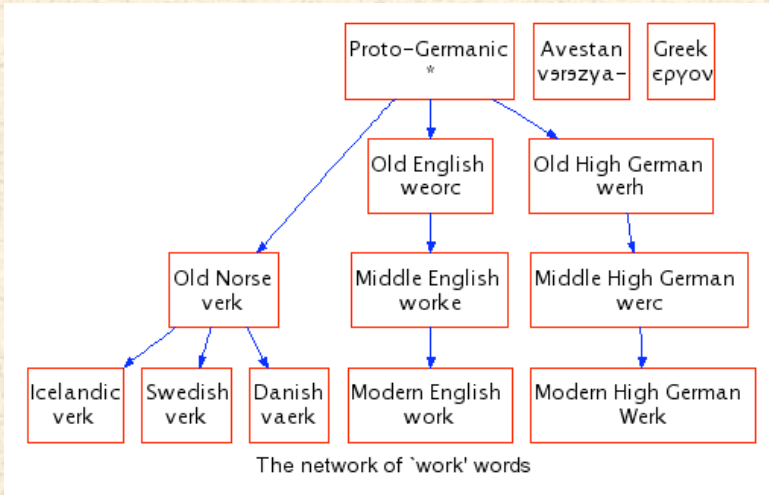

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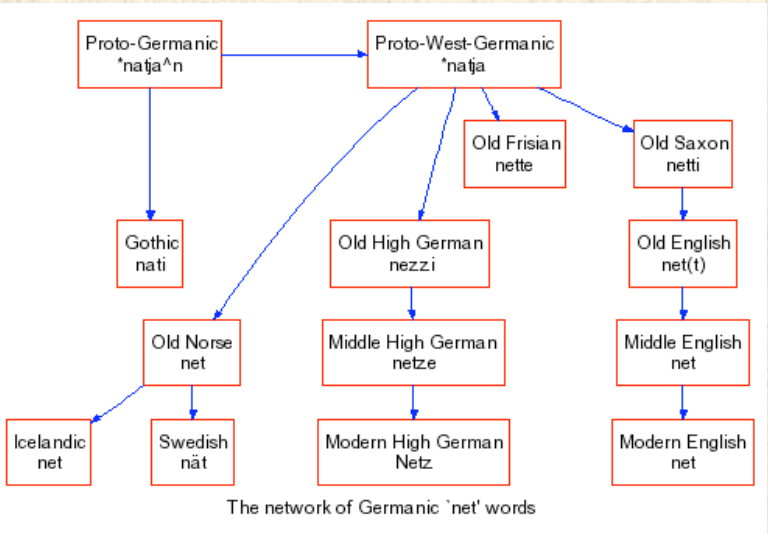

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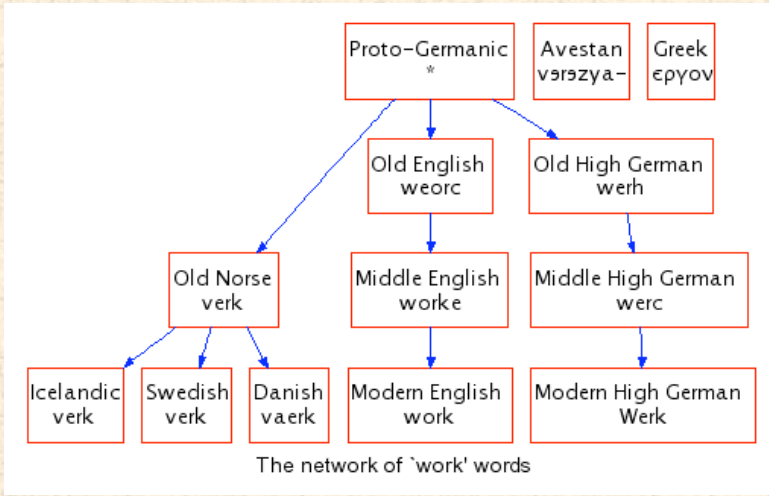

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- c.f., ironwork, stonework, fretwork.

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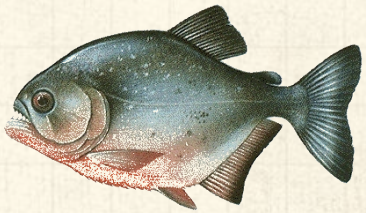

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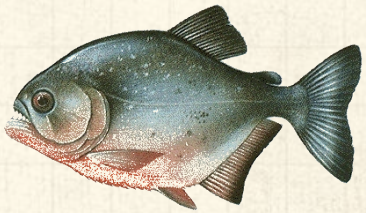

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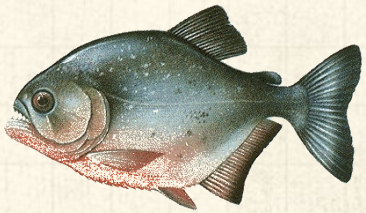

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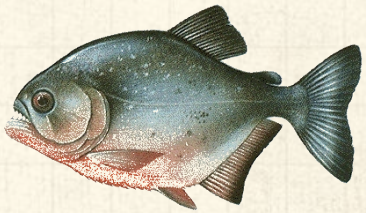

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- See also: https://xkcd.com/793/

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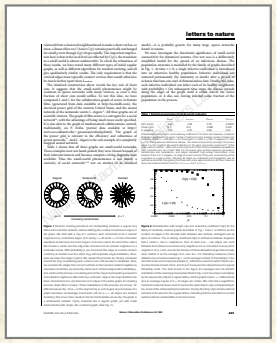

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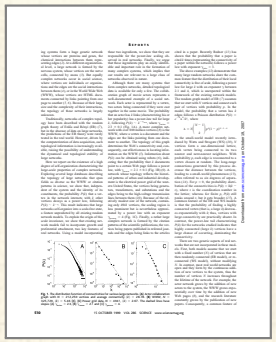

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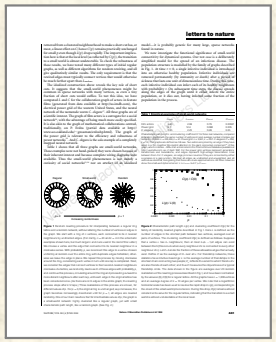

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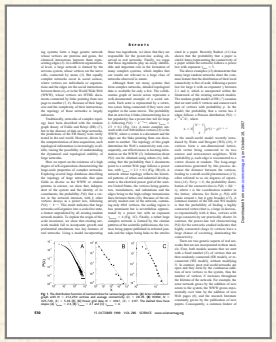

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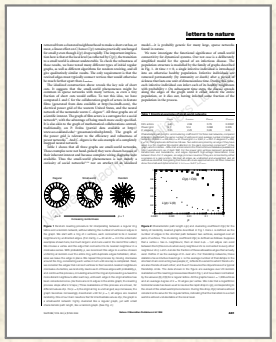

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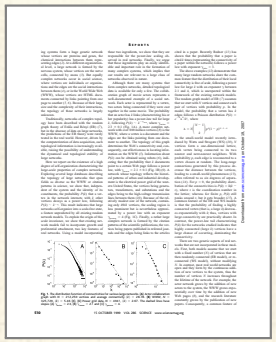


"Emergence of scaling in random networks"
Barabási and Albert,
Science, **286**, 509–511, 1999. [2]

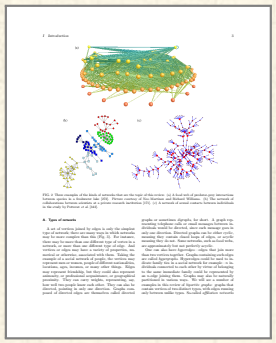
Times cited: $\sim 32,093$ (as of October 24, 2018)

Review articles:

"Complex Networks: Structure and Dynamics"

Boccaletti et al.,
Physics Reports, **424**, 175–308, 2006. [3]

Times cited: ~ 8,533 (as of October 24, 2018)



"The structure and function of complex networks"

M. E. J. Newman,
SIAM Rev., **45**, 167–256, 2003. [12]

Times cited: ~ 17,782 (as of October 24, 2018)

