Semester projects

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Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 300, 303, & 394, 2022–2023 | @pocsvox

Prof. Peter Sheridan Dodds | @peterdodds

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

Outline

Semester projects—Usual plan:

Requirements:

1. 2 minute introduction to project (nth week).
2. 4 minute final presentation.
3. Report: $\geq$ 4 pages (single space), journal-style
4. And/Or: Online visualization.
5. Use Github for code and data visualizations.
6. Work in teams of 2 or 3.

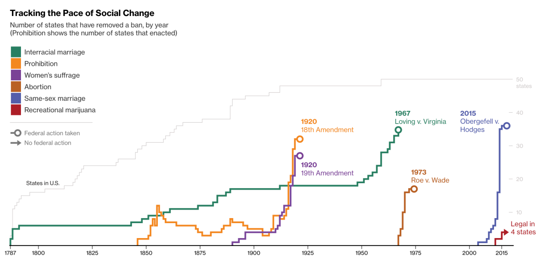
Goals can range a great deal:

- Understand, critique, and communicate published work.
- Seed research papers or help papers along.

The narrative hierarchy—Stories and Storytelling on all Scales:

- 1 to 3 word encapsulation = a soundbite = a buzzframe,
- 1 sentence, title,
- few sentences, a haiku,
- a paragraph, abstract,
- short paper, essay,
- long paper,
- chapter,
- book,
- ...

"This Is How Fast America Changes Its Mind"



Alex Tribou and Keith Collins, 2015

- Flesch–Kincaid readability tests

$$206.835 - 1.015\left(\frac{\text{total words}}{\text{total sentences}}\right) - 84.6\left(\frac{\text{total syllables}}{\text{total words}}\right)$$

Big data-ishness of sociotechnical nature:

- Dynamics of any thematically connected subset of words on Twitter
- Extend bot follower detection per NYT: https://www.nytimes.com/interactive/2018/01/27/technology/social-media-bots.html
- Ratiometer (started) https://fivethirtyeight.com/features/the-worst-tweeter-in-politics-isnt-trump/
- POTUSometer (underway)
- Story Wrangler (underway)
- Everything about hashtags (micro stories)
- Homer's Odyssey: Undefined words
- Story-based study inspired by: The Vanishing of Reality.
- Youtube: 3 degrees of conspiracy theories

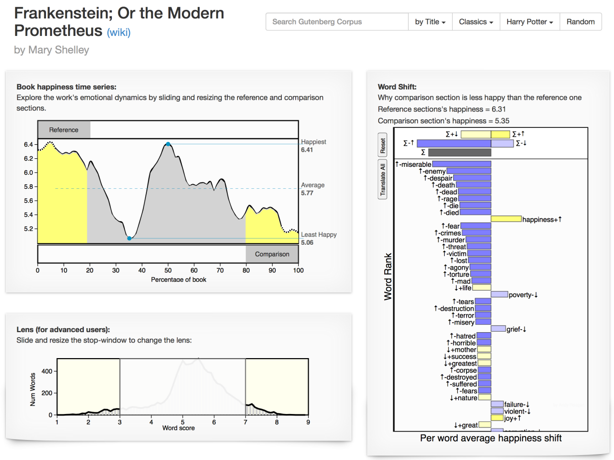
Random:

- Wealth: Simple social model of limited giving and cooperating.
- Scaling regarding component, size, and number for any complex system.
- Exploration of networks underlying many systems (big part of the PoCS to come).

