

# Semester projects

## Principles of Complex Systems

### CSYS/MATH 300, Fall, 2011

Prof. Peter Dodds

Department of Mathematics & Statistics  
 Center for Complex Systems  
 Vermont Advanced Computing Center  
 University of Vermont



Licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License.

Semester projects

The Plan  
 Suggestions for Projects  
 References



1 of 53

## Narrative hierarchy

### Presenting at many scales:

- ▶ 1 to 3 word encapsulation, a soundbite,
- ▶ a sentence/title,
- ▶ a few sentences,
- ▶ a paragraph,
- ▶ a short paper,
- ▶ a long paper,
- ▶ ...

Semester projects

The Plan  
 Suggestions for Projects  
 References



4 of 53

## Outline

The Plan

Suggestions for Projects

References

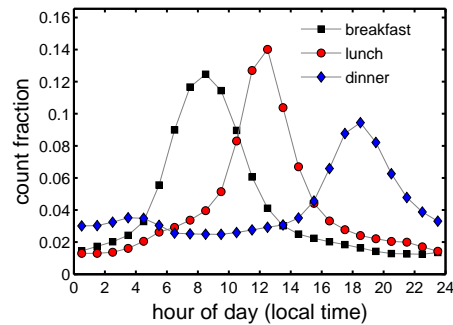
Semester projects

The Plan  
 Suggestions for Projects  
 References



2 of 53

## 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.

Semester projects

The Plan  
 Suggestions for Projects  
 References



5 of 53

## Semester projects

### Requirements:

1. 3 minute introduction to project (5th week).
2. 5-10 minute final presentation.
3. Report:  $\geq 5$  pages (single space), journal-style

### Goals:

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

Semester projects

The Plan  
 Suggestions for Projects  
 References



3 of 53

## topics:

- ▶ Develop and elaborate an **online experiment** to study some aspect of **social phenomena**
- ▶ e.g., collective search, cooperation, cheating, influence, creation, decision-making, etc.
- ▶ Part of the PLAY project.

Semester projects

The Plan  
 Suggestions for Projects  
 References



6 of 53

topics:

Rummage round in the [papers](#) (田) we've covered in our weekly Complex Systems Reading Group at UVM.

Semester projects

The Plan  
 Suggestions for Projects  
 References



Sociotechnical phenomena—Foldit:

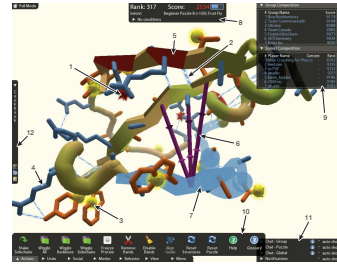


Figure 1 Foldit screenshot illustrating tools and visualizations. The visualizations include a chain representing atoms that are too close (arrow 1); a hydrogen bond (arrow 2); a hydrophobic side chain with a yellow blob because it is exposed (arrow 3); a hydrophilic side chain (arrow 4); and a segment 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).

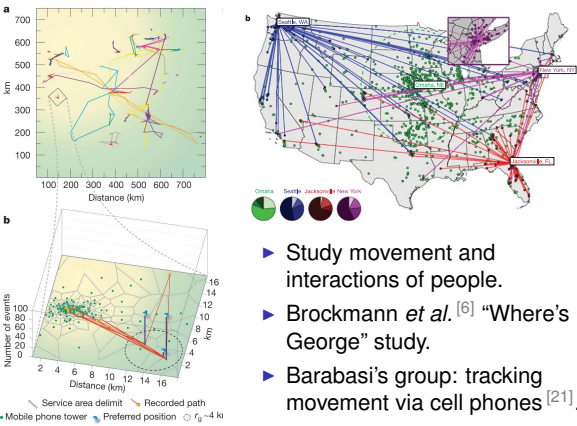
- ▶ "Predicting protein structures with a multiplayer online game." Cooper et al., Nature, 2010. [14]
- ▶ Also: [zooniverse](#) (田), [ESP game](#) (田), [captchas](#) (田).

