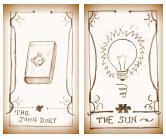
Overview of Complex Networks

Complex Networks | @networksvox
CSYS/MATH 303, Spring, 2016

Prof. Peter Dodds | @peterdodds

Dept. of Mathematics & Statistics | Vermont Complex Systems Center
Vermont Advanced Computing Core | University of Vermont



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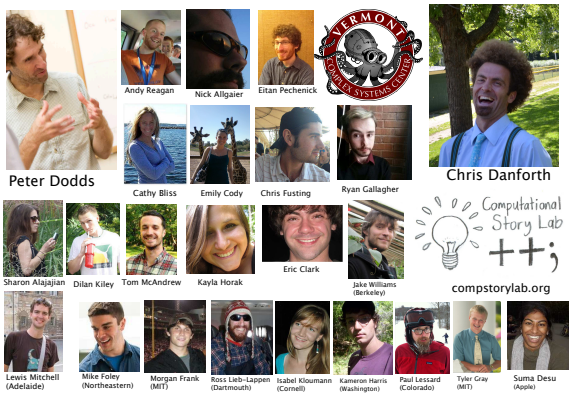

Funding: NSF, NASA, MITRE.

Outline

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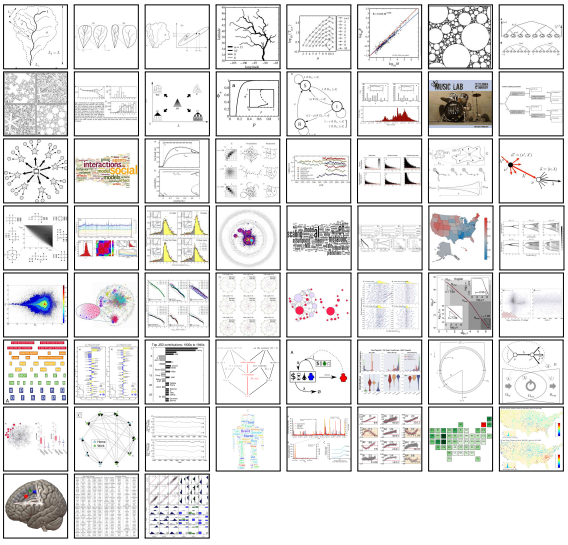

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Basics:

- Instructor: Prof. Peter Dodds
- Lecture room and meeting times: 102 Perkins, Tuesday and Thursday, 1:15 pm to 2:30 pm
- Office: Farrell Hall, second floor, Trinity Campus
- email: peter.dodds@uvm.edu
- Course Website: http://www.uvm.edu/ pdodds/teaching/courses/2016-01UVM-303
- Course Twitter handle: @networksvox
- Course hashtag: #SpringCOcoNuTS2016

Potential paper products:

- The Syllabus and a Poster.

Office hours:

- 2:30 pm to 3:15 pm, Tuesday and Thursday, Perkins 102; 11:00 am to 11:55 am, Wednesday, Farrell., Farrell Hall, second floor, Trinity Campus

Graduate Certificate:

- Principles of Complex Systems is one of two core requirements for UVM's five course Certificate of Graduate Study in Complex Systems.
- Other required course: Prof. Maggie Eppstein's "Modelling Complex Systems" (CSYS/CS 302).
- coCoNuTS: The Sequel to PoCS: "Complex Networks" (CSYS/MATH 303).

Details regarding these artisanal slides:

- Three versions (all in pdf):
  1. Presentation,
  2. Flat Presentation,
  3. Handout (3x2 slides per page).
- Presentation versions are hyperly navigable: ⟲ back + search + forward.
- Web links look like this and are eminently clickable.
- References in slides link to full citation at end. [2]
- Citations contain links to pdfs for papers (if available).
- Some books will be linked to on amazon.
- Brought to you by a frightening melange of XeLaTeX, Beamer, perl, PerlTeX, fevered command-line madness, and an almost fanatical devotion to the indomitable emacs. #superpowers

More super exciting details:

- This is Season 7 of Complex Networks.
- Lectures will be called Episodes.
- All lectures are bottle episodes.
- Other tropes will be involved.
- Last coCoNuTs Episodes are here.

