# Overview of Complex Systems

## Principles of Complex Systems | @pocsvox
## CSYS/MATH 300, Fall, 2017

Prof. Peter Dodds | @peterdodds

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









# Outline





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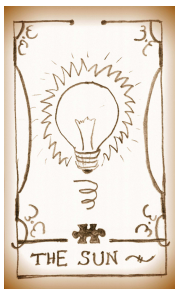


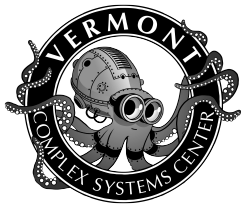



# These slides are also brought to you by:

## Special Guest Executive Producer: Pratchett

On Instagram at pratchett_the_cat






Describe | Explain | Create | Share | Ethos: Play

vermontcomplexsystems.org

## Vermont Complex Systems Center (2006–):

- Diverse research and teaching portfolio (> 400 papers in 2010–2015).
- Funding from many sources: NSF, NIH, DARPA, MITRE, Microsoft, foundations. In 2010–2015, $70M tagged as Complex Systems.
- Regular global press coverage: NYT, BBC, NatGeo, ...
- Conferences: “Big Data, Big Stories”, “Big Scale, Big Fail”, “Prediction: the Next Big Thing” and Flash Mob Research events.
- Well developed Educational platform in Complex Systems and Data Science.
- Faculty hires of true Complex Systems scholars (+4 now).
- Numerous NSF CAREER awards (including PECASE).
- Connecting Graduate and Undergraduate Students across campus (SCRAPS) leading to real research output.





## Vermont Complex Systems Center—Misfit toys:


Peter Dodds, Math/Stats


Josh Bongard, CS


Chris Danforth, Math/Stats


Maggie Eppstein, CS


Hugh Garavan, Neu-ro/Psychiatry


Yves Dubief, ME


Jim Bagrow, Math/Stats


Mads Almassalkhi, EE


Paul Hines, EE


Brian Tivnan, MITRE


Laurent Hébert-Dufresne, CS


Puck Rombach, Math/Stats



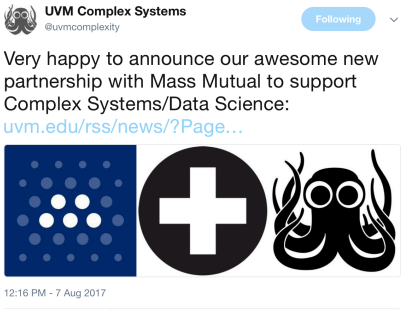
## We're interested in many things:

Sociotechnical systems
Social Contagion and Influence
Happiness and Well-being
Language and Stories
Social unrest
Conflict
Robotics
Artificial Intelligence

Data Science
Complex Networks
Climate
Biology
Ecology
Geomorphology
Space
Complex Fluids
(Smart) Power Grids
Critical infrastructure

Defense Policy
Health systems
Food systems
Epidemiology
Pandemics
Organizations
Economics
Wealth inequality
Financial Systems










## Educational mission:

- Data Science Undergrad.
- Graduate Certificate in Complex Systems.
- Latest: MS in Complex Systems and Data Science.
- Next: PhD in The Study of Interesting Things.

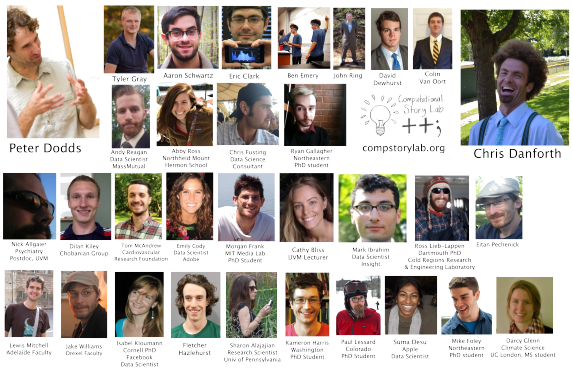


## Graduate Certificate in Complex Systems (and Data Science):

- Principles of Complex Systems is one of two core requirements for UVM's five course teaching-learning/certificate-of-study-in-complex-systems/Certificate of Graduate Study in Complex Systems.
- Other required course: Prof. Maggie Eppstein's “Modelling Complex Systems” (CSYS/CS 302).
- To be required: Prof. Jim Bagrow's “Data Science I” (STAT 287)
- The Sequel to PoCS: “Complex Networks” (CSYS/MATH 303).