Semester projects

The Plan  
 Suggestions for Projects  
 References



topics:



Semester projects

The Plan  
 Suggestions for Projects  
 References



topics:

Explore "Catastrophic cascade of failures in interdependent networks" [7]. Buldyrev et al., Nature 2010.

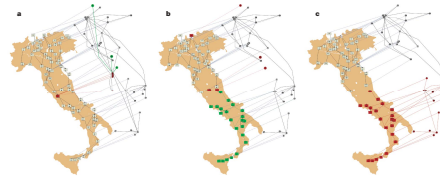


Figure 1 Modeling a blackout in Italy. Illustration of an iterative process of a cascade of failures using real-world data from a power network (located on the map of Italy) and an Internet network (sketched above the map) that were implicated in an electrical blackout that occurred in Italy in September 2009. The networks are drawn using the real geographical locations and every Internet server is connected to the geographically nearest power station. **a** One power station is removed (red node on map) from the power network and as a result the Internet nodes depending on it are removed from the Internet network (red nodes above the map). The nodes that will be disconnected from the giant cluster (a cluster that spans the entire network)

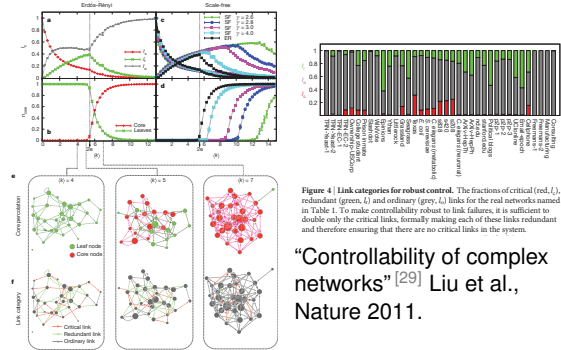
at the next step are marked in green. **b**. Additional nodes that were disconnected from the Internet communication network giant component are removed (red nodes above map). As a result the power stations depending on them are removed from the power network (red nodes on map). Again, the nodes that will be disconnected from the giant cluster at the next step are marked in green. **c**. Additional nodes that were disconnected from the giant component of the power network are removed (red nodes on map) as well as the nodes in the Internet network that depend on them (red nodes above map).

Semester projects

The Plan  
 Suggestions for Projects  
 References



topics:



Semester projects

The Plan  
 Suggestions for Projects  
 References



Voting

Score-based voting versus rank-based voting:

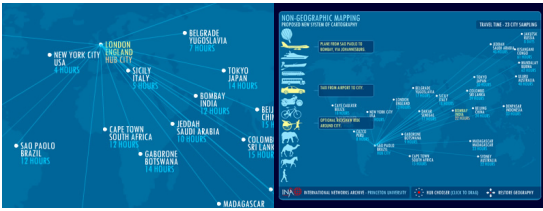
- ▶ Balinski and Laraki [2] "A theory of measuring, electing, and ranking" Proc. Natl. Acad. Sci., pp. 8720–8725 (2007)

Semester projects

The Plan  
 Suggestions for Projects  
 References



## The madness of modern geography:



- ▶ Explore distances between points on the Earth as travel times.
- ▶ See Jonathan Harris's work [here](#) (田) and [here](#) (田).

Semester projects

The Plan  
Suggestions for Projects  
References



13 of 53

## 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. [33]
- ▶ “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.”
- ▶ Later in class: Doyle et al., robust-yet-fragile systems

Semester projects

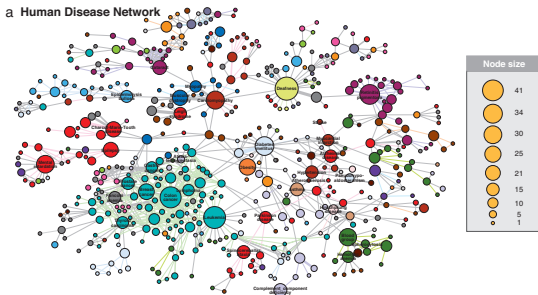
The Plan  
Suggestions for Projects  
References



