Overview of Complex Networks

Last updated: 2019/01/14, 22:05:08

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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Sealie & Lambie
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Special Guest Executive Producer

📷 On Instagram at pratchett_the_cat 🔗

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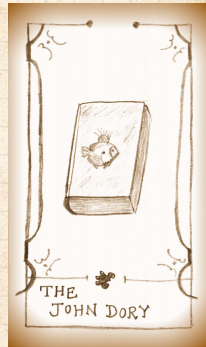Everything is connected

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THE NETWORKS COMPLEX

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THE JOHN DORY

Peter Dodds

Tyler Gray Aaron Schwartz Eric Clark Ben Emery David Dewhurst Colin Van Oort

Abby Ross
Northfield Mount
Hermon School

Chris Fusting
Data Science
Consultant

Ryan Gallagher
Northeastern
PhD student

John Ring

compstorylab.org

Chris Danforth

Nick Allgaier
Psychiatry
Postdoc, UVM

Dilan Kiley
Chobanian Group

Tom McAndrew
Cardiovascular
Research Foundation

Emily Cody
Data Scientist
Adobe

Morgan Frank
MIT Media Lab
PhD Student

Cathy Bliss
UVM Lecturer

Mark Ibrahim
Data Scientist
Insight

Ross Lieb-Lappen
Dartmouth PhD
Cold Regions Research
& Engineering Laboratory

Eitan Pechenick

Andy Reagan
Data Scientist
MassMutual

Lewis Mitchell
Adelaide Faculty

Jake Williams
Drexel Faculty

Isabel Kloumann
Cornell PhD
Facebook
Data Scientist

Fletcher
Hazlehurst

Sharon Alajajian
Research Scientist
Univ of Pennsylvania

Kameron Harris
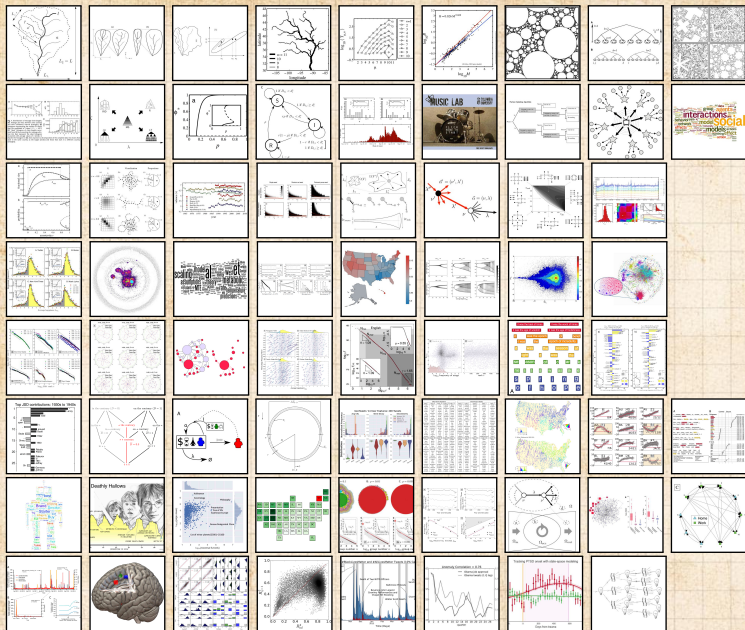Washington
PhD Student

Paul Lessard
Colorado
PhD Student

Suma Desu
Apple
Data Scientist

Mike Foley
Northeastern
PhD student

Darcy Glenn
Climate Science
UC London, MS student

Funding: NSF, NASA, MITRE.

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Basics:

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- 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

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Potential paper products:

🎲 The Syllabus ⬈ and a Poster ⬈.

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Office hours:

🧊 10:05 am to 12:00 pm, Tuesday and Thursday,
Farrell Hall, second floor, Trinity Campus

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Office hours:

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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).

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Details regarding these artisanal slides:

Three versions (all in pdf):

1. Presentation,
2. Flat Presentation,
3. Handout (3x2 slides per page).

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- References in slides link to full citation at end. [2]

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  indomitable emacs ⬀.
  #evilsuperpowers

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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.

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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�.

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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 .