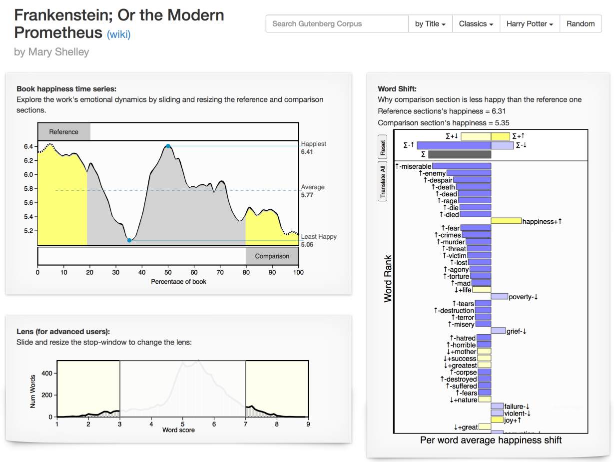
Mathematical models, simulations:

- Toy models at large (cellular automata)
- Generalization of rich-get-richer model
- Risk: Extreme value problems and rich-get-rich models (floods, finance, earthquakes).
- Big data climate patterns and dynamics
- Teletherm (well developed)
- Wind (under way)

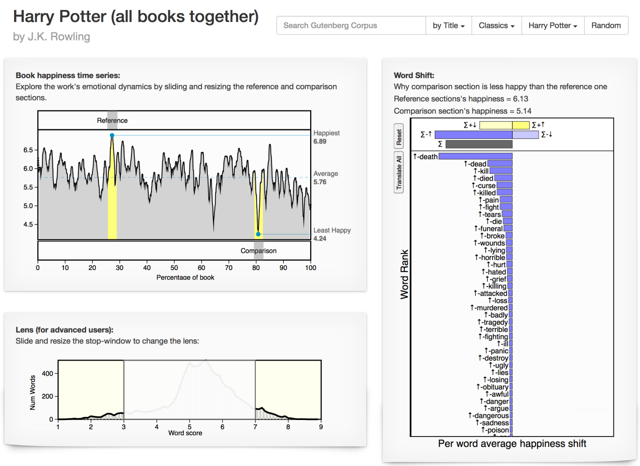
Online, interactive Emotional Shapes of Stories for 10,000+ books:



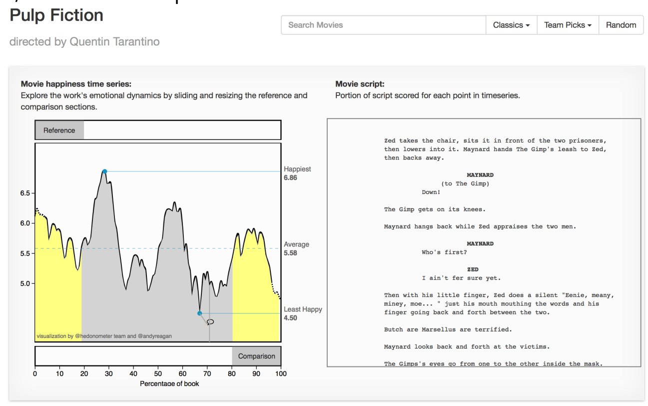
Online, interactive Emotional Shapes of Stories for 10,000+ books:



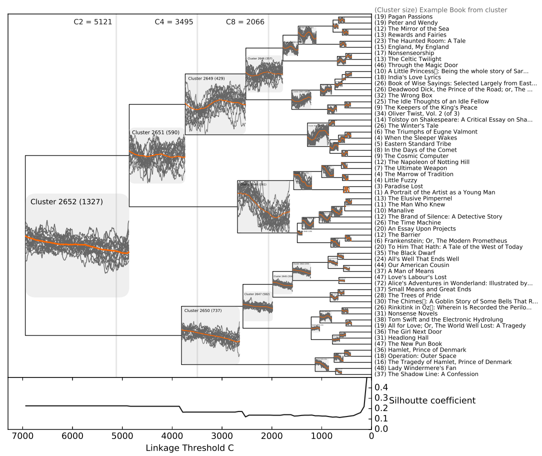
Online, interactive Emotional Shapes of Stories for 10,000+ books:



Online, interactive Emotional Shapes of Stories for 1,000+ movie scripts:



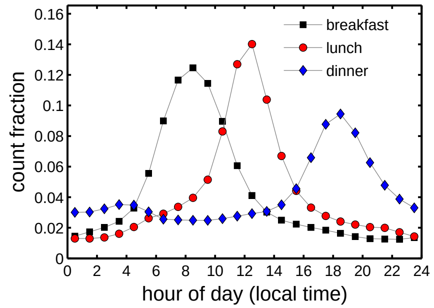
Emotional arcs for 1748 books from gutenberg.org



For story explorers:

- Plots from Wikipedia: https://github.com/markriedl/WikiPlots
- Millions of books on the VACC: Hathitrust data set.
- So many possibilities

Twitter—living in the now:



- Research opportunity: be involved in our socio-info-algorithmo-econo-geo-technico-physical systems research group studying Twitter and other wordful large data sets.