14 of 53

## topics:

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



Semester projects

The Plan  
Suggestions for Projects  
References



15 of 53

## topics:

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

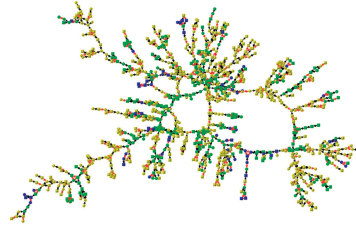


Figure 1. Loneliness clusters in the Framingham Social Network. The graph shows the largest component of friends, spouses, and siblings at Framingham over the year 2003. There are 1059 individuals shown. Each node represents a participant, and its size shows gender (red for male, blue for female), spouse or child. Lines between nodes indicate relationships and the color shows the number of days the participant was in the study. Nodes color shows the mean number of days the participant was in the study, with colors being 0-1 days, green being 2 days, and blue being greater than 7 days or more. The graph requires clustering algorithms and a relationship between being peripheral and being lonely, both of which are confirmed by statistical models discussed in the main text.

- ▶ Obesity [10]
- ▶ Smoking cessation [11]
- ▶ Happiness [19]
- ▶ Loneliness [8]

## One of many questions:

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

Semester projects

The Plan  
Suggestions for Projects  
References



16 of 53

## topics:

### The problem of missing data in networks:

- ▶ Clauset et al. (2008) “Hierarchical structure and the prediction of missing links in networks” [12]
- ▶ Kossinets (2006) “Effects of missing data in social networks” [27]

Semester projects

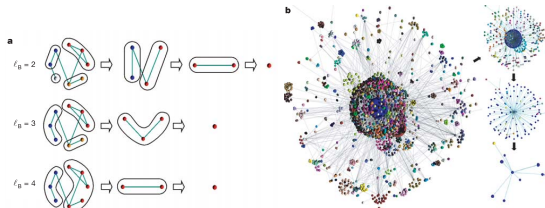
The Plan  
Suggestions for Projects  
References



17 of 53

## topics:

- ▶ Explore “self-similarity of complex networks” [34, 35] First work by Song et al., Nature, 2005.
- ▶ See accompanying comment by Strogatz [36]
- ▶ See also “Coarse-graining and self-dissimilarity of complex networks” by Itzkovitz et al. [2]



Semester projects

The Plan  
Suggestions for Projects  
References



18 of 53

topics:

Related papers:

- ▶ “Origins of fractality in the growth of complex networks”  
Song et al. (2006a) [35]
- ▶ “Skeleton and Fractal Scaling in Complex Networks”  
Go et al. (2006a) [20]
- ▶ “Complex Networks Renormalization: Flows and Fixed Points”  
Radicchi et al. (2008a) [32]

Semester projects

The Plan  
Suggestions for Projects  
References



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 “Growth, innovation, scaling, and the pace of life in cities” [4]

Semester projects

The Plan  
Suggestions for Projects  
References



topics:

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



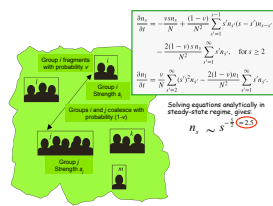
Semester projects

The Plan  
Suggestions for Projects  
References



topics:

- ▶ Physics/Society—Wars: Study work that started with Lewis Richardson’s “Variation of the frequency of fatal quarrels with magnitude” in 1949.
- ▶ Specifically explore Clauset et al. and Johnson et al.’s work [13, 24, 5] on terrorist attacks and civil wars
- ▶ Richardson bonus: Britain’s coastline, turbulence, weather prediction, ...



Semester projects

The Plan  
Suggestions for Projects  
References



topics:

“Looking at Gielen’s work, it’s tempting to propose a new branch of the human sciences: geometric sociology, a study of nothing but the shapes our inhabited spaces make. Its research agenda would ask why these forms, angles and geometries emerge so consistently, from prehistoric settlements to the fringes of exurbia. Are sites like these an aesthetic pursuit, a mathematical accident, a calculated bending of property lines based on glitches in the local planning code or an emergent combination of all these factors? Or are they the expression of something buried deep in human culture and the unconscious, something only visible from high above?”

