

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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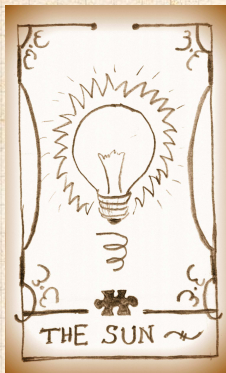
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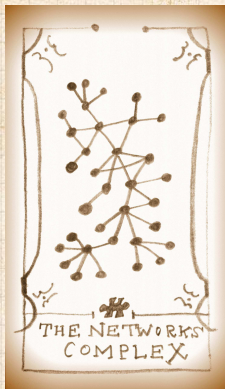
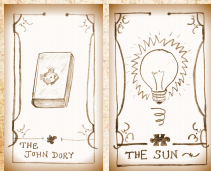
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Andy Reagan



Nick Allgaier



Eitan Pechenick



Chris Danforth



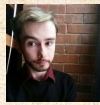
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Chris Fusting



Ryan Gallagher



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Dilan Kiley



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Funding: NSF, NASA, MITRE.

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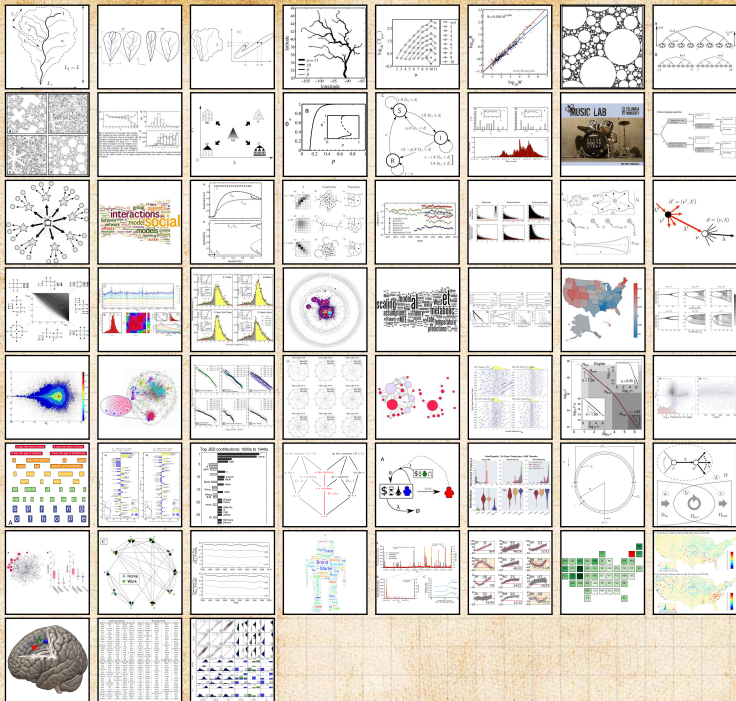
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Basics:

- ▶ 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

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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).

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


- ▶ Some books will be linked to on amazon.

- ▶ Brought to you by a frightening melange of , , , , , and an almost fanatical devotion  to the

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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.

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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.
- ▶ Once invited, please sign up here:
<http://teampocs.slack.com>
- ▶ Very good: Install Slack app on laptops, tablets, phone.
- ▶ Everyone will behave wonderfully.



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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%)**



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.



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.



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;

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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 VACCE](#) 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.

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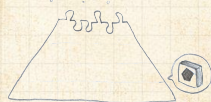
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The narrative hierarchy—Stories and Storytelling on all Scales: ↗



- ▶ 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.
- ▶ Opens door to mathematical and numerical analysis.
- ▶ Dominant approach of last decade of a theoretical-physics/stat-mech flavor.
- ▶ Mindboggling amount of work published on complex networks since 1998 ...
- ▶ ...due to your typical theoretical physicist!