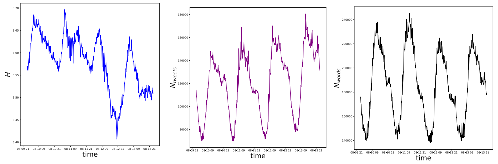
topics:

Rummage round in the papers we've covered in our weekly Complex Systems Reading Group at UVM.

topics:

- Explore the Sociotechnocene.
- Develop and elaborate an online experiment to study some aspect of sociotechnical phenomena
- e.g., collective search, cooperation, cheating, influence, creation, decision-making, language, belief, stories, etc.
- Part of the PLAY project.

Storyfinder:



The Sixipedia!

Sociotechnical phenomena—Foldit:

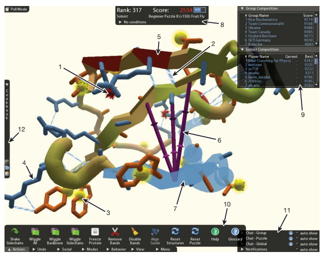
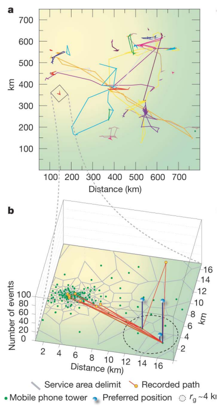
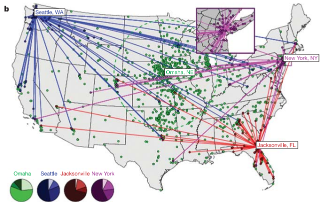


Figure 1 | Foldit screenshot illustrating tools and visualizations. The visualizations include a clash representing atoms that are too close (arrow 1); a hydrogen bond (arrow 2); a hydrophobic side chain with a yellow blob because it is exposed (arrow 3); a hydrophilic side chain (arrow 4); and a segment of the backbone that is red due to high residue energy (arrow 5). The players can make modifications including 'rubber bands' (arrow 6), which add constraints to guide automated tools, and freezing (arrow 7), which prevents degrees of freedom from changing. The user interface includes information about the player's current status, including score (arrow 8); a leader board (arrow 9), which shows the scores of other players and groups; toolbars for accessing tools and options (arrow 10); chat for interacting with other players (arrow 11); and a 'cookbook' for making new automated tools or 'recipes' (arrow 12).

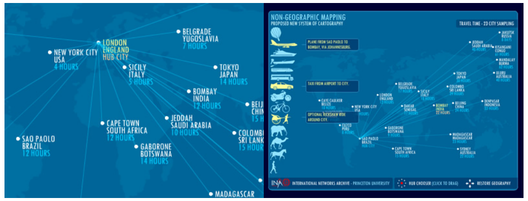
- "Predicting protein structures with a multiplayer online game." Cooper et al., Nature, 2010. [12]
- Also: zooniverse, ESP game, captchas.





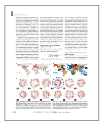
- Study movement and interactions of people.
- Brockmann *et al.* [5] "Where's George" study.
- Barabasi's group: tracking movement via cell phones [21].

The madness of modern geography:



- Explore distances between points on the Earth as travel times.
- See Jonathan Harris's work here and here.