"Statistical mechanics of complex networks"

Albert and Barabási,
Rev. Mod. Phys., **74**, 47–97, 2002. [1]

Times cited: ~ 20,531 (as of October 24, 2018)

Popularity according to textbooks:

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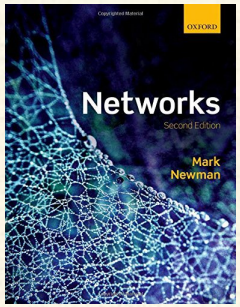
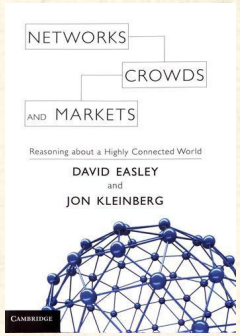


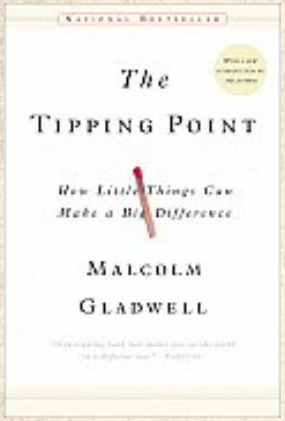
"Networks"
by Mark Newman (2018). [11]



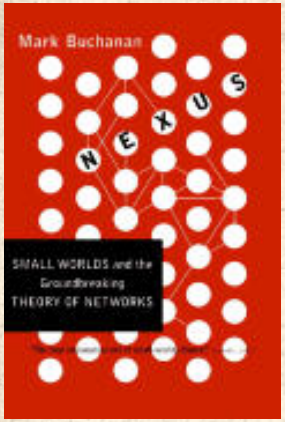
"Networks, crowds, and markets: Reasoning about a highly connected world"
by Easley and Kleinberg (2010). [7]

http://cs.cornell.edu/home/kleinber/networks-book/

Popularity according to books:



The Tipping Point: How Little Things can make a Big Difference—Malcolm Gladwell [8]



Nexus: Small Worlds and the Groundbreaking Science of Networks—Mark Buchanan

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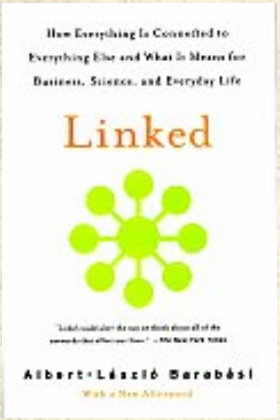
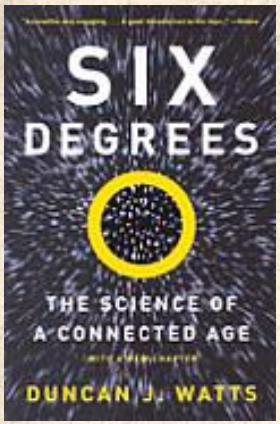


Linked: How Everything Is Connected to Everything Else and What It Means—Albert-Laszlo Barabási



Six Degrees: The Science of a Connected Age—Duncan Watts [15]

Numerous others ...

- Complex Social Networks—F. Vega-Redondo [14]
- Fractal River Basins: Chance and Self-Organization—I. Rodríguez-Iturbe and A. Rinaldo [13]
- Random Graph Dynamics—R. Durette
- Scale-Free Networks—Guido Caldarelli
- Evolution and Structure of the Internet: A Statistical Physics Approach—Romu Pastor-Satorras and Alessandro Vespignani
- Complex Graphs and Networks—Fan Chung
- Social Network Analysis—Stanley Wasserman and Kathleen Faust
- Handbook of Graphs and Networks—Eds: Stefan Bornholdt and H. G. Schuster [5]
- Evolution of Networks—S. N. Dorogovtsev and J. F. F. Mendes [6]

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More observations

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**If this is upsetting, maybe string theory is for you ...*

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- We still need to understand.

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Links = Connections between nodes

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- e.g., people, forks in rivers, proteins, webpages, organisms, ...

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Other spiffing words: vertices and edges.

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- Defn: $\mathcal{N}_i$ = the set of i's k_i neighbors

Super Basic definitions

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- We represent a directed network by a matrix A with link weight a_{ij} for nodes i and j in entry (i, j).

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- (n.b., for numerical work, we always use sparse matrices.)

Examples

So what passes for a complex network?

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- Complex networks are large (in node number)

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- Complex networks are large (in node number)
- Complex networks are sparse (low edge to node ratio)
- Complex networks are usually dynamic and evolving
- Complex networks can be social, economic, natural, informational, abstract, ...

Outline

Complex Networks Basics
Etymology
Popularity
Graph theory?
Basic definitions

Examples of Complex Networks
Physical networks
Interaction networks
Relational networks

References

Examples

Physical networks

- River networks

Examples

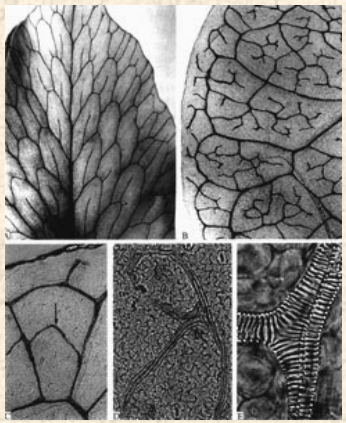
Physical networks

- River networks
- Neural networks

Examples

Physical networks

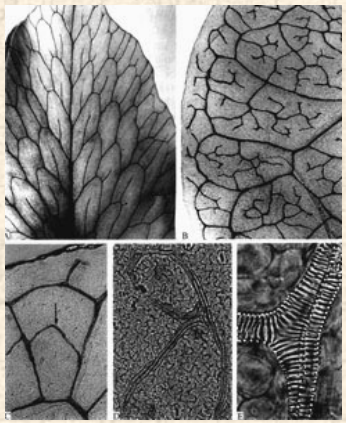
- River networks
- Neural networks
- Trees and leaves



Examples

Physical networks

- River networks
- Neural networks
- Trees and leaves
- Blood networks



Examples

Physical networks

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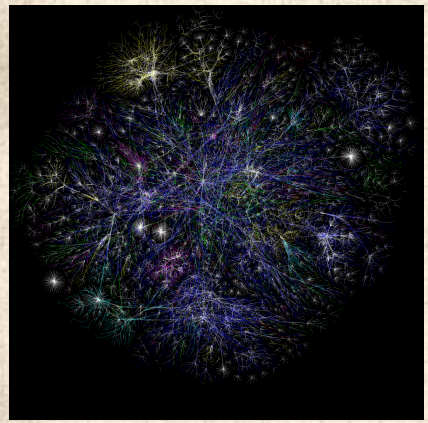

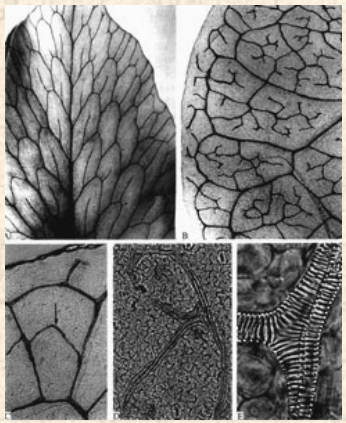

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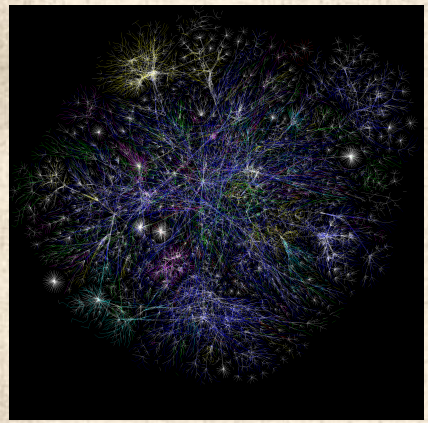

