Overview of Complex Networks

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Complex Networks | @networksvox
CSYS/MATH 303, Spring, 2019

Prof. Peter Dodds | @peterdodds

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

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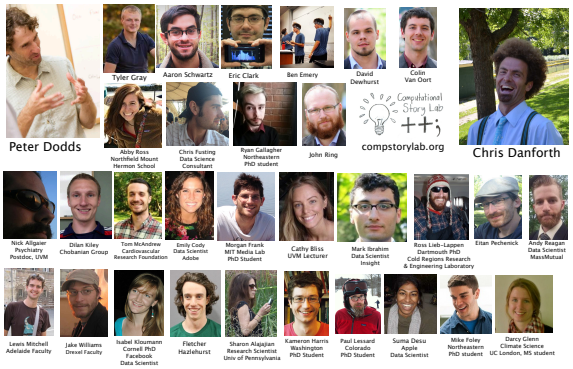
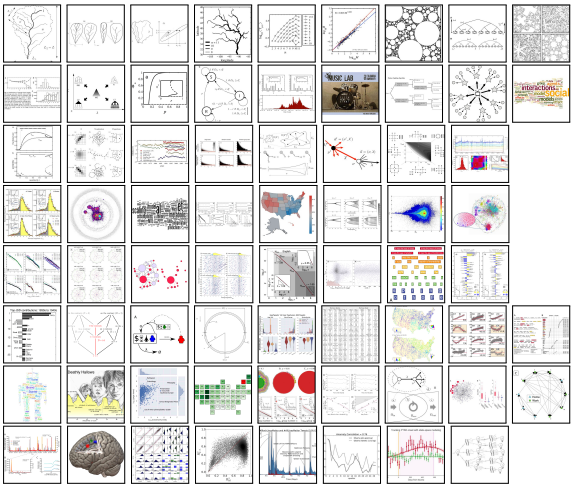
Outline



Funding: NSF, NASA, MITRE.



Basics:

- Instructor: Prof. Peter Dodds
- Lecture room and meeting times: Decision Theater, Farrell Hall, Tuesday and Thursday, 1:15 pm to 2:30 pm
- Office: Farrell Hall, second floor, Trinity Campus
- email: pdodds+coconuts@uvm.edu
- Course Website: http://www.uvm.edu/pdodds/teaching/courses/2019-01UVM-303
- Course Twitter handle: @networksvox
- Course hashtag: #SpringCOcoNuTS2019

Potential paper products:

- The Syllabus and a Poster.

Office hours:

- 10:05 am to 12:00 pm, Tuesday and Thursday, 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.
  #evilsuperpowers

More super exciting details:

- We use Open Sans and make math look good:

```
\setmainfont[Ligatures=TeX]{Open Sans}
\setsansfont[Ligatures=TeX]{Open Sans}
\usefonttheme[onlymath]{serif}
```

- Working towards putting the course on Github.
- And writing a book. A few books.

Yet more super exciting details:

- This is Season 9 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.

Important things:

1. Classes run from Tuesday, January 16 to Thursday, May 4.
2. Add/Drop, Audit, Pass/No Pass deadline—Monday, January 29.
3. Last day to withdraw—Monday, April 2 (Never!).
4. Reading and Exam period—Monday, May 7 to Friday, May 11.

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.

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 (1/16 and 1/18)	overview, branching networks I	branching networks I and II
2 (1/23 and 1/25)	branching networks II	optimal supply networks I and II
3 (1/30 and 2/1)	optimal supply networks II	optimal supply networks II
4 (2/6 and 2/8)	optimal supply networks II	optimal supply networks III
5 (2/13 and 2/15)	optimal supply networks III, random networks	random networks
6 (2/20 and 2/22)	generating functions	random bipartite networks
7 (2/27 and 3/1)	Town meeting day	project presentations†
8 (3/6 and 3/8)	Spring Recess	Spring Recess
9 (3/13 and 3/15)	random networks	bipartite networks
10 (3/20 and 3/22)	contagion	contagion
11 (3/27 and 3/29)	contagion	chaotic contagion
12 (4/3 and 4/5)	multilayer networks	multilayer networks
13 (4/10 and 4/12)	assortativity	mixed random networks
14 (4/17 and 4/19)	centrality	structure detection
15 (4/24 and 4/26)	structure detection	structure detection
16 (5/1 and 5/3)	organizational networks	special topics

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

How grading works:

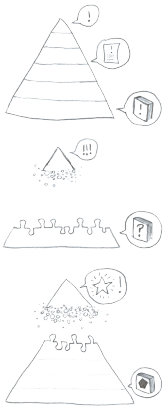
Questions are worth 3 points according to the following scale:

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

Projects

- Semester-long projects, teams (maybe multiple)
- Big themes: Stories, Narratives, and Language.
- Big goal: Aim to submit to arXiv/journal by end of semester.
- Continue from PoCS/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!