"A universal model for mobility and migration patterns"
Simini et al.,
Nature, **484**, 96–100, 2012. [37]



"The hidden geometry of complex, network-driven contagion phenomena"
Brockmann and Helbing,
Science, **342**, 1337–1342, 2013. [4]

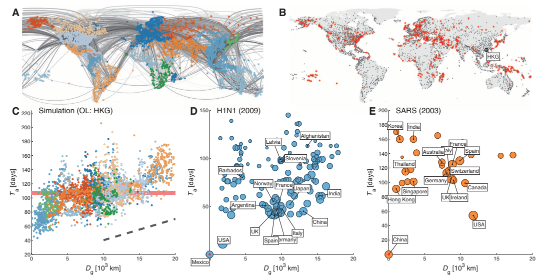


Fig. 1. Complexity in global, network-driven contagion phenomena. (**A**) The global mobility network (GMN). Gray lines represent passenger flows along direct connections between 4069 airports worldwide. Geographic regions are distinguished by color [classified according to network modularity maximization (*39*)]. (**B**) Temporal snapshot of a simulated global pandemic with initial outbreak location (OL) in Hong Kong (HKG). The simulation is based on the metapopulation model defined by Eq. 3 with parameters $R_0 = 1.5$, $\beta = 0.285$ day^{-1}, $\gamma = 2.8 \times 10^{-3}$ day^{-1}, $\varepsilon = 10^{-6}$. Red symbols depict locations with epidemic arrival times in the time window 105 days $\leq T_a \leq$ 110 days. Because of the multiscale structure of the underlying network, the spatial distribution of disease prevalence (i.e., the fraction of infected individuals) lacks geometric coherence. No clear wavefront is visible, and based on this dynamic state, the OL cannot be easily deduced. (**C**) For the same simulation as in (B), the panel depicts arrival times T_a as a function of geographic distance D_g from the OL [nodes are colored according to geographic region as in (A)] for each of the 4069 nodes in the network. On a global scale, T_a weakly correlates with geographic distance D_g ($R^2 = 0.34$). A linear fit yields an average global spreading speed of v_g = 331 km/day (see also fig. S7). Using D_g and v_g to estimate arrival times for specific locations, however, does not work well owing to the strong variability of the arrival times for a given geographic distance. The red horizontal bar corresponds to the arrival time window shown in (B). (**D**) Arrival times versus geographic distance from the source (Mexico) for the 2009 H1N1 pandemic. Symbols represent 140 affected countries, and symbol size quantifies total traffic per country. Arrival times are defined as the date of the first confirmed case in a given country after the initial outbreak on 17 March 2009. As in the simulated scenario, arrival time and geographic distance are only weakly correlated ($R^2 = 0.0394$). (**E**) In analogy to (D), the panel depicts the arrival times versus geographic distance from the source (China) of the 2003 SARS epidemic for 29 affected countries worldwide. Arrival times are taken from WHO published data (*2*). As in (C) and (D), arrival time correlates weakly with geographic distance.