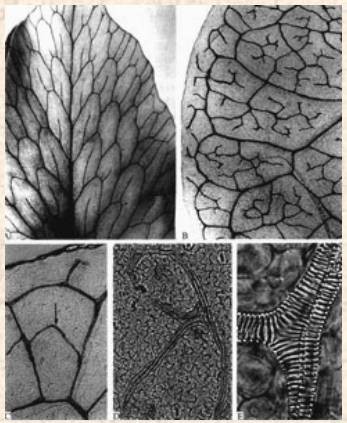

Examples

Physical networks

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- Neural networks
- Trees and leaves
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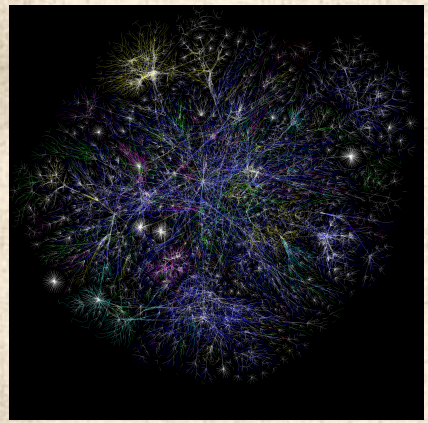
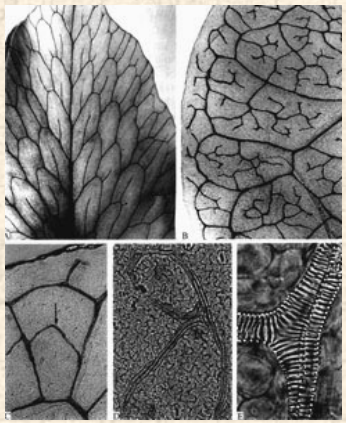
- Road networks
- Power grids





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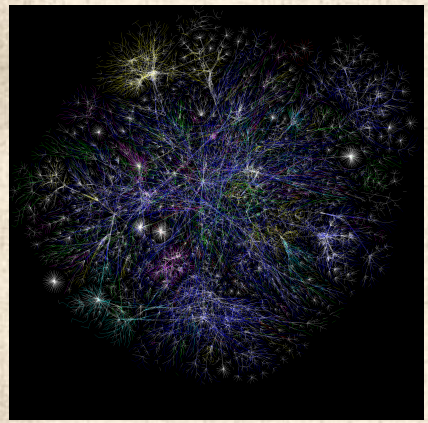
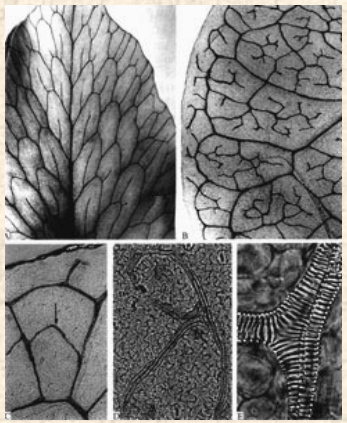




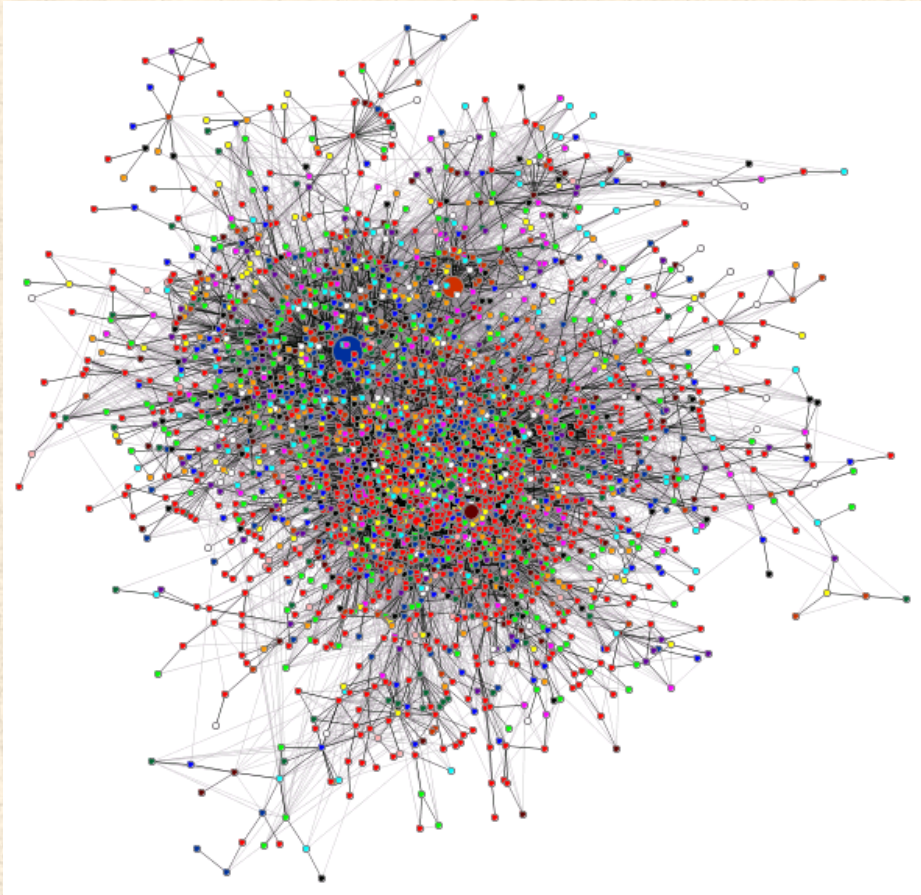
- Distribution (branching) versus redistribution (cyclical)

Outline

Examples

Interaction networks

- The Blogosphere



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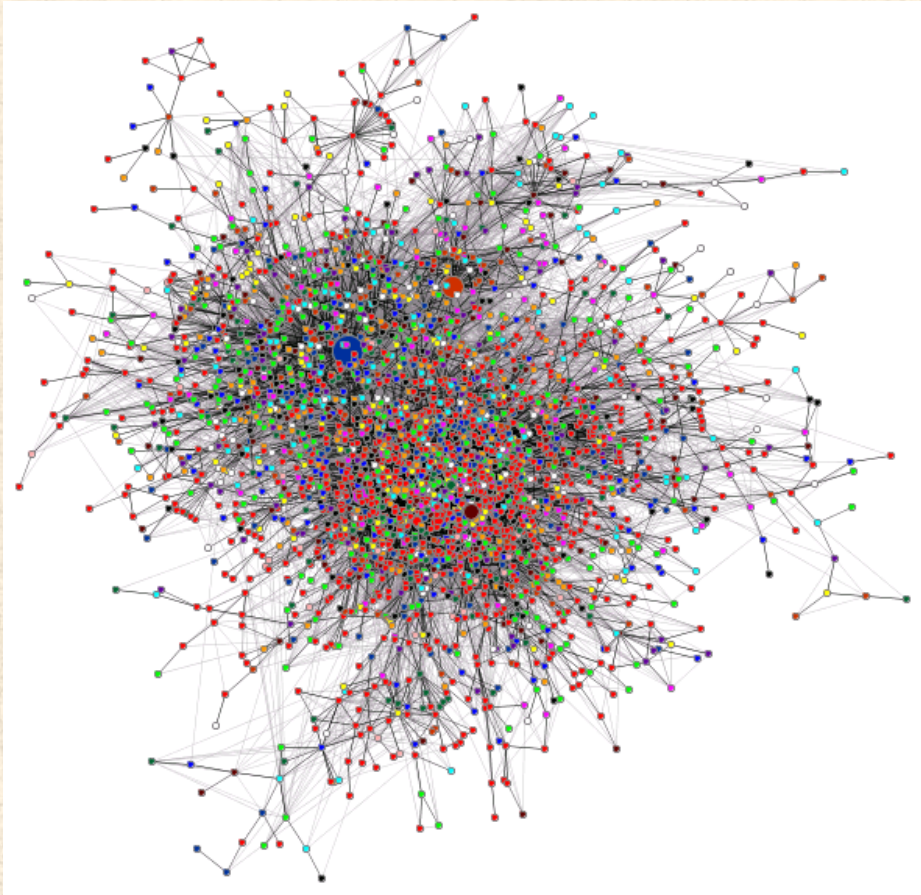
- Biochemical networks