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, ...)

Popularity (according to Google Scholar)

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

Duncan Watts and Steve Strogatz
Nature, 1998

Times cited: 35,226 (as of January 15, 2018)

"Emergence of scaling in random networks" [3]

László Barabási and Réka Albert
Science, 1999

Times cited: 30,242 (as of January 15, 2018)

Models

Some important models:

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

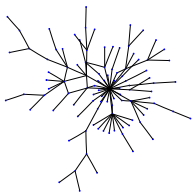
Models

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 ...

Models

2. 'scale-free networks':



γ = 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.

Models

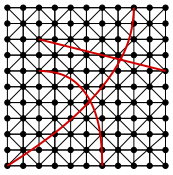
3. small-world networks

- Introduced by Watts and Strogatz [10]

Two scales:

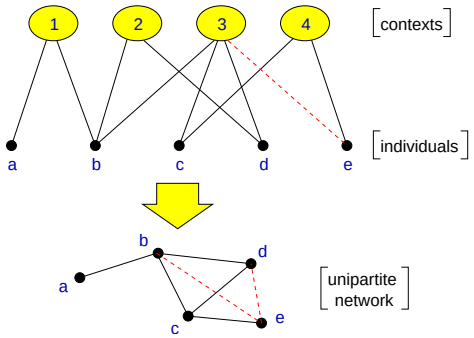
- local regularity (an individual's friends know each other)
- global randomness (shortcuts).

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



Models

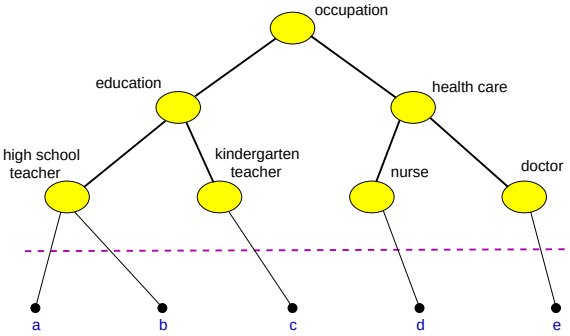
5. generalized affiliation networks



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

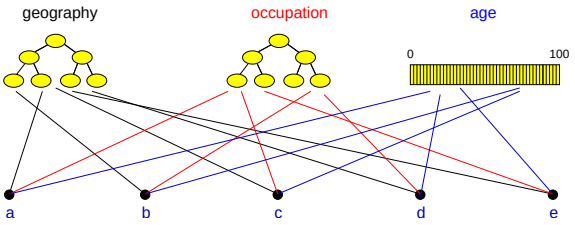
Models

5. generalized affiliation networks



Models

5. generalized affiliation networks



- 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: 7,897 (as of January 15, 2018)
- M. Newman,
  SIAM Review, 2003,
  "The structure and function of complex networks" [7]
  Times cited: 16,768 (as of January 15, 2018)
- R. Albert and A.-L. Barabási
  Reviews of Modern Physics, 2002,
  "Statistical mechanics of complex networks" [1]
  Times cited: 20,656 (as of January 15, 2018)

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).

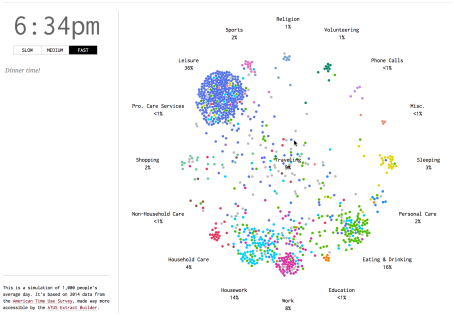
Nutshell:

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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More is different.
Science, 177(4047):393–396, 1972. pdf

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Emergence of scaling in random networks.
Science, 286:509–511, 1999. pdf

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

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[5] S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, and D.-U. Hwang.
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[6] R. L. Breiger.
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Social Forces, 53(2):181–190, 1974. pdf

[7] M. E. J. Newman.
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SIAM Rev., 45(2):167–256, 2003. pdf

[8] G. Simmel.
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American Journal of Sociology, 8:1–46, 1902.

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[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