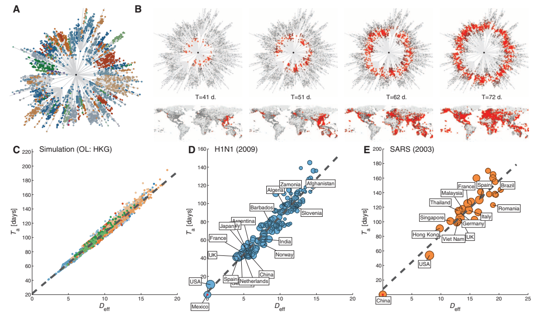


Fig. 2. Understanding global contagion phenomena using effective distance. (**A**) The structure of the shortest path tree (in gray) from Hong Kong (central node). Radial distance represents effective distance D_{eff} as defined by Eqs. 4 and 5. Nodes are colored according to the same scheme as in Fig. 1A. (**B**) The sequence (from left to right) of panels depicts the time course of a simulated model disease with initial outbreak in Hong Kong (HKG), for the same parameter set as used in Fig. 1B. Prevalence is reflected by the redness of the symbols. Each panel compares the state of the system in the conventional geographic representation (bottom) with the effective distance representation (top). The complex spatial pattern in the conventional view is equivalent to a homogeneous wave that propagates outwards at constant effective speed in the effective distance representation. (**C**) Epidemic arrival time T_a versus effective distance D_{eff} for the same simulated epidemic as in (B). In contrast to geographic distance (Fig. 1C), effective distance correlates strongly with arrival time ($R^2 = 0.973$), i.e., effective distance is an excellent predictor of arrival times. (**D** and **E**) Linear relationship between effective distance and arrival time for the 2009 H1N1 pandemic (D) and the 2003 SARS epidemic (E). The arrival time data are the same as in Fig. 1, D and E. The effective distance was computed from the projected global mobility network between countries. As in the model system, we observe a strong correlation between arrival time and effective distance.

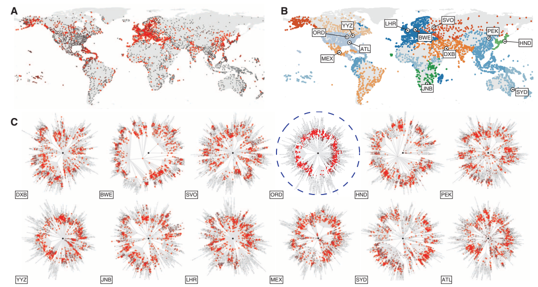
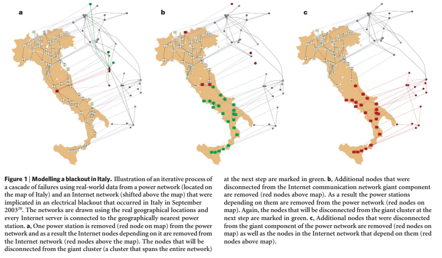


Fig. 3. Qualitative outbreak reconstruction based on effective distance. (**A**) Spatial distribution of prevalence $j_n(t)$ at time T = 81 days for OL Chicago (parameters $\beta = 0.28$ day^{-1}, $R_0 = 1.9$, $\gamma = 2.8 \times 10^{-3}$ day^{-1}, and $\varepsilon = 10^{-6}$). After this time, it is difficult, if not impossible, to determine the correct OL from snapshots of the dynamics. (**B**) Candidate OLs chosen from different geographic regions. (**C**) Panels depict the state of the system shown in (A) from the perspective of each candidate OL, using each OL's shortest path tree representation. Only the actual OL (ORD, circled in blue) produces a circular wavefront. Even for comparable North American airports [Atlanta (ATL), Toronto (YYZ), and Mexico City (MEX)], the wavefronts are not nearly as concentric. Effective distances thus permit the extraction of the correct OL, based on information on the mobility network and a single snapshot of the dynamics.

Multilayer networks:

Explore "Catastrophic cascade of failures in interdependent networks" [6]. Buldyrev et al., Nature 2010.



HOT networks:

"The "Robust yet Fragile" nature of the Internet"
Doyle et al.,
Proc. Natl. Acad. Sci., **2005**, 14497–14502, 2005. [17]

topics:

- Read and critique "Historical Dynamics: Why States Rise and Fall" by Peter Turchin. [41]
- Can history be explained by differential equations?: Clyodynamics,
- Construct a working version of Psychohistory.
- "Big History"

"The life-spans of Empires"
Samuel Arbesman,
Historical Methods: A Journal of Quantitative and Interdisciplinary History, **44**, 127–129, 2011. [1]

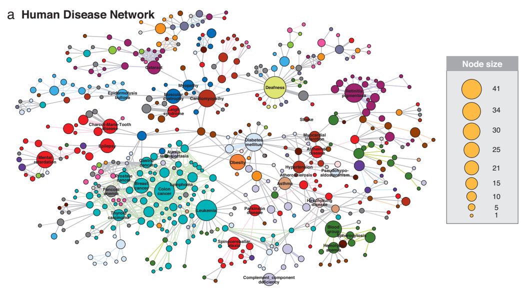
- Also see "Secular Cycles".

topics:

- Explore general theories on system robustness.
- Are there universal signatures that presage system failure?
- See "Early-warning signals for critical transitions" Scheffer et al., Nature 2009. [35]
- "Although predicting such critical points before they are reached is extremely difficult, work in different scientific fields is now suggesting the existence of generic early-warning signals that may indicate for a wide class of systems if a critical threshold is approaching."
- Robust-yet-fragile systems, HOT theory.