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Interaction networks

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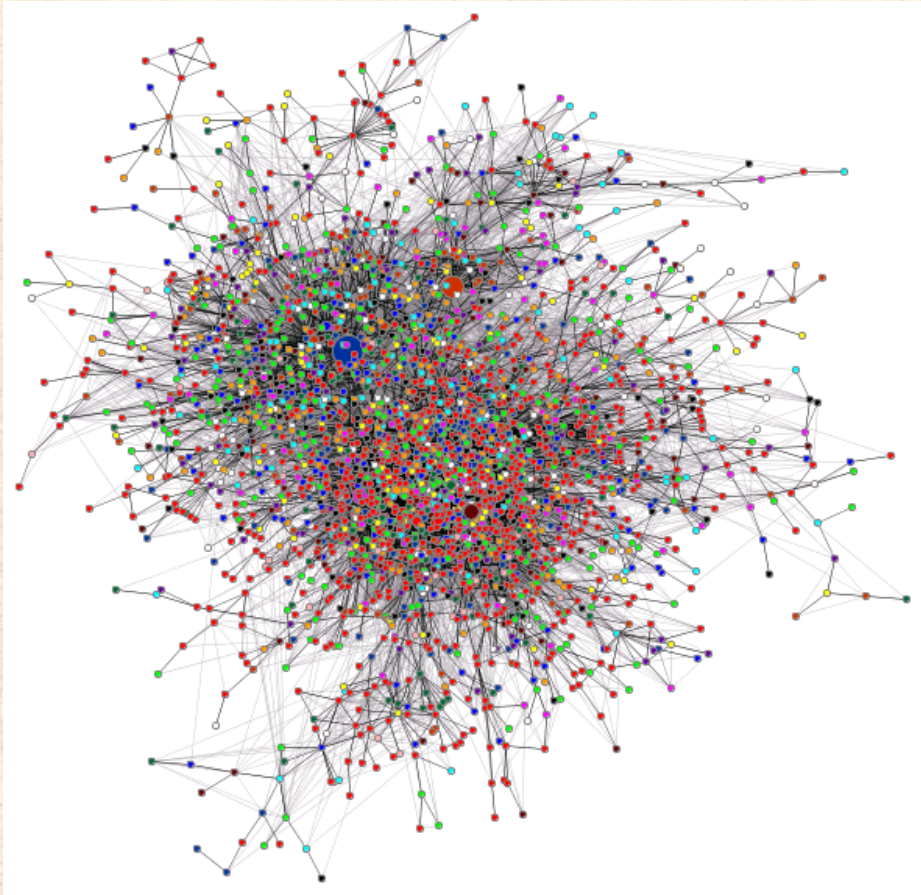
- Gene-protein networks



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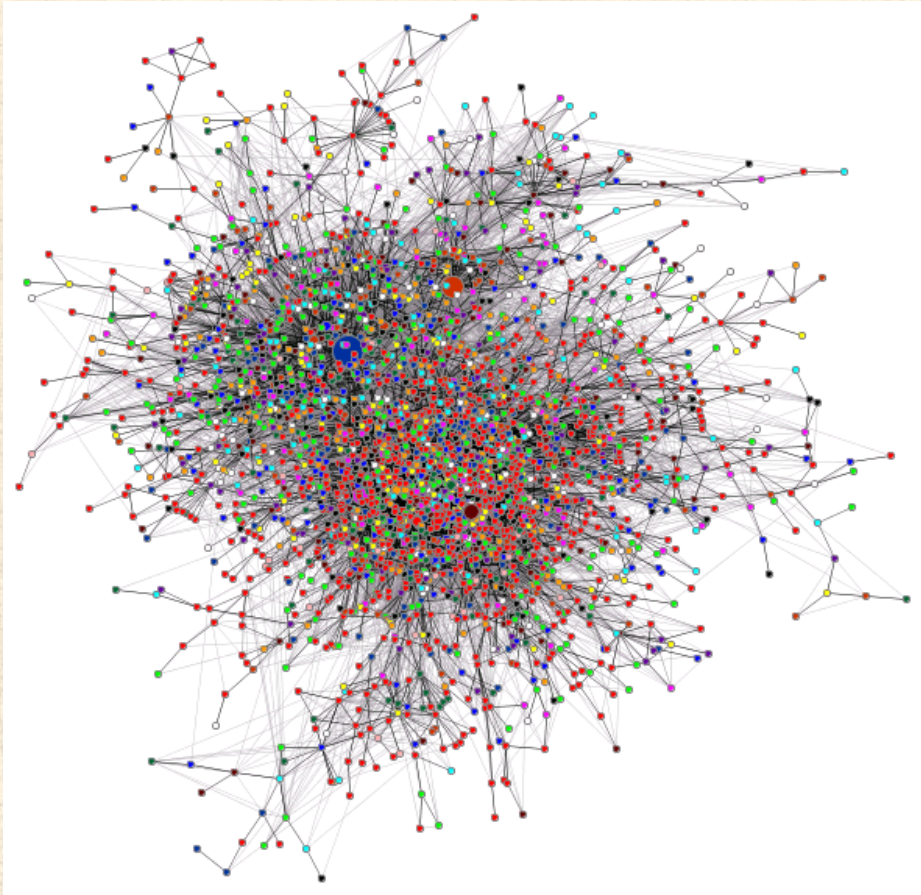
- Food webs: who eats whom



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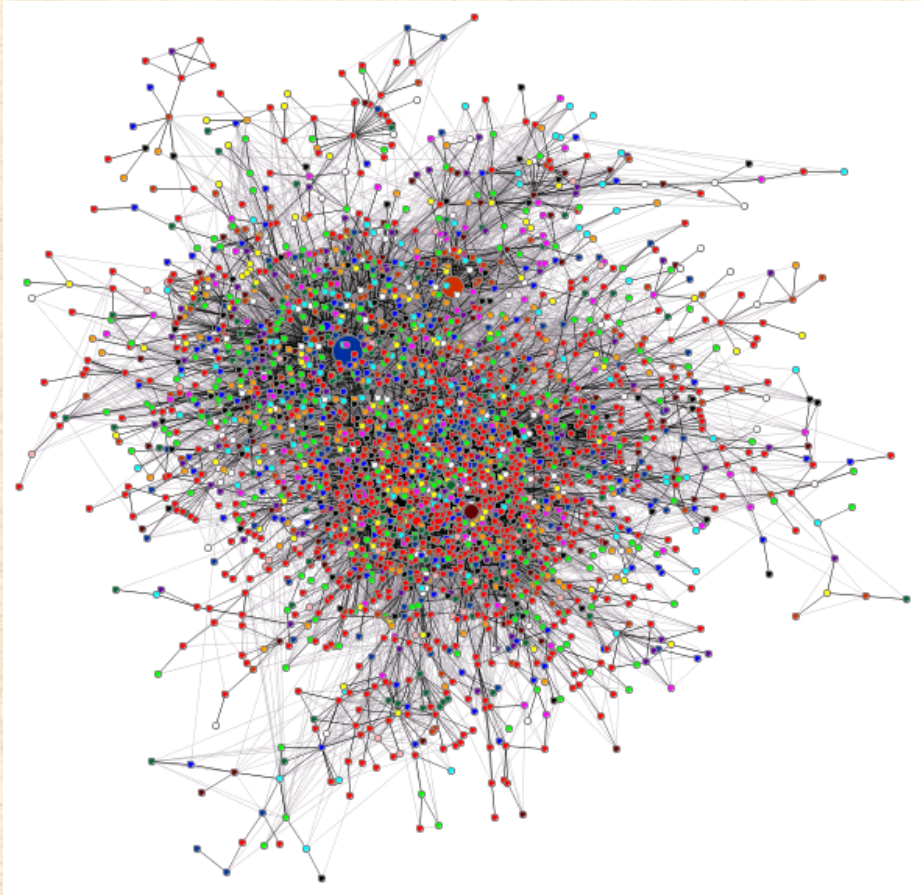