Wonderful foundational support for PoCS and CoNKS has come from the NSF:

- "CAREER: Explorations of Complex Social and Psychological Phenomena through Multiscale Online Sociological Experiments, Empirical Studies, and Theoretical Models." 2009–2015.
- SES Division of Social and Economic Sciences SBE Directorate for Social, Behavioral & Economic Sciences
- Abstract is here.
- Last season's Episodes are here.

Team coCoNuTs

We'll be carrying on with the PoCS Slack:

- Place for discussions about all things PoCS/coCoNuTs including assignments and projects.
- Once invited, please sign up here: http://teampocs.slack.com
- Very good: Install Slack app on laptops, tablets, phone.
- Everyone will behave wonderfully.

Grading breakdown:

- Projects/talks (36%)—Students will work on semester-long projects. Students will develop a proposal in the first few weeks of the course which will be discussed with the instructor for approval.
  Details: 12% for the first talk, 12% for the final talk, and 12% for the written project.
- Assignments (60%)—All assignments will be of equal weight and there will be 10 ± 1 of them.
- General attendance/Class participation (4%)

Schedule in detail:

Week number (dates)	Tuesday	Thursday
1 (1/18 and 1/20)	overview, branching networks I	branching networks I and II
2 (1/25 and 1/27)	branching networks II	optimal supply networks I and II
3 (2/2 and 2/4)	optimal supply networks II	optimal supply networks II
4 (2/9 and 2/11)	optimal supply networks II	optimal supply networks III
5 (2/16 and 2/18)	optimal supply networks III, random networks	random networks
6 (2/23 and 2/25)	generating functions	random bipartite networks
7 (3/1 and 3/3)	Town meeting day	project presentations†
8 (3/8 and 3/10)	Spring Recess	Spring Recess
9 (3/15 and 3/17)	random networks	bipartite networks
10 (3/22 and 3/24)	contagion	contagion
11 (3/29 and 3/31)	contagion	chaotic contagion
12 (4/5 and 4/7)	multilayer networks	multilayer networks
13 (4/12 and 4/14)	assortativity	mixed random networks
14 (4/19 and 4/21)	centrality	structure detection
15 (4/26 and 4/28)	structure detection	structure detection
16 (4/3)	organizational networks	—

†: 3-4 minutes each + 1 or 2 questions;

How grading works:

Questions are worth 3 points according to the following scale:

- 3 = correct or very nearly so.
- 2 = acceptable but needs some revisions.
- 1 = needs major revisions.
- 0 = way off.

Projects

- Semester-long projects.
- Possible theme: Stories, Narratives, and Language.
- Develop proposal in first few weeks.
- May range from novel research to investigation of an established area of complex systems.
- Two talks + written piece + Project on Github Pages.
- Usage of the VACC is encouraged (ability to code well = super powers).
- Massive data sets available, including Twitter.
- Academic output (journal papers) resulting from Principles of Complex Systems and Complex Networks can be found here. Add more!
- We'll go through a list of possible projects soon.

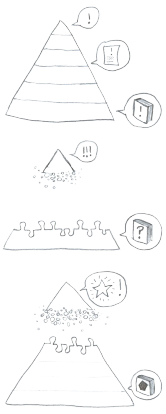
Important things:

1. Classes run from Tuesday, January 19 to Tuesday, May 4.
2. Add/Drop, Audit, Pass/No Pass deadline—Monday, February 1.
3. Last day to withdraw—Monday, April 4 (Never!).
4. Reading and Exam period—Thursday, May 6 to Friday, May 13.

Do check the course Twitter account, @networksvox, for updates regarding the course (part of the course site).

Academic assistance: Anyone who requires assistance in any way (as per the ACCESS program or due to athletic endeavors), please see or contact me as soon as possible.

The narrative hierarchy—Stories and Storytelling on all Scales:

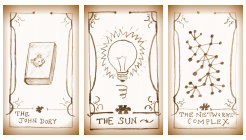


- 1 to 3 word encapsulation = a soundbite = a buzzframe,
- 1 sentence, title,
- few sentences, a haiku,
- a paragraph, abstract,
- short paper, essay,
- long paper,
- chapter,
- book,
- ...

Key Observation:

- Many complex systems can be viewed as complex networks of physical or abstract interactions.
- Opens door to mathematical and numerical analysis.
- Dominant approach of last decade of a theoretical-physics/stat-mechish flavor.
- Mindboggling amount of work published on complex networks since 1998 ...
- ...due to your typical theoretical physicist:

- *Piranha physicus*
- Hunt in packs.
- Feast on new and interesting ideas (see chaos, cellular automata, ...)