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Team coCoNuTs

We'll be carrying on with the PoCS Slack:

Place for discussions about all things PoCS/coCoNuTs including assignments and projects.

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- Very good: Install Slack app on laptops, tablets, phone.

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- 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%)

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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.

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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.

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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;

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Projects

- Semester-long projects, teams (maybe multiple)

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Projects

- Semester-long projects, teams (maybe multiple)
- Big themes: Stories, Narratives, and Language.

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- 🎲 Semester-long projects, teams (maybe multiple)
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- 🎲 Continue from PoCS/Develop proposal in first few weeks

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🗃 Semester-long projects, teams (maybe multiple)

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🗃 May range from novel research to investigation of an established area of complex systems.

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🎲 Usage of the VACC ⬚ is encouraged (ability to code well = super powers).

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- Two talks + written piece + Project on Github Pages.
- Usage of the VACC☒ is encouraged (ability to code well = super powers).
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- Academic output (journal papers) resulting from Principles of Complex Systems and Complex Networks can be found here☒. Add more!

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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,
- 🧊 ...

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Key Observation:

Many **complex systems**
can be viewed as **complex networks**
of physical or abstract interactions.

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Key Observation:

- Many complex systems can be viewed as complex networks of physical or abstract interactions.
- Opens door to mathematical and numerical analysis.

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Key Observation:

- Many complex systems
  can be viewed as complex networks
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- Opens door to mathematical and numerical
  analysis.

- Dominant approach of last decade of a
  theoretical-physics/stat-mechish flavor.

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- Mindboggling amount of work published on
  complex networks since 1998 …

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- …due to your typical theoretical physicist:

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Piranha physicus

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- ...due to your typical theoretical physicist:

- *Piranha physicus*
- Hunt in packs.

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

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

> Duncan Watts and Steve Strogatz
> Nature, 1998
>
> Times cited: ⬚ (as of January 15, 2018)

"Emergence of scaling in random networks" [3]

> László Barabási and Réka Albert
> Science, 1999
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"Emergence of scaling in random networks" [3]

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Science, 1999

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

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Models

Some important models:

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Some important models:

1. generalized random networks (touched on in PoCS)

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1. generalized random networks (touched on in PoCS)

2. scale-free networks ⬈ (partly covered in PoCS)

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2. scale-free networks ⬀ (partly covered in PoCS)
3. small-world networks ⬀ (covered in PoCS)
4. statistical generative models (p^*)

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3. small-world networks ☐ (covered in PoCS)
4. statistical generative models (p^*)
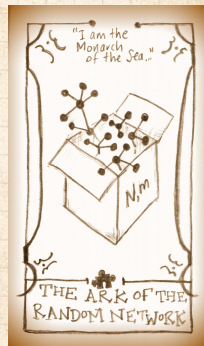5. generalized affiliation networks (covered in PoCS)

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"I am the Monarch of the Sea..."

THE ARK OF THE RANDOM NETWORK

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1. generalized random networks:

🧊 Arbitrary degree distribution P_k.

Models

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🧊 Wire nodes together randomly.

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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.

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Models

1. generalized random networks:

- Arbitrary degree distribution P_k.
- Wire nodes together randomly.
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- Interesting, applicable, rich mathematically.

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Models

1. generalized random networks:

- Arbitrary degree distribution P_k.
- Wire nodes together randomly.
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- Interesting, applicable, rich mathematically.
- We will have fun with these things ...
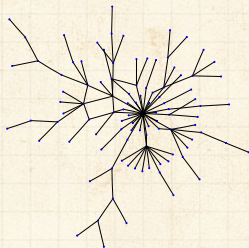
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Models

2. 'scale-free networks':

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

Models

2. 'scale-free networks':

📦 Introduced by Barabasi and Albert [3]

📦 Generative model

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

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Models

2. 'scale-free networks':

- Introduced by Barabasi and Albert [3]
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- Preferential attachment model with growth:

$\gamma = 2.5$, $\langle k \rangle = 1.8$, $N = 150$
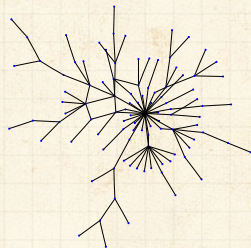
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2. 'scale-free networks':

- Introduced by Barabasi and Albert [3]
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- Preferential attachment model with growth:
- $P[\text{attachment to node } i] \propto k_i^\alpha$.

