

# Semester projects

## Principles of Complex Systems

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

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## Outline

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## Semester projects

### 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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## 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,
- ▶ ...

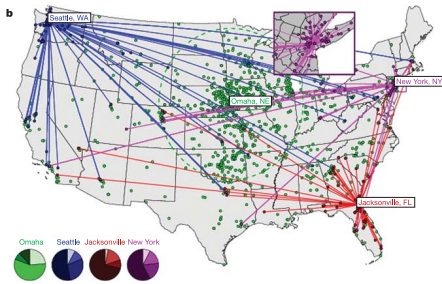
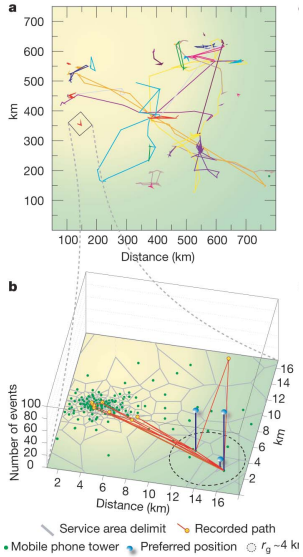
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## topics



- ▶ 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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## System robustness

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 [24]

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

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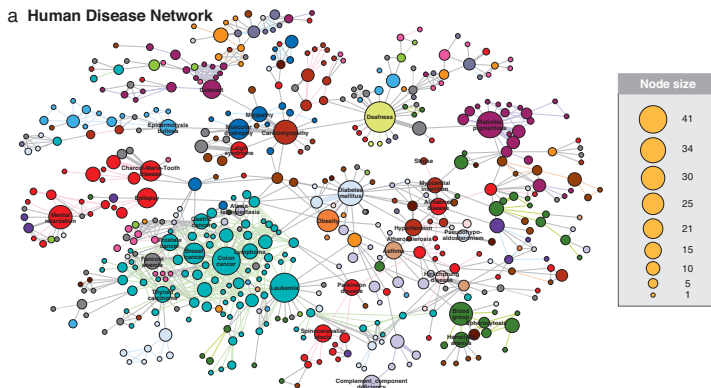
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## topics

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



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## project topics:

### 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]

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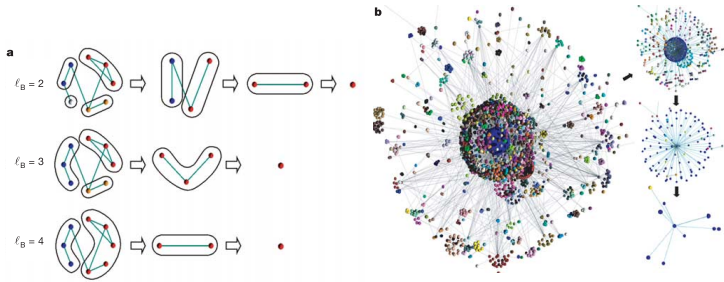
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## topics

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



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## project topics:

### Related papers:

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

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## 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” [2]

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## project topics:

- ▶ 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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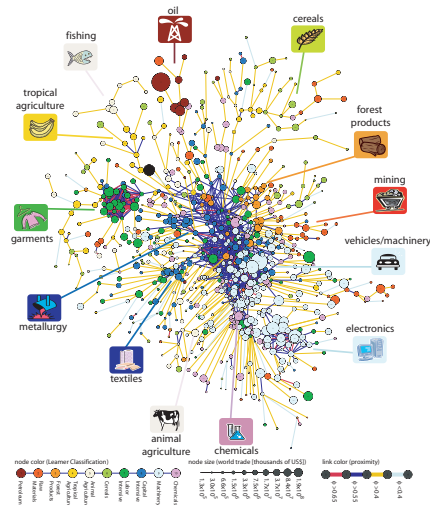
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## project topics:

- ▶ 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?



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## project topics:

- ▶ Explore proposed measures of system complexity.

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Frame 16/45



## 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>.

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## topics

- ▶ 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...

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## topics

- ▶ 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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Frame 19/45



## 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).

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Frame 20/45



## project topics:

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

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Frame 21/45

## 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."<sup>[20]</sup>
- ▶ Much work to explore: voter models, contagion-type models, etc.

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Frame 22/45

## 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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Frame 23/45

## project topics:

- ▶ Investigate **safety codes** (building, fire, etc.).
- ▶ What kind of relational networks do safety codes form? How have they evolved?

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Frame 24/45

## project topics:

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

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Frame 25/45



## 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.

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Frame 26/45



## project topics:

- ▶ Read and critique "Historical Dynamics: Why States Rise and Fall" by Peter Turchin.<sup>[28]</sup>
- ▶ Can history Clyodynamics (田), Psychohistory, ...
- ▶ Also see "Secular Cycles" (田).

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Frame 27/45



## project topics:

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

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Frame 28/45



## project topics:

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

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Frame 29/45



## 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 [7, 8, 9]

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Frame 30/45



## project topics:

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



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Frame 31/45



## 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. [19]
- ▶ "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)

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Frame 32/45





## 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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## topics

- ▶ 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.

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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, . . .

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*Shape and Structure, from Engineering to Nature.*  
Cambridge Univ. Press, Cambridge, UK, 2000.
-  **L. M. A. Bettencourt, J. Lobo, D. Helbing, Kühnhert, and G. B. West.**  
Growth, innovation, scaling, and the pace of life in cities.  
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-  **D. Brockmann, L. Hufnagel, and T. Geisel.**  
The scaling laws of human travel.  
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Hierarchical structure and the prediction of missing links in networks.  
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On the Frequency of Severe Terrorist Events.  
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Part I: The spiral modes resulting from time-periodic iterations.  
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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)
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*Science*, 317:482–487, 2007. [pdf](#) (田)




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Five rules for the evolution of cooperation.  
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