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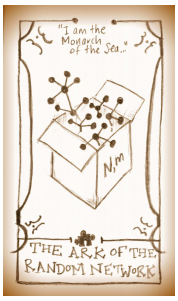

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Popularity (according to Google Scholar)

"Collective dynamics of 'small-world' networks" [10]

Duncan Watts and Steve Strogatz
Nature, 1998

Times cited: $\sim 28,017$ (as of January 18, 2016)

"Emergence of scaling in random networks" [3]

László Barabási and Réka Albert
Science, 1999

Times cited: $\sim 24,236$ (as of January 18, 2016)

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Models

1. generalized random networks:
   - Arbitrary degree distribution P_k.
   - Wire nodes together randomly.
   - Create ensemble to test deviations from randomness.
   - Interesting, applicable, rich mathematically.
   - We will have fun with these things ...

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Models

Some important models:

1. generalized random networks (touched on in 300)
2. scale-free networks (partly covered in 300)
3. small-world networks (covered in 300)
4. statistical generative models (p^*)
5. generalized affiliation networks (covered in 300)

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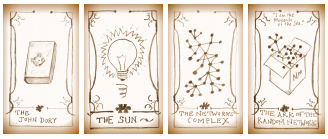

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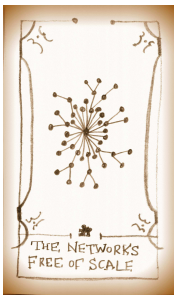

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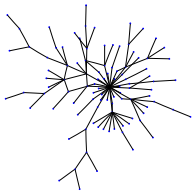
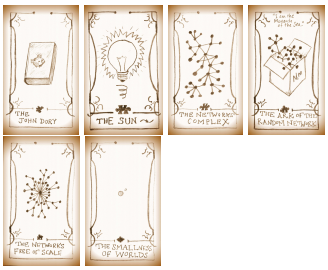
Models

2. 'scale-free networks':



$\gamma = 2.5$, $\langle k \rangle = 1.8$, $N = 150$

- Introduced by Barabasi and Albert [3]
- Generative model
- Preferential attachment model with growth:
- $P[\text{attachment to node } i] \propto k_i^{\alpha}$.
- Produces $P_k \sim k^{-\gamma}$ when $\alpha = 1$.
- Trickiness: other models generate skewed degree distributions.



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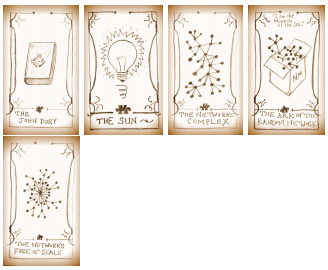

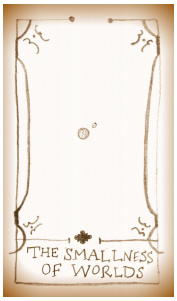

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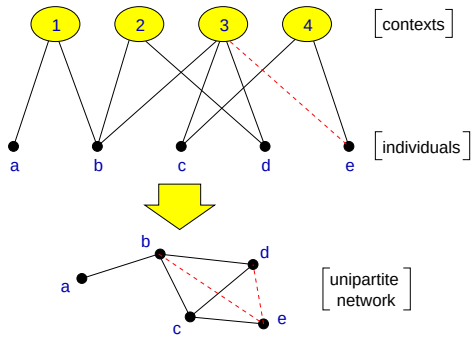
5. generalized affiliation networks



Bipartite affiliation networks: boards and directors, movies and actors.

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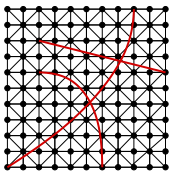
3. small-world networks

- Introduced by Watts and Strogatz [10]

Two scales:

- local regularity (an individual's friends know each other)
- global randomness (shortcuts).