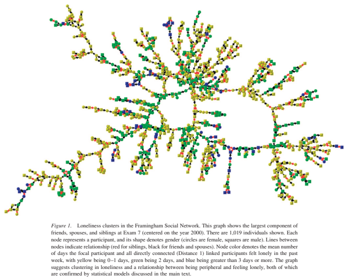
topics:

- Study the human disease and disease gene networks (Goh *et al.*, 2007):



topics:

Explore and critique Fowler and Christakis et al. work on social contagion of:



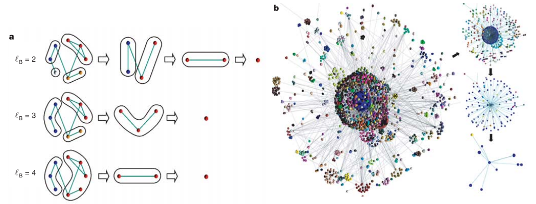
- Obesity [9]
- Smoking cessation [10]
- Happiness [19]
- Loneliness [7]

One of many questions:

How does the (very) sparse sampling of a real social network affect their findings?

topics:

- Explore "self-similarity of complex networks" [38, 39] First work by Song *et al.*, Nature, 2005.
- See accompanying comment by Strogatz [40]
- See also "Coarse-graining and self-dissimilarity of complex networks" by Itzkovitz et al. [?]



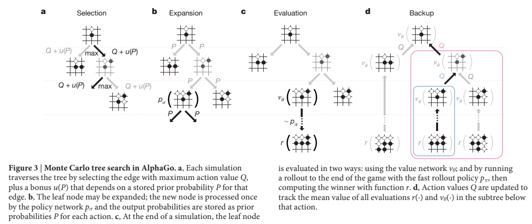
topics:

Related papers:

- "Origins of fractality in the growth of complex networks"
  Song et al. (2006a) [39]
- "Skeleton and Fractal Scaling in Complex Networks"
  Go et al. (2006a) [20]
- "Complex Networks Renormalization: Flows and Fixed Points"
  Radicchi et al. (2008a) [34]

Advances in sociotechnical algorithms:

"Mastering the game of Go with deep neural networks and tree search"
Silver and Silver,
Nature, **529**, 484–489, 2016. [36]



- Nature News (2016): Digital Intuition
- Wired (2012): Network Science of the game of Go

topics:

- Explore patterns, designed and undesigned, of cities and suburbs.

topics:

- Study collective creativity arising out of social interactions
- Productivity, wealth, creativity, disease, etc. appear to increase superlinearly with population
- Start with Bettencourt et al.'s (2007) "Growth, innovation, scaling, and the pace of life in cities" [3]
- Dig into Bettencourt (2013) "The Origins of Scaling in Cities" [3]

Study networks and creativity:

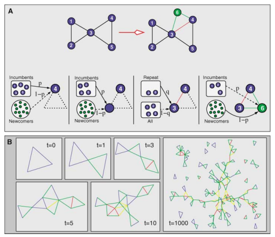


Fig. 2. Modeling the emergence of collaboration networks in creative enterprises. (**A**) Creation of a team with $m = 3$ agents. Consider, at time zero, a collaboration network comprising five agents, all incumbents (blue circles). Along with the incumbents, there is a large pool of newcomers (green circles) available to participate in new teams. Each agent in a team has a probability p of being drawn from the pool of incumbents and a probability $1 - p$ of being drawn from the pool of newcomers. For the second and subsequent agents selected from the incumbents' pool: (i) with probability q, the new agent is randomly selected from among the set of collaborators of a randomly selected incumbent already in the team; (ii) otherwise, he or she is selected at random among all incumbents in the network. For concreteness, let us assume that incumbent 4 is selected as the first agent in the new team (leftmost box). Let us also assume that the second agent is an incumbent, too (center-left box). In this example, the second agent is a past collaborator of agent 4, specifically agent 3 (center-right box). Lastly, the third agent is selected from the pool of newcomers; this agent becomes incumbent 6 (rightmost box). In these boxes and in the following panels and figures, blue lines indicate newcomer-newcomer collaborations, green lines indicate newcomer-incumbent collaborations, yellow lines indicate new incumbent-incumbent collaborations, and red lines indicate repeat collaborations. (**B**) Time evolution of the network of collaborations according to the model for $p = 0.5$, $q = 0.5$, and $m = 3$.