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- ▶ 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:



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- ▶ 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: ~ 28,017  (as of January 18, 2016)

“Emergence of scaling in random networks”^[3]

László Barabási and Réka Albert
Science, 1999

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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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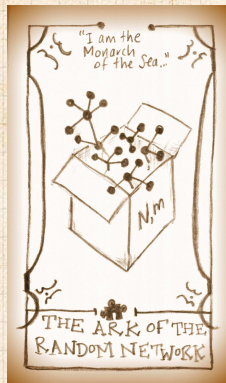
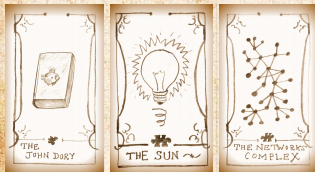
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- ▶ Arbitrary degree distribution P_k .
- ▶ Wire nodes together randomly.
- ▶ Create ensemble to test deviations from randomness.
- ▶ Interesting, applicable, rich mathematically.
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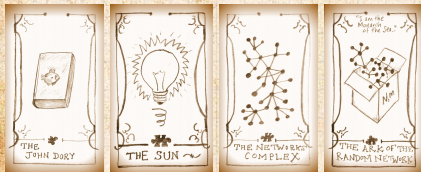
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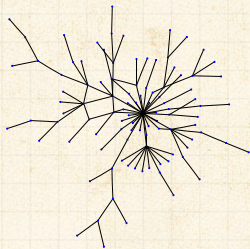


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2. 'scale-free networks':



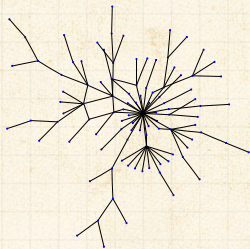
$$\gamma = 2.5, \langle k \rangle = 1.8, \\ N = 150$$

- ▶ Introduced by Barabasi and Albert [1]
- ▶ 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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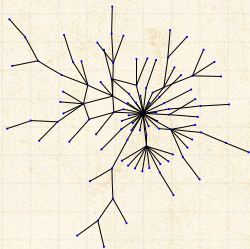


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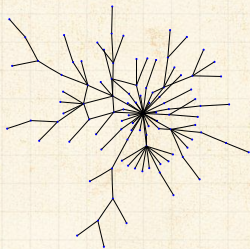
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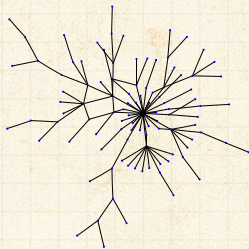
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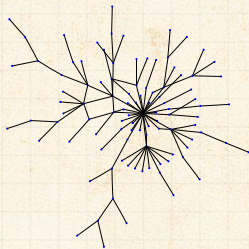


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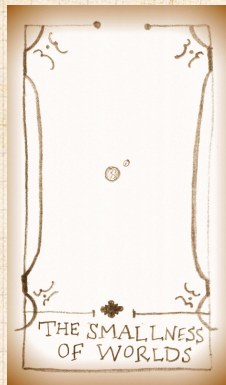
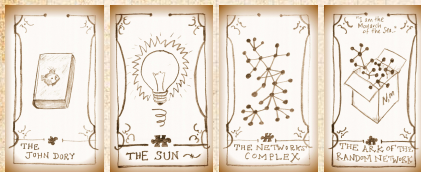
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3. small-world networks

- ▶ Introduced by Watts and Strogatz ^[10]
- ▶ **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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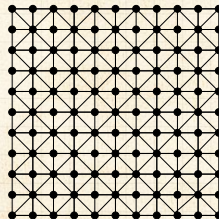
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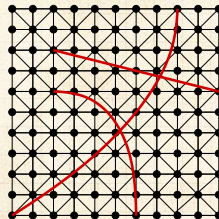
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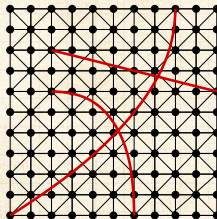
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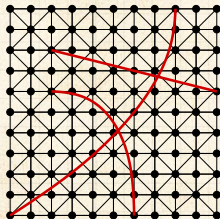
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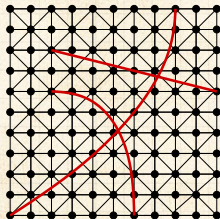
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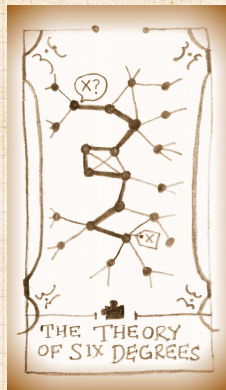
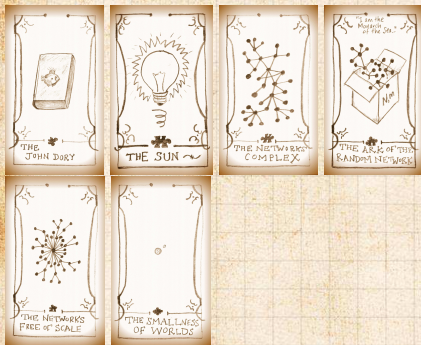
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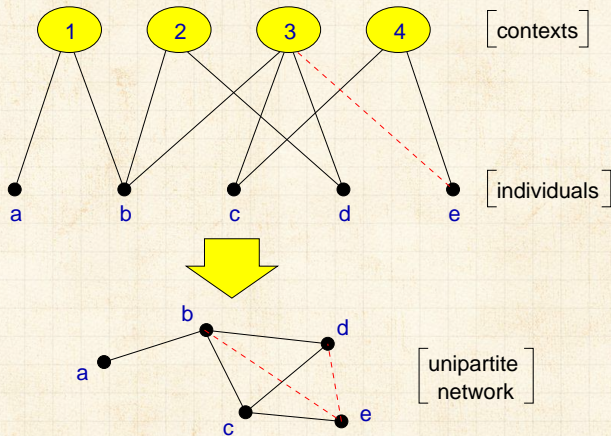