- Shortcuts allow disease to jump
- Number of infectives increases exponentially in time
- Facilitates synchronization



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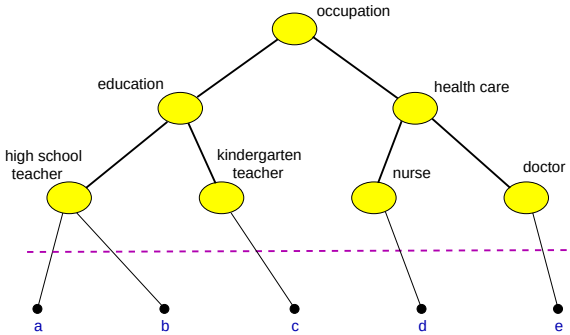

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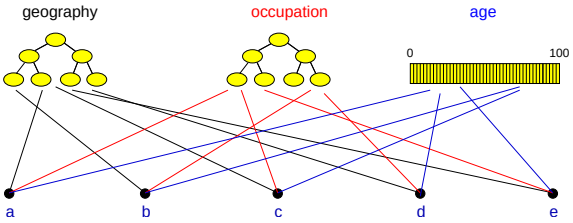


- Blau & Schwartz [4], Simmel [8], Breiger [6], Watts *et al.* [9]

Bonus materials:

Textbooks:

- Mark Newman (Physics, Michigan)
  "Networks: An Introduction"
- David Easley and Jon Kleinberg (Economics and Computer Science, Cornell)
  "Networks, Crowds, and Markets: Reasoning About a Highly Connected World"

Bonus materials:

Review articles:

- S. Boccaletti et al.,
  Physics Reports, 2006,
  "Complex networks: structure and dynamics" [5]
  Times cited: ~ 6,034 (as of January 18, 2016)
- M. Newman,
  SIAM Review, 2003,
  "The structure and function of complex networks" [7]
  Times cited: ~ 13,536 (as of January 18, 2016)
- R. Albert and A.-L. Barabási
  Reviews of Modern Physics, 2002,
  "Statistical mechanics of complex networks" [1]
  Times cited: ~ 16,041 (as of January 18, 2016)

Nutshell:

Overview Key Points:

- The field of complex networks came into existence in the late 1990s.
- Explosion of papers and interest since 1998/99.
- Hardened up much thinking about complex systems.
- Specific focus on networks that are large-scale, sparse, natural or man-made, evolving and dynamic, and (crucially) measurable.
- Three main (blurred) categories:
  1. Physical (e.g., river networks),
  2. Interactional (e.g., social networks),
  3. Abstract (e.g., thesauri).

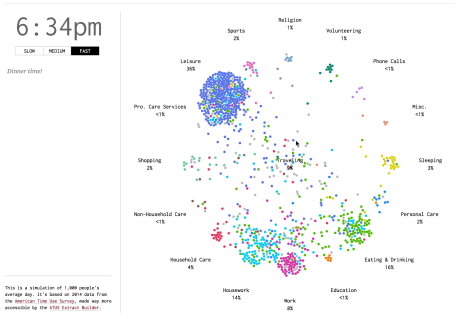
Nutshell:

Overview Key Points (cont.):

- Obvious connections with the vast extant field of graph theory.
- But focus on dynamics is more of a physics/stat-mech/comp-sci flavor.
- Two main areas of focus:
  1. Description: Characterizing very large networks
  2. Explanation: Micro story ⇒ Macro features
- Some essential structural aspects are understood: degree distribution, clustering, assortativity, group structure, overall structure, ...
- Still much work to be done, especially with respect to dynamics ...exciting!

Neural solace—Temporal social networks:

Visualizing a day in the life of Americans



- Source: Flowing Data/Nathan Yau.

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[1] R. Albert and A.-L. Barabási.
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[2] P. W. Anderson.
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Science, 177(4047):393–396, 1972. pdf

[3] A.-L. Barabási and R. Albert.
Emergence of scaling in random networks.
Science, 286:509–511, 1999. pdf

[4] P. M. Blau and J. E. Schwartz.
Crosscutting Social Circles.
Academic Press, Orlando, FL, 1984.

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[5] S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, and D.-U. Hwang.
Complex networks: Structure and dynamics.
Physics Reports, 424:175–308, 2006. pdf

[6] R. L. Breiger.
The duality of persons and groups.
Social Forces, 53(2):181–190, 1974. pdf

[7] M. E. J. Newman.
The structure and function of complex networks.
SIAM Rev., 45(2):167–256, 2003. pdf

[8] G. Simmel.
The number of members as determining the sociological form of the group. I.
American Journal of Sociology, 8:1–46, 1902.

References III

[9] D. J. Watts, P. S. Dodds, and M. E. J. Newman.
Identity and search in social networks.
Science, 296:1302–1305, 2002. pdf

[10] D. J. Watts and S. J. Strogatz.
Collective dynamics of 'small-world' networks.
Nature, 393:440–442, 1998. pdf