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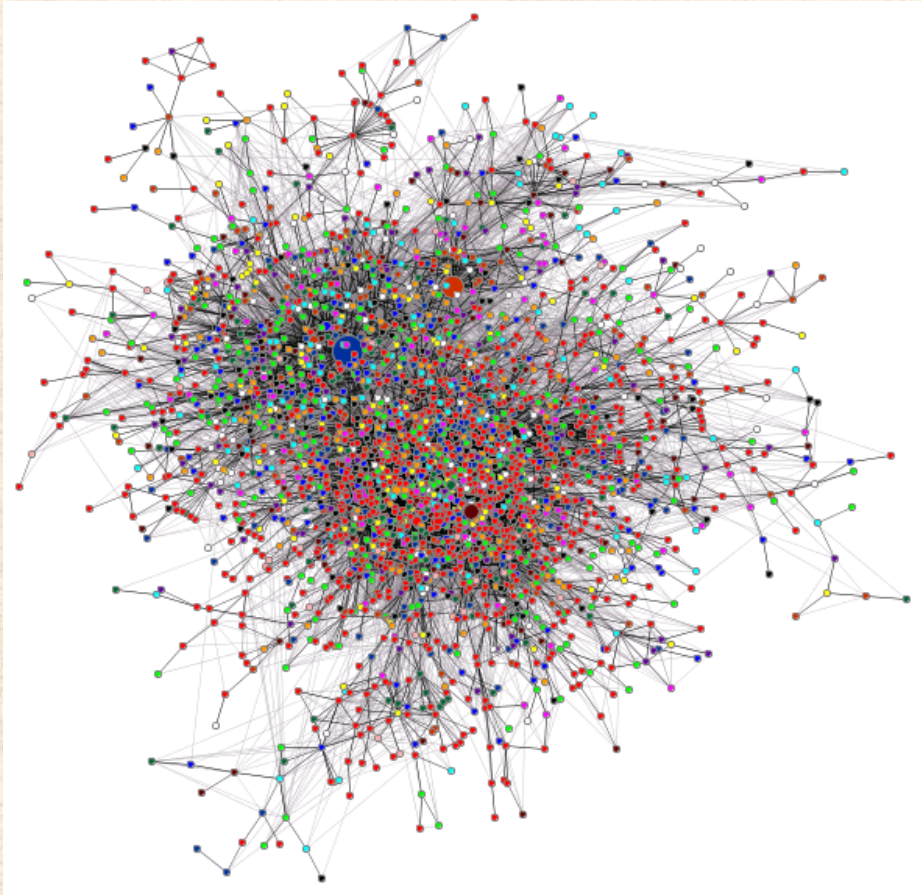

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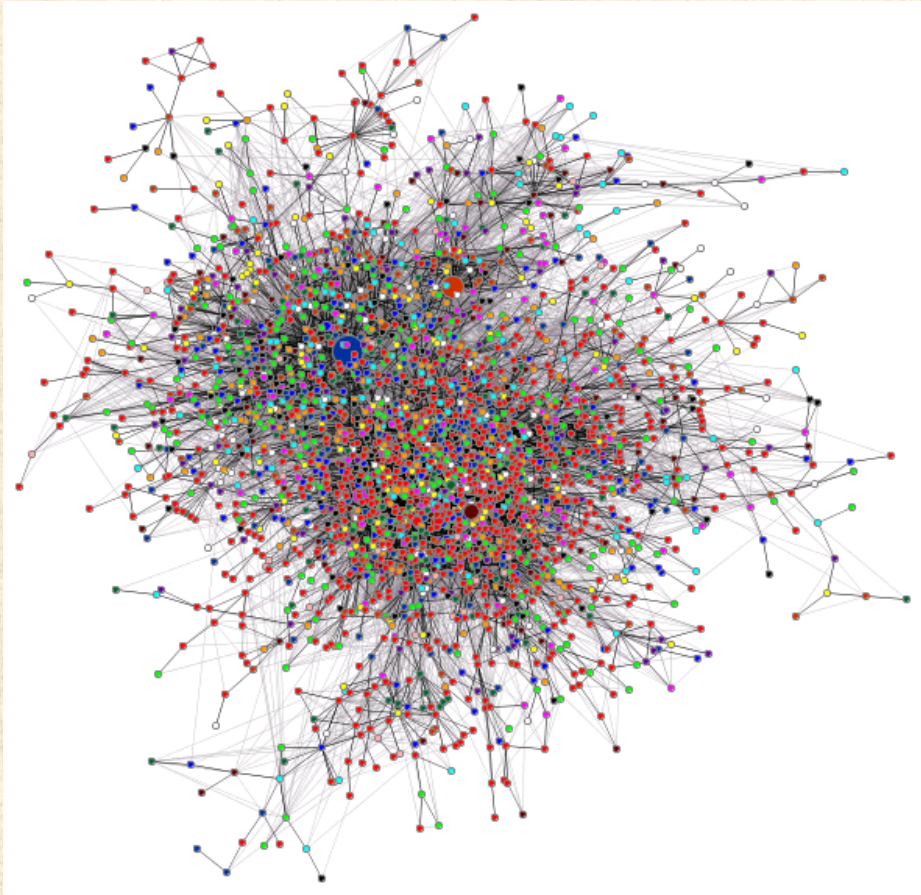

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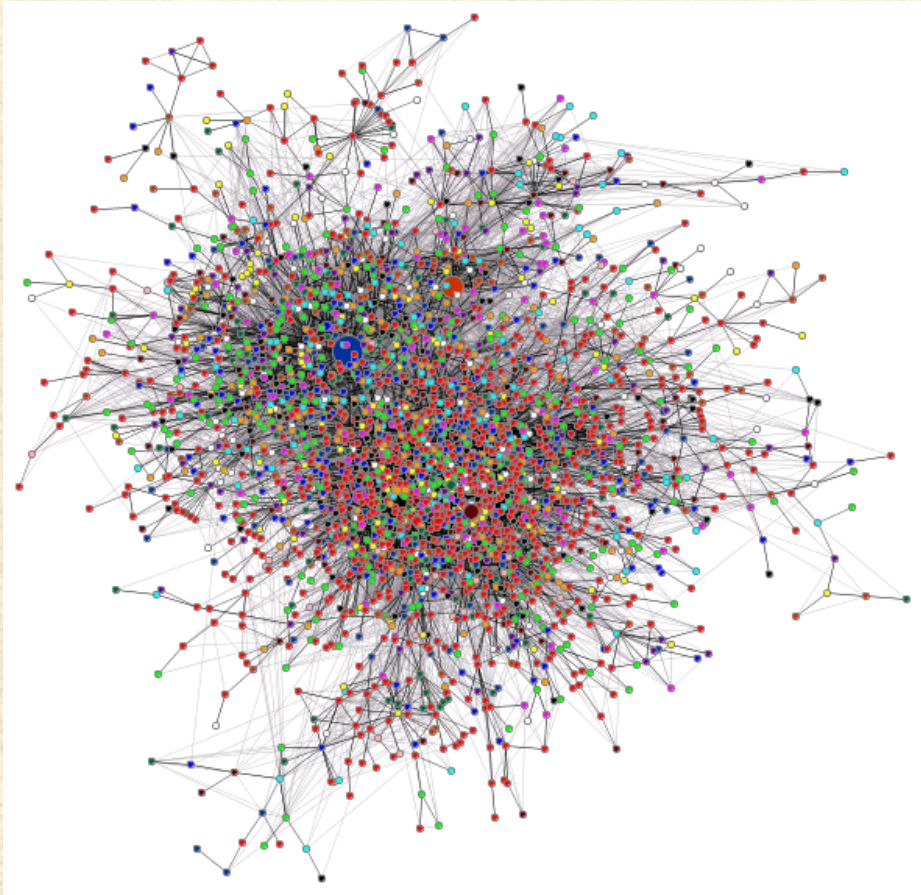