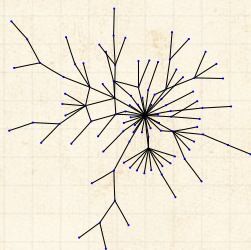$\gamma = 2.5$, $\langle k \rangle = 1.8$,
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2. 'scale-free networks':
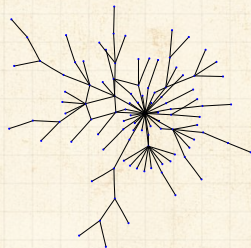

- Introduced by Barabasi and Albert [3]
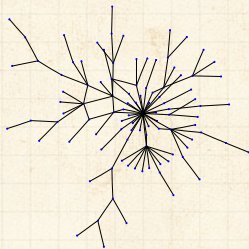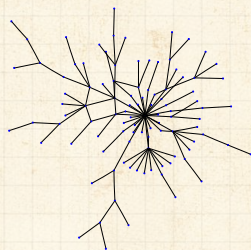- Generative model
- Preferential attachment model with growth:
- $P[\text{attachment to node } i] \propto k_i^{\alpha}$.
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$\gamma = 2.5$, $\langle k \rangle = 1.8$,
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2. 'scale-free networks':

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- 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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THE SMALLNESS OF WORLDS

Models

3. small-world networks

🎲 Introduced by Watts and Strogatz [10]

Models

3. small-world networks

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Two scales:

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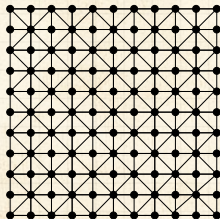
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Models

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Two scales:

 local regularity (an individual's friends know each other)

Models

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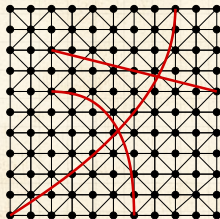@networksvox
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Models

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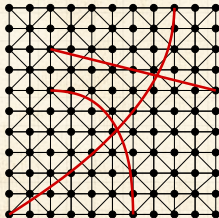References

3. small-world networks

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🧊 global randomness (shortcuts).

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🧊 Number of infectives increases exponentially in time

Models

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Two scales:

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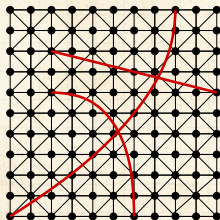
🎲 global randomness (shortcuts).

🎲 Shortcuts allow disease to jump

🎲 Number of infectives increases exponentially in time

🎲 Facilitates synchronization

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THE SUN

THE THEORY OF SIX DEGREES

Models

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5. generalized affiliation networks

[contexts]

[individuals]
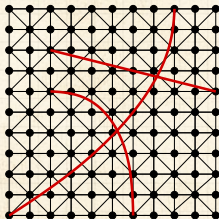
[unipartite
 network]
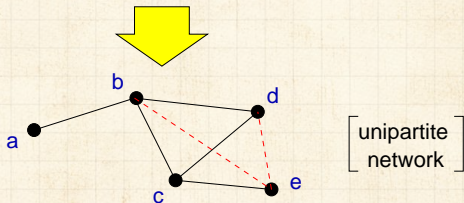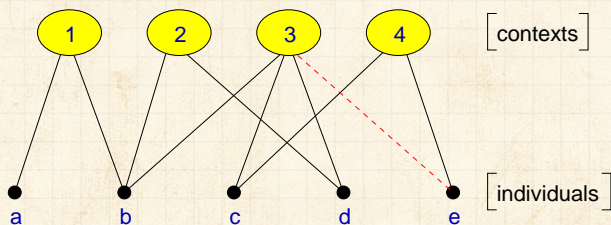
Bipartite affiliation networks: boards and directors,
movies and actors.
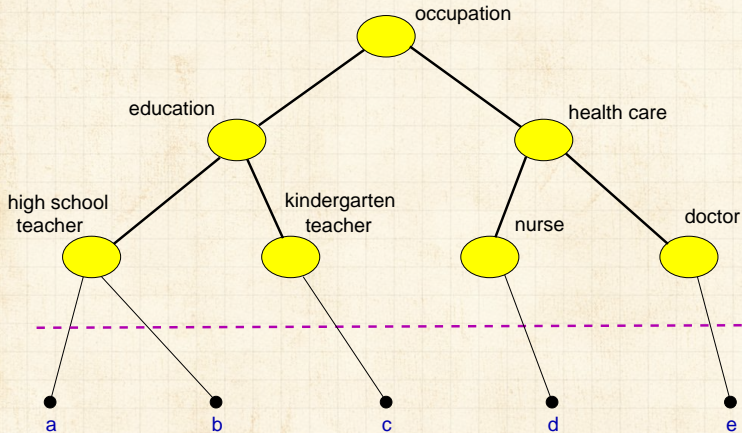
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5. generalized affiliation networks