- Guimerà et al., Science 2005: [22] "Team Assembly Mechanisms Determine Collaboration Network Structure and Team Performance"
- Broadway musical industry
- Scientific collaboration in Social Psychology, Economics, Ecology, and Astronomy.

topics:

Vague/Large:

- Study Yelp: is there Accounting for Taste?
- Study Metacritic: the success of stories.
- Study TV Tropes
- Study proverbs.
- Study amazon's recommender networks.

See work by Sornette *et al.*.

- Vague/Large:
  Study Netflix's open data (movies and people form a bipartite graph).

topics:

More Vague/Large:

- How do countries depend on each other for water, energy, people (immigration), investments?
- How is the media connected? Who copies whom?
- (Problem: Need to be able to measure interactions.)
- Investigate memetics, the 'science' of memes.
- http://memetracker.org/
- Work on the evolution of proverbs and sayings.

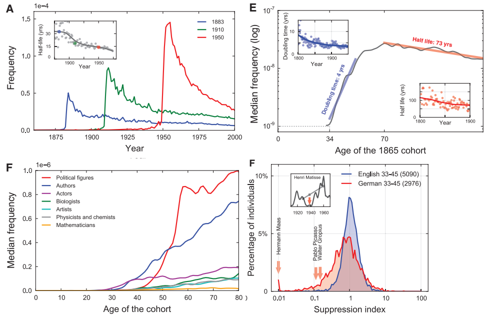
topics:

More Vague/Large:

- How does advertising work collectively?
- Does one car manufacturers' ads indirectly help other car manufacturers?
- Ads for junk food versus fruits and vegetables.
- Ads for cars versus bikes versus walking.

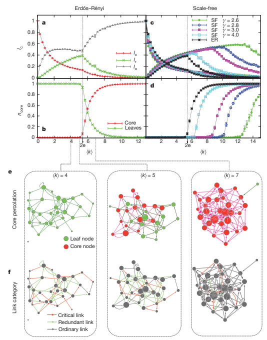
Culturomics:

"Quantitative analysis of culture using millions of digitized books" by Michel et al., Science, 2011 [30]



http://www.culturomics.org/
Google Books ngram viewer
Done!: Crushed by Pechenick, Danforth, Dodds [32, 33]

topics:



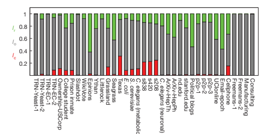


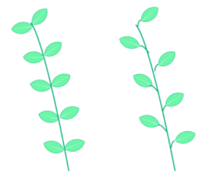
Figure 4 | Link categories for robust control. The fractions of critical (red, l_c), redundant (green, l_r) and ordinary (grey, l_o) links for the real networks named in Table 1. To make controllability robust to link failures, it is sufficient to double only the critical links, formally making each of these links redundant and therefore ensuring that there are no critical links in the system.

"Controllability of complex networks" [29] Liu et al., Nature 2011. Controversial ...

topics:

- Study phyllotaxis, how plants grow new buds and branches.
- Some delightful mathematics appears involving the Fibonacci series.
- Excellent work to start with: "Phyllotaxis as a Dynamical Self Organizing Process: Parts I, II, and III" by Douady and Couder [14, 15, 16]

http://andbug.blogspot.com/



Wikipedia

topics:

The problem of missing data in networks:

- Clauset et al. (2008)
  "Hierarchical structure and the prediction of missing links in networks" [11]
- Kossinets (2006)
  "Effects of missing data in social networks" [27]
- Much more ...