<http://opinionator.blogs.nytimes/.../the-geometry-of-sprawl/> (E)

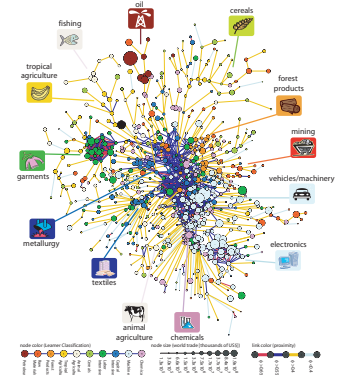
Semester projects

The Plan  
Suggestions for Projects  
References



topics:

- ▶ Study Hidalgo et al.’s “The Product Space Conditions the Development of Nations” [22]
- ▶ 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?



Semester projects

The Plan  
Suggestions for Projects  
References



## topics:

- ▶ Explore [Dunbar's number](#) (田)
- ▶ See [here](#) (田) and [here](#) (田) for some food for thought regarding large-scale online games and Dunbar's number. [<http://www.lifewithalacrity.com> (田)]
- ▶ Recent work: "Network scaling reveals consistent fractal pattern in hierarchical mammalian societies" Hill et al. (2008) <sup>[23]</sup>.

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 25 of 53

## topics:

- ▶ Study **collective tagging** (or folksonomy)
- ▶ e.g., del.icio.us, flickr
- ▶ See work by Bernardo Huberman et al. at HP labs.

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 28 of 53

## topics:

- ▶ Study scientific collaboration networks.
- ▶ Mounds of data + good models.
- ▶ See seminal work by De Solla Price <sup>[31]</sup>, plus modern work by Redner, Newman, *et al.*
- ▶ We will study some of this in class...

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 26 of 53

## 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." <sup>[30]</sup> and related works.
- ▶ Much work to explore: voter models, contagion-type models, etc.

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 29 of 53

## topics:

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

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 27 of 53

## 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 <sup>[18]</sup>
- ▶ 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.

Semester projects

The Plan  
Suggestions for  
Projects  
References



↶ ↷ ↻ 30 of 53

## topics:

- ▶ Explore proposed measures of system complexity.
- ▶ Study Stuart Kauffman's *nk boolean networks* which model regulatory gene networks<sup>[25]</sup>

Semester projects

The Plan  
Suggestions for  
Projects  
References



31 of 53

## topics:

- ▶ Review: Study Castronova's and others' work on massive multiplayer online games. How do social networks form in these games?<sup>[9]</sup>
- ▶ See work by Johnson et al. on gang formation in the real world and in World of Warcraft (really!).

Semester projects

The Plan  
Suggestions for  
Projects  
References



34 of 53

## topics:

- ▶ Critically explore Bejan's Constructal Theory.
- ▶ See Bejan's book "Shape and Structure, from Engineering to Nature."<sup>[3]</sup>
- ▶ Bejan asks why we see branching network flow structures so often in Nature—trees, rivers, etc.
- ▶ Read and critique "Historical Dynamics: Why States Rise and Fall" by Peter Turchin.<sup>[37]</sup>
- ▶ Can history *Clyodynamics* (田), *Psychohistory* (田), ...
- ▶ "Big History" (田)
- ▶ Arbesman: "The life-spans of Empires"<sup>[1]</sup>
- ▶ Also see "*Secular Cycles*" (田).

Semester projects

The Plan  
Suggestions for  
Projects  
References



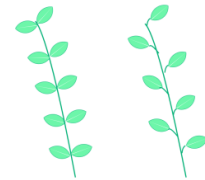
32 of 53

## topics:

- ▶ Study *phyllotaxis* (田), 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<sup>[15, 16, 17]</sup>



<http://anobug.blogspot.com/> (田)



Wikipedia (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



35 of 53

## topics:

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

Semester projects

The Plan  
Suggestions for  
Projects  
References



33 of 53

## 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.<sup>[28]</sup>
- ▶ "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> (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



36 of 53



topics:

Vague/Large:

- ▶ Study amazon's recommender networks.

Customers Who Bought This Item Also Bought



See work by Sornette *et al.*

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

Semester projects

The Plan  
 Suggestions for Projects  
 References



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.

Semester projects

The Plan  
 Suggestions for Projects  
 References



topics:

Vague/Large:

- ▶ Study how the Wikipedia's content is interconnected.