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5. generalized affiliation networks
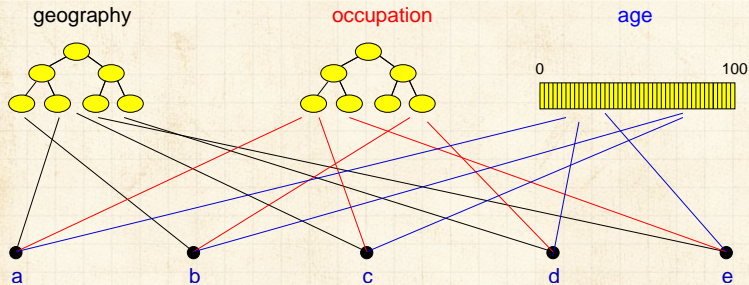
Blau & Schwartz [4], Simmel [8], Breiger [6], Watts *et al.* [9]

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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" ☑

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Review articles:

S. Boccaletti et al.,
Physics Reports, 2006,
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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)

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Overview Key Points:

🎲 The field of complex networks came into existence in the late 1990s.

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Nutshell:

Overview Key Points:

- ♣ The field of complex networks came into existence in the late 1990s.
- ♣ Explosion of papers and interest since 1998/99.

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Nutshell:

Overview Key Points:

- The field of complex networks came into existence in the late 1990s.
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- Hardened up much thinking about complex systems.

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Nutshell:

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- ♣ 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.

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Nutshell:

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- ⬢ 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).

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Nutshell:

Overview Key Points (cont.):

🎲 Obvious connections with the vast extant field of graph theory.

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Nutshell:

Overview Key Points (cont.):

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🎲 But focus on dynamics is more of a physics/stat-mech/comp-sci flavor.

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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 $\Rightarrow$ Macro features

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Nutshell:

Overview Key Points (cont.):

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🎲 Some essential structural aspects are understood: degree distribution, clustering, assortativity, group structure, overall structure, ...

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♙ Still much work to be done, especially with respect to dynamics ...

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- 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!

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Visualizing a day in the life of Americans ⌉
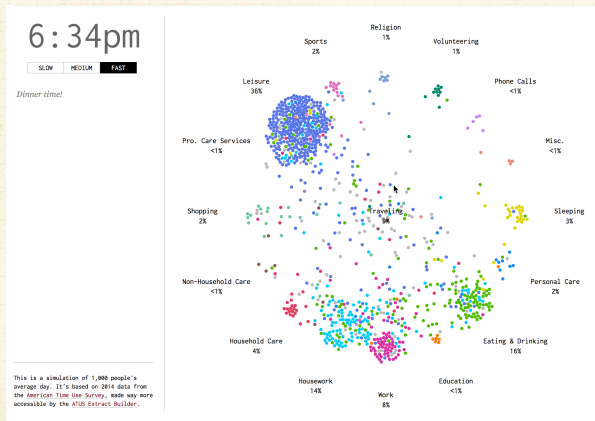
Source: Flowing Data/Nathan Yau.

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[9]   D. J. Watts, P. S. Dodds, and M. E. J. Newman.
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      Science, 296:1302–1305, 2002. pdf 🔗

[10] D. J. Watts and S. J. Strogatz.
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