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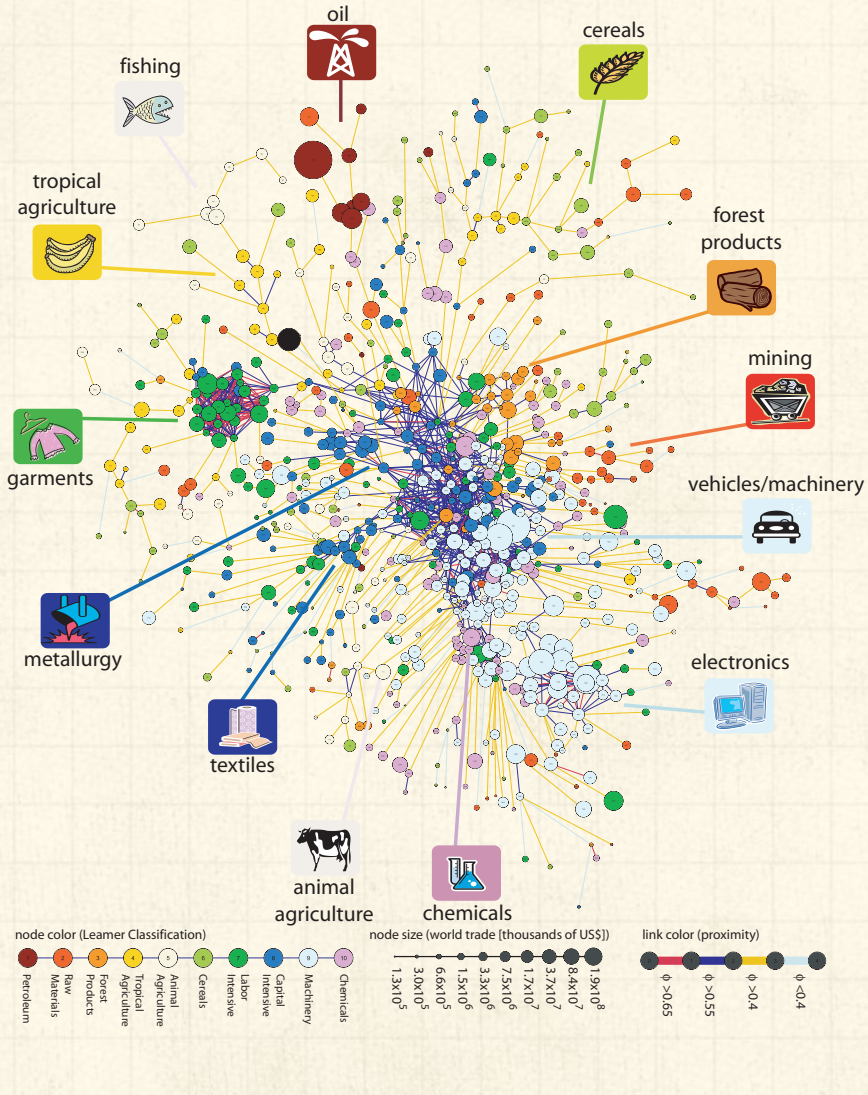
topics:

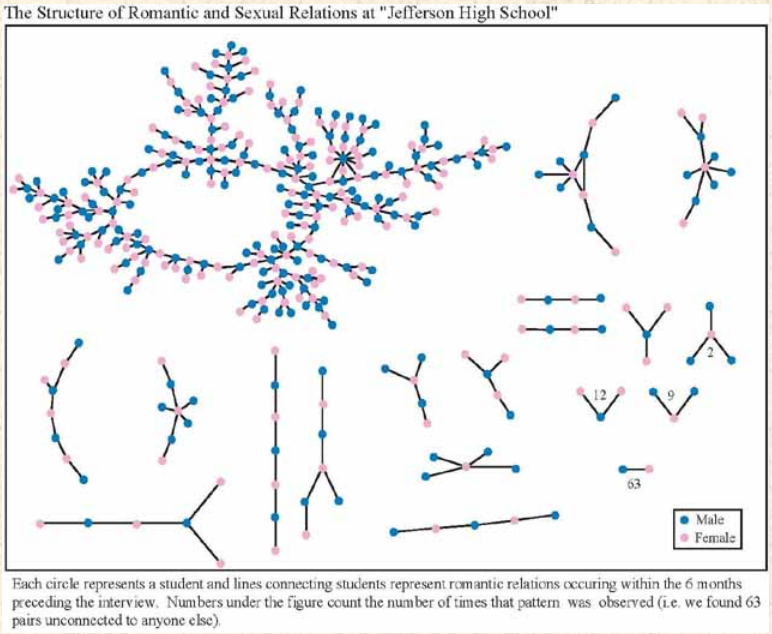
- Hidalgo et al.'s "The Product Space Conditions the Development of Nations" [10]
- How do products depend on each other, and how does this network evolve?
- How do countries depend on each other for water, energy, people (immigration), investments?



Examples

Interaction networks: social networks

- Snogging



(Bearman *et al.*, 2004)

Examples

Interaction networks: social networks

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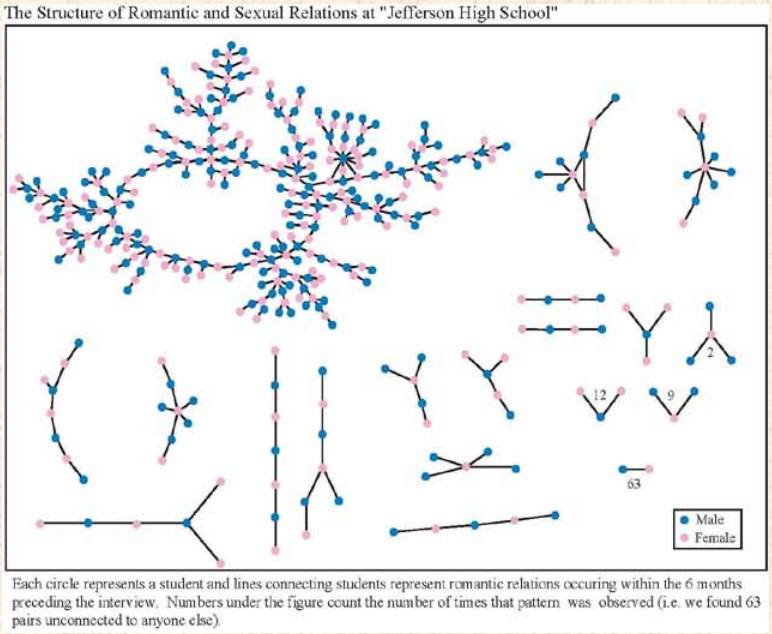
- Friendships



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Examples

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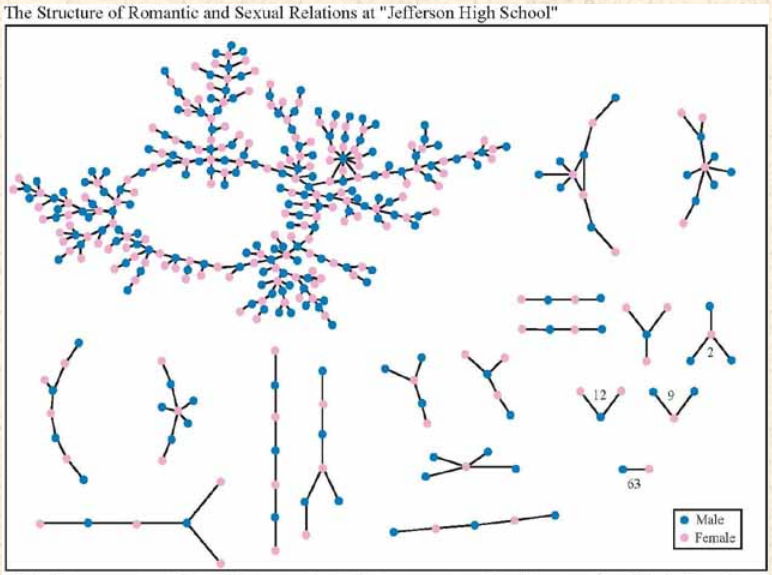
- Acquaintances



Each circle represents a student and lines connecting students represent romantic relations occuring within the 6 months preceding the interview. Numbers under the figure count the number of times that pattern was observed (i.e. we found 63 pairs unconnected to anyone else).