Semester projects

The Plan  
 Suggestions for Projects  
 References



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.

Semester projects

The Plan  
 Suggestions for Projects  
 References



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/> (田)
- ▶ Sport...

Semester projects

The Plan  
 Suggestions for Projects  
 References



References I

[1] S. Arbesman.  
 The life-spans of empires.  
[Historical Methods: A Journal of Quantitative and Interdisciplinary History](#), 44:127–129, 2011. pdf (田)

[2] M. Balinski and R. Laraki.  
 A theory of measuring, electing, and ranking.  
[Proc. Natl. Acad. Sci.](#), 104(21):8720–8725, 2007.  
 pdf (田)

[3] A. Bejan.  
[Shape and Structure, from Engineering to Nature](#).  
 Cambridge Univ. Press, Cambridge, UK, 2000.

Semester projects

The Plan  
 Suggestions for Projects  
 References



## References II

- [4] L. M. A. Bettencourt, J. Lobo, D. Helbing, Kühnhert, and G. B. West.  
Growth, innovation, scaling, and the pace of life in cities.  
[Proc. Natl. Acad. Sci.](#), 104(17):7301–7306, 2007. pdf (田)
- [5] J. C. Bohorquez, S. Gourley, A. R. Dixon, M. Spagat, and N. F. Johnson.  
Common ecology quantifies human insurgency.  
[Nature](#), 462:911–914, 2009. pdf (田)
- [6] D. Brockmann, L. Hufnagel, and T. Geisel.  
The scaling laws of human travel.  
[Nature](#), pages 462–465, 2006. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



43 of 53

## References III

- [7] S. V. Buldyrev, R. Parshani, G. Paul, H. E. Stanley, and S. Havlin.  
Catastrophic cascade of failures in interdependent networks.  
[Nature](#), 464:1025–1028, 2010. pdf (田)
- [8] J. T. Cacioppo, J. H. Fowler, and N. A. Christakis.  
Alone in the crowd: The structure and spread of loneliness in a large social network.  
[Journal of Personality and Social Psychology](#), 97:977–991, 2009. pdf (田)
- [9] E. Castronova.  
[Synthetic Worlds: The Business and Culture of Online Games](#).  
University of Chicago Press, Chicago, IL, 2005.

Semester projects

The Plan  
Suggestions for  
Projects  
References



44 of 53

## References IV

- [10] N. A. Christakis and J. H. Fowler.  
The spread of obesity in a large social network over 32 years.  
[New England Journal of Medicine](#), 357:370–379, 2007. pdf (田)
- [11] N. A. Christakis and J. H. Fowler.  
The collective dynamics of smoking in a large social network.  
[New England Journal of Medicine](#), 358:2249–2258, 2008. pdf (田)
- [12] A. Clauset, C. Moore, and M. E. J. Newman.  
Hierarchical structure and the prediction of missing links in networks.  
[Nature](#), 453:98–101, 2008. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



45 of 53

## References V

- [13] A. Clauset, M. Young, and K. S. Gleditsch.  
On the Frequency of Severe Terrorist Events.  
[Journal of Conflict Resolution](#), 51(1):58–87, 2007. pdf (田)
- [14] S. Cooper, F. Khatib, A. Treuille, J. Barbero, J. Lee, M. Beenen, A. Leaver-Fay, D. Baker, Z. Popović, and F. players.  
Predicting protein structures with a multiplayer online game.  
[Nature](#), 466:756–760, 466. pdf (田)
- [15] S. Douady and Y. Couder.  
Phyllotaxis as a dynamical self organizing process Part I: The spiral modes resulting from time-periodic iterations.  
[J. Theor. Biol.](#), 178:255–274, 1996. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



46 of 53

## References VI

- [16] S. Douady and Y. Couder.  
Phyllotaxis as a dynamical self organizing process Part II: The spontaneous formation of a periodicity and the coexistence of spiral and whorled patterns.  
[J. Theor. Biol.](#), 178:275–294, 1996. pdf (田)
- [17] S. Douady and Y. Couder.  
Phyllotaxis as a dynamical self organizing process Part III: The simulation of the transient regimes of ontogeny.  
[J. Theor. Biol.](#), 178:295–312, 1996. pdf (田)
- [18] R. Ferrer i Cancho and R. Solé.  
The small world of human language.  
[Proc. R. Soc. Lond. B](#), 26:2261–2265, 2001. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