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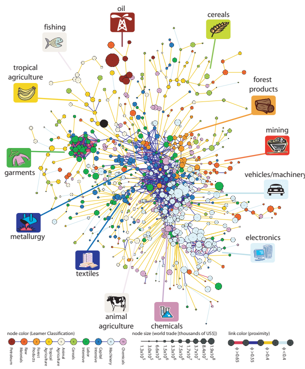
topics:

- Study Hidalgo et al.'s "The Product Space Conditions the Development of Nations" [23]
- 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?



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topics:

- Explore Dunbar's number
- See here and here for some food for thought regarding large-scale online games and Dunbar's number. [http://www.lifewithalacrity.com]
- Recent work: "Network scaling reveals consistent fractal pattern in hierarchical mammalian societies" Hill et al. (2008) [24].

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topics:

- Study scientific collaboration networks.
- Mounds of data + good models.
- See seminal work by De Solla Price [13].
  plus modern work by Redner, Newman, *et al.*
- We will study some of this in class...

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topics:

- Study Kearns et al.'s experimental studies of people solving classical graph theory problems [26]
- "An Experimental Study of the Coloring Problem on Human Subject Networks"
- (Possibly) Run some of these experiments for our class.

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topics:

- Study games (as in game theory) on networks.
- For cooperation: Review Martin Nowak's piece in Science, "Five rules for the evolution of cooperation." [31] and related works.
- Much work to explore: voter models, contagion-type models, etc.

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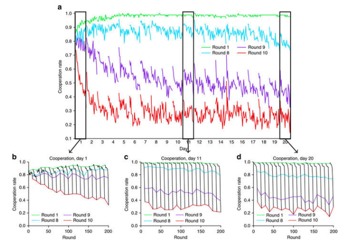
Resilient cooperators stabilize long-run cooperation in the finitely repeated Prisoner's Dilemma

Mao et al., 2017.



https://www.nature.com/articles/ncomms13800

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topics:

- Semantic networks: explore word-word connection networks generated by linking semantically related words.
- Also: Networks based on morphological or phonetic similarity.
- More general: Explore language evolution
- One paper to start with: "The small world of human language" by Ferrer i Cancho and Solé [18]
- Study spreading of neologisms.
- Examine new words relative to existing words—is there a pattern? Phonetic and morphological similarities.
- Crazy: Can new words be predicted?
- Use Google Books n-grams as a data source.

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topics:

- Explore work by Doyle, Alderson, et al. as well as Pastor-Satorras et al. on the structure of the Internet(s).

topics:

- Review: Study Castronova's and others' work on massive multiplayer online games. How do social networks form in these games? [8]
- See work by Johnson et al. on gang formation in the real world and in World of Warcraft (really!).

topics:

Social networks:

- Study social networks as revealed by email patterns, Facebook connections, tweets, etc.
- "Empirical analysis of evolving social networks" Kossinets and Watts, Science, Vol 311, 88-90, 2006. [28]
- "Inferring friendship network structure by using mobile phone data" Eagle, et al., PNAS, 2009.
- "Community Structure in Online Collegiate Social Networks"
  Traud et al., 2008.
  http://arxiv.org/abs/0809.0690

Voting

Score-based voting versus rank-based voting:

- Balinski and Laraki [2]
  "A theory of measuring, electing, and ranking"
  Proc. Natl. Acad. Sci., pp. 8720–8725 (2007)

topics:

More Vague/Large:

- Study spreading of anything where influence can be measured (very hard).
- Study any interesting micro-macro story to do with evolution, biology, ethics, religion, history, food, international relations, ...
- Data is key.

topics:

Vague/Large:

- Study how the Wikipedia's content is interconnected.

"Connecting every bit of knowledge: The structure of Wikipedia's First Link Network"
Ibrahim, Danforth, and Dodds,
Available online at
https://arxiv.org/abs/1605.00309, 2016. [25]

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