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Examples

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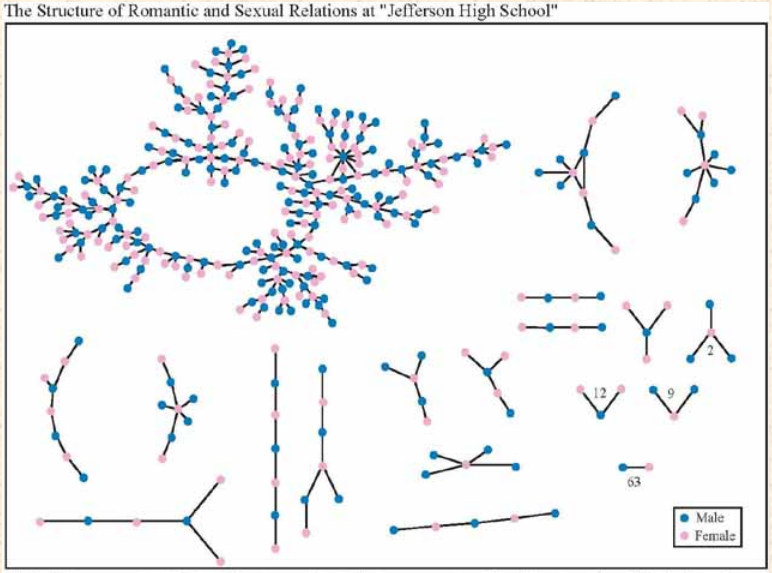
- Boards and directors



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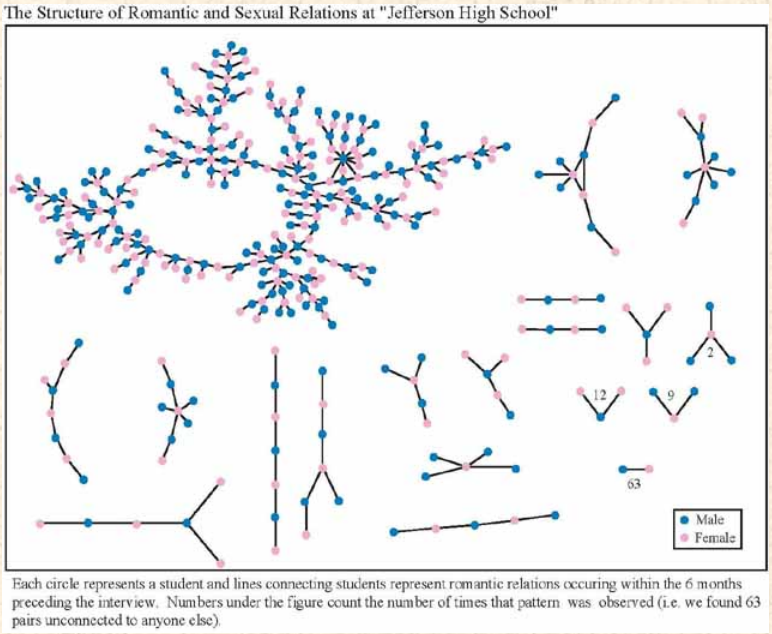

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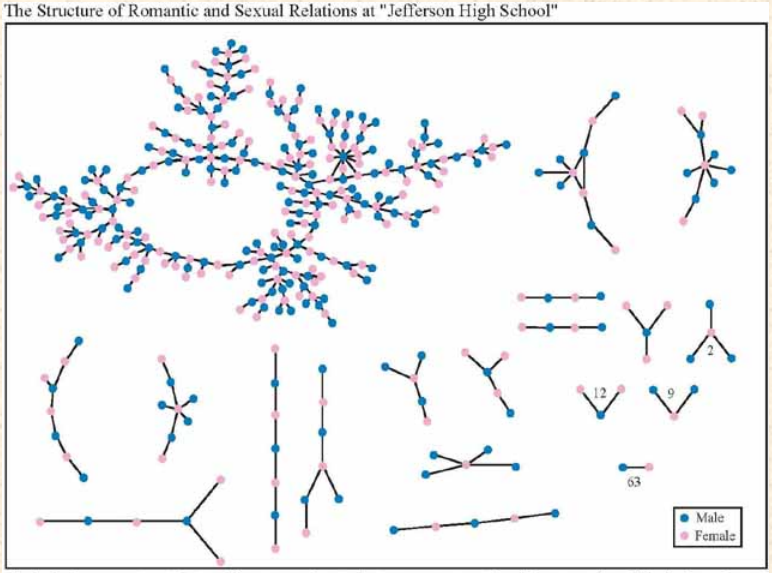

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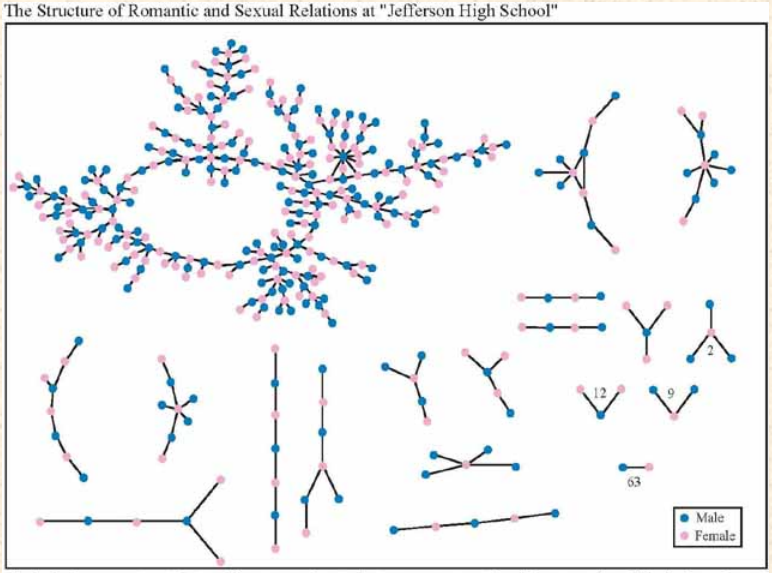

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- 'Remotely sensed' by: email activity, instant messaging, phone logs .

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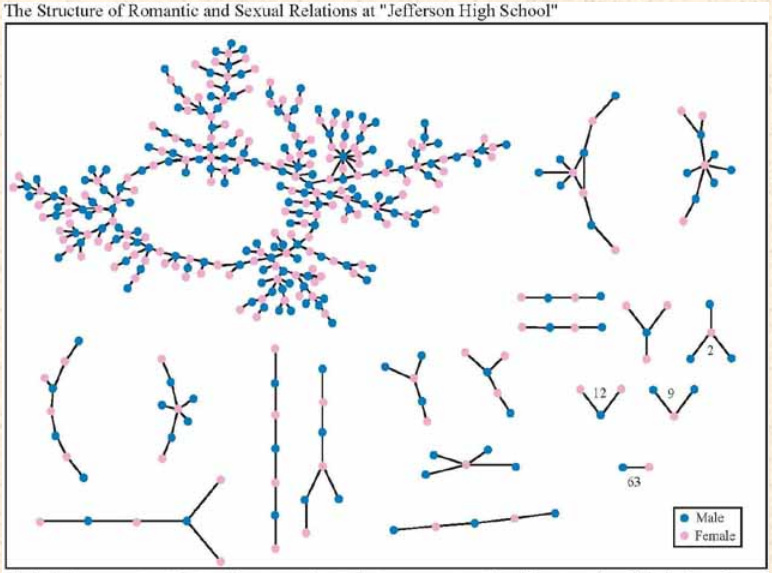