47 of 53

## References VII

- [19] J. H. Fowler and N. A. Christakis.  
Dynamic spread of happiness in a large social network: longitudinal analysis over 20 years in the Framingham Heart Study.  
[BMJ](#), 337:article #2338, 2008. pdf (田)
- [20] K.-I. Goh, G. Salvi, B. Kahng, and D. Kim.  
Skeleton and fractal scaling in complex networks.  
[Phys. Rev. Lett.](#), 96:018701, 2006. pdf (田)
- [21] M. C. González, C. A. Hidalgo, and A.-L. Barabási.  
Understanding individual human mobility patterns.  
[Nature](#), 453:779–782, 2008. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



48 of 53



## References VIII

- [22] C. A. Hidalgo, B. Klinger, A.-L. Barabási, and R. Hausman.  
The product space conditions the development of nations.  
[Science](#), 317:482–487, 2007. pdf (田)
- [23] R. A. Hill, R. A. Bentley, and R. I. M. Dunbar.  
Network scaling reveals consistent fractal pattern in hierarchical mammalian societies.  
[Biology Letters](#), 2008. pdf (田)
- [24] N. F. Johnson, M. Spagat, J. A. Restrepo, O. Becerra, J. C. Bohorquez, N. Suarez, E. M. Restrepo, and R. Zarama.  
Universal patterns underlying ongoing wars and terrorism, 2006. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



49 of 53

## References IX

- [25] S. Kauffman.  
The Origins of Order.  
Oxford, 1993.
- [26] M. Kearns, S. Suri, and N. Montfort.  
An experimental study of the coloring problem on human subject networks.  
[Science](#), 313:824–827, 2006. pdf (田)
- [27] G. Kossinets.  
Effects of missing data in social networks.  
[Social Networks](#), 28(3):247–268, 2006. pdf (田)
- [28] G. Kossinets and D. J. Watts.  
Empirical analysis of evolving social networks.  
[Science](#), 311:88–90, 2006. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



50 of 53

## References X

- [29] Y.-Y. Liu, J.-J. Slotine, and A.-L. Barabási.  
Controllability of complex networks.  
[Nature](#), 473:167–173, 2011. pdf (田)
- [30] M. A. Nowak.  
Five rules for the evolution of cooperation.  
[Science](#), 314:1560–1563, 2006. pdf (田)
- [31] D. J. d. S. Price.  
Networks of scientific papers.  
[Science](#), 149:510–515, 1965. pdf (田)
- [32] F. Radicchi, J. J. Ramasco, A. Barrat, and S. Fortunato.  
Complex networks renormalization: Flows and fixed points.  
[Phys. Rev. Lett.](#), 101:148701, 2008. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



51 of 53

## References XI

- [33] M. Scheffer, J. Bascompte, W. A. Brock, V. Brovkin, S. R. Carpenter, V. Dakos, H. Held, E. H. van Nes, M. Rietkerk, and G. Sugihara.  
Early-warning signals for critical transition.  
[Nature](#), 461:53–59, 2009. pdf (田)
- [34] C. Song, S. Havlin, and H. A. Makse.  
Self-similarity of complex networks.  
[Nature](#), 433:392–395, 2005. pdf (田)
- [35] C. Song, S. Havlin, and H. A. Makse.  
Origins of fractality in the growth of complex networks.  
[Nature Physics](#), 2:275–281, 2006. pdf (田)
- [36] S. H. Strogatz.  
Romanesque networks.  
[Nature](#), 433:365–366, 2005. pdf (田)

Semester projects

The Plan  
Suggestions for  
Projects  
References



52 of 53

## References XII

- [37] P. Turchin.  
Historical Dynamics: Why States Rise and Fall.  
Princeton University Press, Princeton, NJ, 2003.

Semester projects

The Plan  
Suggestions for  
Projects  
References



53 of 53