

# Semester projects

## Principles of Complex Systems

### Course CSYS/MATH 300, Fall, 2009

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University of Vermont



# Outline

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## Requirements:

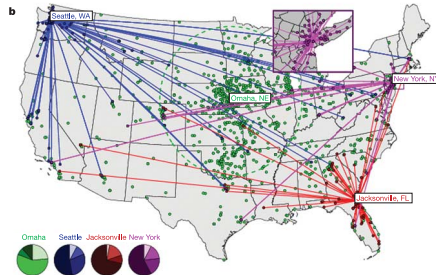
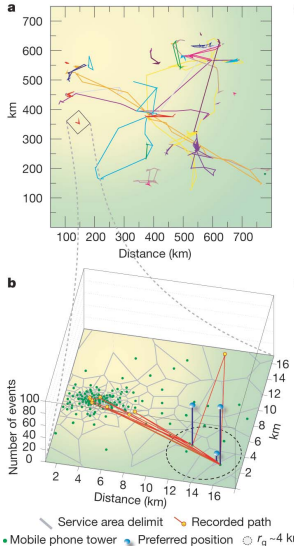
1.  $\approx$  5 minute introduction to project (fourth week)
2. 15 to 20 minute final presentation
3. Report:  $\geq$  5 pages (single space), journal-style
4. Goal: seed papers or help papers along.

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## 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,
- ▶ ...



- ▶ Study movement and interactions of people.
- ▶ Brockmann *et al.* [3] “Where’s George” study.
- ▶ Barabasi’s group: tracking movement via cell phones [12].

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Are there universal signatures that presage system failure?:

## “Early-warning signals for critical transitions”

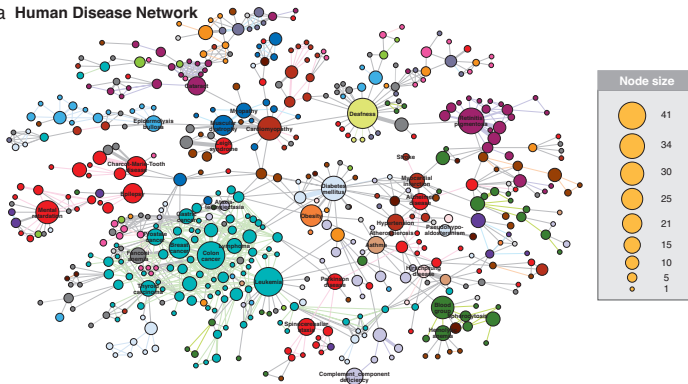
**Abstract:** Complex dynamical systems, ranging from ecosystems to financial markets and the climate, can have tipping points at which a sudden shift to a contrasting dynamical regime may occur. Although predicting such critical points before they are reached is extremely difficult, work in different 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.

Scheffer et al., Nature 2009 <sup>[24]</sup>

(We will talk about work by Doyle et al. on robust-yet-fragile systems)

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

a Human Disease Network

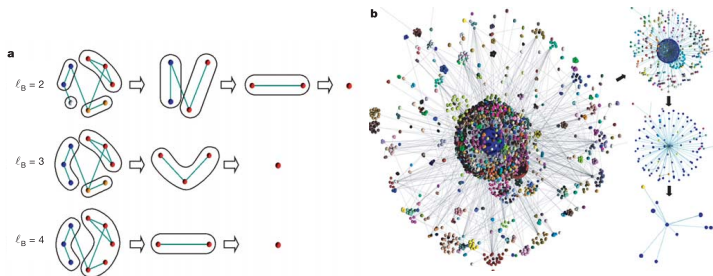




## The problem of missing data in networks:

- ▶ Clauset et al. (2008)  
“Hierarchical structure and the prediction of missing links in networks” [5]
- ▶ Kossinets (2006)  
“Effects of missing data in social networks” [18]

- ▶ Explore “self-similarity of complex networks” [25, 26]  
First work by Song *et al.*, Nature, 2005.
- ▶ See accompanying comment by Strogatz [27]



## Related papers:

- ▶ “Origins of fractality in the growth of complex networks”  
Song et al. (2006a) <sup>[26]</sup>
- ▶ “Skeleton and Fractal Scaling in Complex Networks”  
Go et al. (2006a) <sup>[11]</sup>
- ▶ “Complex Networks Renormalization: Flows and Fixed Points”  
Radicchi et al. (2008a) <sup>[22]</sup>

# project topics:

- ▶ Develop and elaborate an **online experiment** to study some aspect of **social phenomena**
- ▶ e.g., cheating, cooperation, influence, decision-making, etc.

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# project topics:

- ▶ **Statistics:** Study Peter Hoff's (and others') work on **latent variables**.
- ▶ **Idea:** explain connection pattern in a network through hidden individual or dyadic variables
- ▶ Method has been applied to the study of international relations networks.