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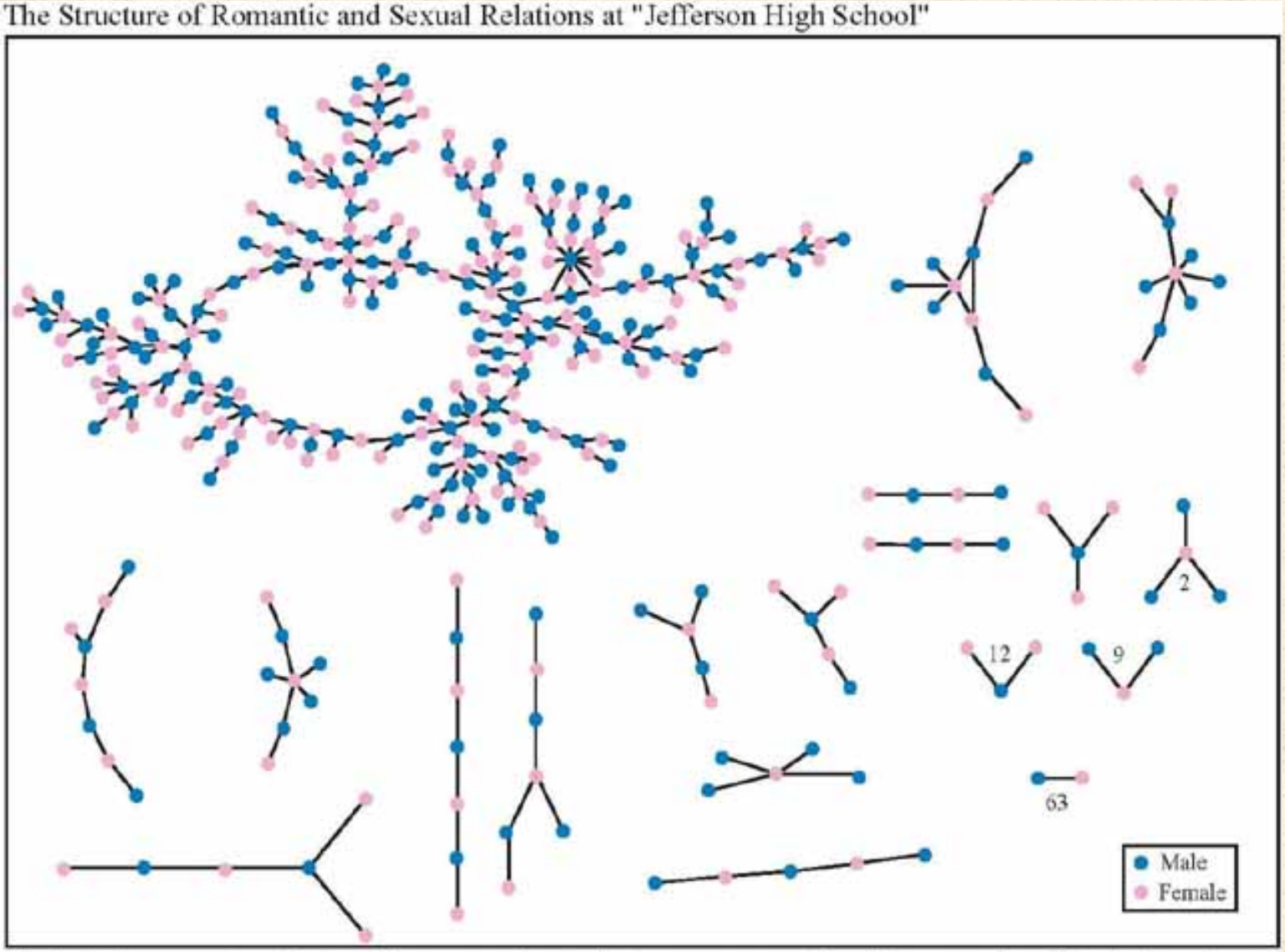
- 'Remotely sensed' by: email activity, instant messaging, phone logs (*cough*).

Examples



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Outline

Examples

Relational networks

- Consumer purchases

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Relational networks

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- Thesauri: Networks of words generated by meanings

Examples

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Examples

Relational networks

- Consumer purchases (Walmart, Target, Amazon, ...)
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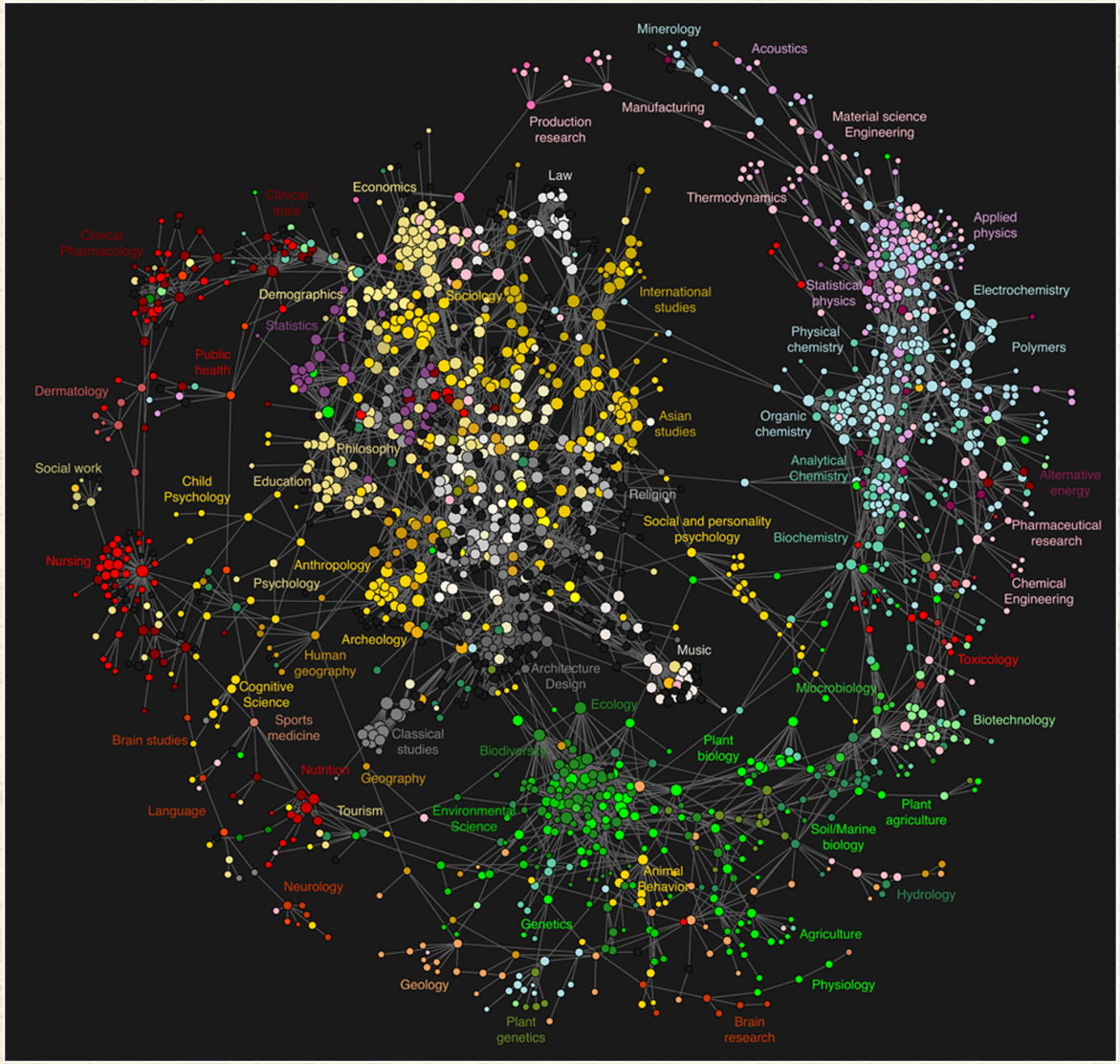
- Metadata—Tagging: bit.ly flickr

common tags cloud | list

community daily dictionary education **encyclopedia**
english free imported info **information** internet knowledge
learning news **reference** research resource
resources search tools useful web web2.0 **wiki**
wikipedia

Clickworthy Science:



"Clickstream Data Yields High-Resolution Maps of Science", Bollen et al. [4], 2009.

Neural reboot (NR):

Dog has fun.

https://www.youtube.com/watch?v=7xEX-48RHCY?rel=0

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