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5. generalized affiliation networks



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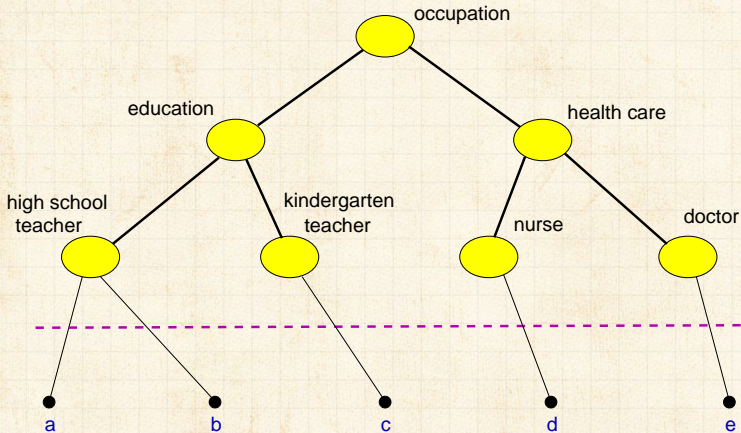
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Bipartite affiliation networks: boards and directors,
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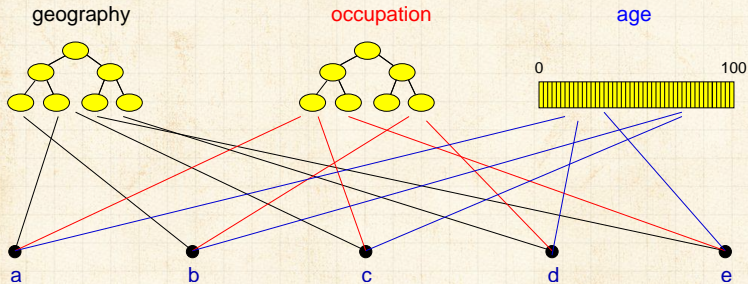


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► Blau & Schwartz ^[4], Simmel ^[8], Breiger ^[6], Watts *et al.* ^[9]



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Bonus materials:

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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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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)

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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),
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 3. **Abstract** (e.g., thesauri).

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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
- ▶ 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 ...

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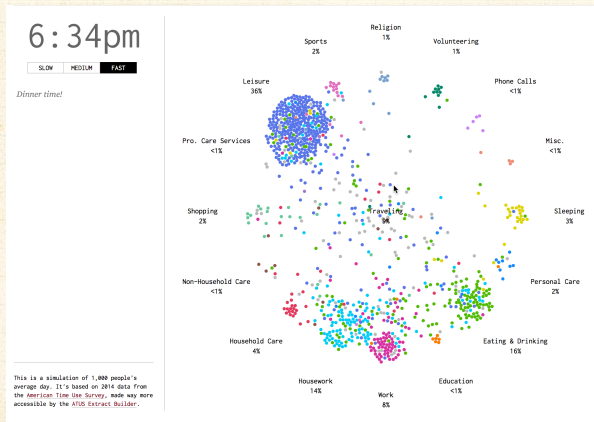
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► Source: Flowing Data/Nathan Yau.



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