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# project 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”<sup>[2]</sup>

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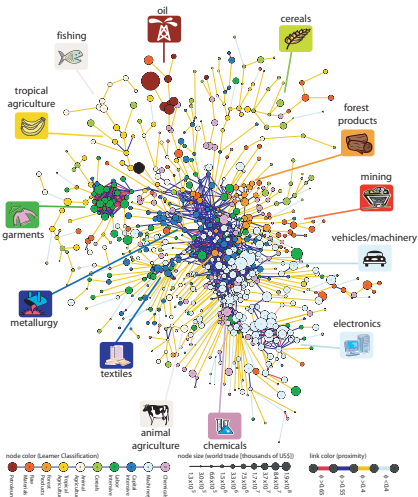
- ▶ Physics/Society—**Wars**: Study work that started with Lewis Richardson's "Variation of the frequency of fatal quarrels with magnitude" in 1949. [23, 29]
- ▶ Specifically explore Clauset et al. and Johnson et al.'s work on terrorist attacks and civil wars. [6, 15]

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# project topics:

- ▶ Study Hidalgo et al.'s “The Product Space Conditions the Development of Nations” [13]
- ▶ 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?



# project topics:

- ▶ Explore proposed measures of system complexity.

## project 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>[14]</sup>.

- ▶ Study scientific collaboration networks.
- ▶ Mounds of data + good models.
- ▶ See seminal work by De Solla Price<sup>[21]</sup>.  
plus modern work by Redner, Newman, *et al.*
- ▶ We will study some of this in class...

- ▶ Study Kearns et al.'s experimental studies of people solving classical graph theory problems<sup>[17]</sup>
- ▶ “An Experimental Study of the Coloring Problem on Human Subject Networks”
- ▶ (Possibly) Run some of these experiments for our class.



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- ▶ Vague/Large:  
Study amazon's recommender networks.

### Customers Who Bought This Item Also Bought



The screenshot shows a navigation arrow on the left and four product recommendations. Each item has a 'LOOK INSIDE!' button above it. The first item is 'Harry Potter Schoolbooks: Fantastic Beasts and...' by J.K. Rowling, priced at \$10.19 with a 4.5-star rating (465 reviews). The second is 'The Tales of Beedle the Bard, Collector's E...' by J.K. Rowling, priced at \$10.88 with a 4.5-star rating (153 reviews). The third is 'Harry, A History: The True Story of a Boy Wizar..' by Melissa Anelli, priced at \$10.88 with a 4.5-star rating (52 reviews). The fourth is 'Inkdeath (Inkheart)' by Cornelia Funke, priced at \$16.49 with a 4.5-star rating (41 reviews).

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See work by Sornette *et al.*.

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

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# project topics:

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

# project topics:

- ▶ Study games (as in game theory) on networks.
- ▶ For cooperation: Review Martin Nowak's recent piece in Science: "Five rules for the evolution of cooperation." [20]
- ▶ Much work to explore: voter models, contagion-type models, etc.

# project topics:

- ▶ **Semantic networks**: explore word-word connection networks generated by linking semantically related words.
- ▶ More general: Explore **language evolution**
- ▶ One paper to start with: “The small world of human language” by Ferrer i Cancho and Solé<sup>[10]</sup>
- ▶ Study spreading of neologisms (also: baby names)
- ▶ Study models/theories/data re the origin and evolution of language.

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- ▶ Investigate **safety codes** (building, fire, etc.).
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# project topics:

- ▶ Study Stuart Kauffman's *nk boolean networks* which model regulatory gene networks<sup>[16]</sup>

## project topics:

- ▶ Critically explore Bejan's Constructal Theory.
- ▶ See Bejan's book "Shape and Structure, from Engineering to Nature."<sup>[1]</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>[28]</sup>
- ▶ Can history Clyodynamics (⊞), Psychohistory, ...
- ▶ Also see “Secular Cycles” (⊞).

## project topics:

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



# project topics:

- ▶ Review: Study Castronova's and others' work on massive multiplayer online games. How do social networks form in these games? <sup>[4]</sup>
- ▶ See work by Johnson et al. on gang formation in the real world and in World of Warcraft (really!).

# project 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<sup>[7, 8, 9]</sup>

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# project topics:

- ▶ Vague/Large:  
Study how the Wikipedia's content is interconnected.



## project topics:

- ▶ 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>[19]</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)

# project 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?
- ▶ Investigate memetics, the 'science' of memes.
- ▶ Sport...

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- ▶ 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.




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# project topics:

- ▶ Vague/Large:  
Study spreading of anything where influence can be measured (very hard).
- ▶ Vague/Large:  
Any interesting micro-macro story to do with evolution, biology, ethics, religion, history, food, international relations, . . .

-  **A. Bejan.**  
*Shape and Structure, from Engineering to Nature.*  
Cambridge Univ. Press, Cambridge, UK, 2000.
-  **L. M. A. Bettencourt, J. Lobo, D. Helbing, Kühnhert,  
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Network scaling reveals consistent fractal pattern in  
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 N. F. Johnson, M. Spagat, J. A. Restrepo, O. Becerra,  
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