## Leveling up:

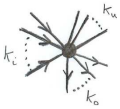
- MS in Complex Systems and Data Science (Fall 2015)
- Next: PhD in Complex Systems and Data Science in the Fall of 2018




+ Brian Tivnan's MITRE team;
Funding: NSF, NASA, MITRE, DARPA; [YOUR WONDERFUL FUNDING AGENCY HERE]
Adjacent: Strava Story Lab team



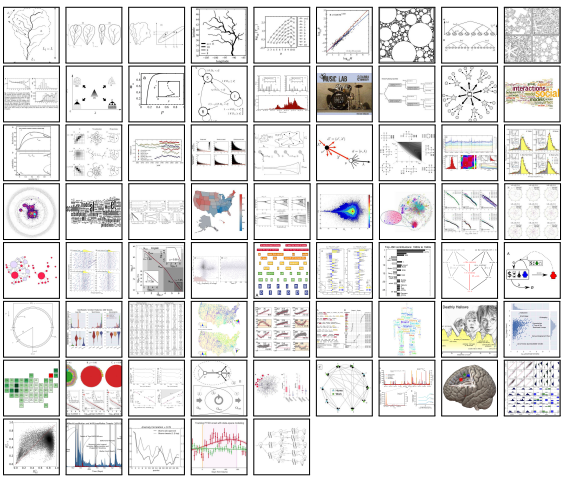
## Courses:



- CSYS/MATH 300: Principles of Complex Systems (@pocsvox)
- CSYS/MATH 303: Complex Networks (@networksvox)
- MATH 124/122: Matrixology (Linear Algebra) (@matrixologyvox and @svdthematrices)
- MATH 237: Numerical Analysis (@MachEps237)
- MATH 266: Chaos, fractals & dynamical systems (@NonperiodicFlow)
- MATH 330: Ordinary Differential Equations (@dallthethingsdt)

- Courses act as research incubators and have helped generate many papers (35+)







## Basics:

- Instructor: Prof. Peter Dodds
- Lecture room and meeting times: 102 Perkins, Tuesday and Thursday, 11:40 am to 12:55 pm
- Office: Farrell Hall, second floor, Trinity Campus
- email: peter.dodds+pocs@uvm.edu
- Course Website: http://www.uvm.edu/pdodds/teaching/courses/2017-08UVM-300
- Course Twitter handle: @pocsvox
- Course hashtag: #FallPoCS2017



### Potential paper products:

- The Syllabus and a Poster.

### Office hours:

- 1:15 pm to 2:30 pm on Tuesday, 1:15 pm to 4:45 pm Thursday,
Farrell Hall, second floor, Trinity Campus



## Exciting details regarding these 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.
- References in slides link to full citation at end. [1]
- 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.





## Yet more super exciting details:

- This is Season 11 of Principles of Complex Systems.
- Lectures will be called Episodes.
- All lectures are bottle episodes.
- Other tropes will be involved.

- Last season's 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.

- People have said nice things about PoCS





## Team PoCS

### We'll continue to try out Slack:

- Place for discussions about all things PoCS 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 $10 \pm 1$ 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, August 29 to Friday, December 8.
2. Add/Drop, Audit, Pass/No Pass deadline—Monday, September 11.
3. Last day to withdraw—Monday, October 30 (Sadness!).
4. Reading and Exam period—Saturday, December 9 to Friday, December 15.

**Do** check the course Twitter account, @pocsvox, 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 nature of PoCS:

- Transitional from standard coursework to research-focused work. #alittlescary

## Major themes:

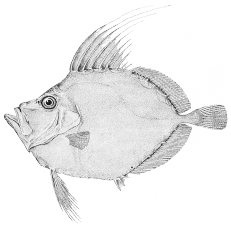
- The Complexity Manifesto;
- Complex Systems ≡ Modern, Normal Science;
- Roles and limits of Data, Theory, and Experiment;
- Emergence;
- Universality and Accidents of History;
- Structure and Stories: Micro-to-macro Mechanisms;
- Elements: Scaling, Surprise, Networks, Robustness, Failure, and Spreading.
- The Theory of Anything: Why Complexify?
- It's all about stories.





## Cryptolect:

### Course mascot:



- What's the Story?
- What's the John Dory?
- What's the John Dory for Rhyming Slang?
- Hemiteleia: beers ⇒ Edward Lears ⇒ Edwards.
- Also: Taxis ⇒ Boris Spasskies ⇒ Borises





## Topics:

### Scaling phenomena:

- Allometry
- Scaling of social phenomena: crime, creativity, and consumption.
- Power law size distributions and non-Gaussian statistics
- Zipf's law
- Key mechanisms for generating power law size distributions
- Scaling in biology (elephants and platypuses).
- Law and Order—Theoricide Unit.
- Dimensional Analysis and Renormalization.





## Topics:

### Complex networks:

- Structure and Dynamics
- Statistical Mechanics
- Phase transitions
- Random Networks
- Scale-free Networks
- Small-world Networks
- Multilayer networks
- Much more in Complex Networks next semester

### Multiscale complex systems:

- Hierarchies and Scaling
- Modularity





## Topics:

### Integrity of complex systems:

- Generic failure mechanisms
- Network robustness
- Highly Optimized Tolerance (HOT): Robustness and fragility
- Predictablity

### Information and Language:

- Search in networked systems (e.g., the web, social systems)
- Search on scale-free networks
- Knowledge trees, metadata and tagging
- Evolution and structure of natural languages



## Topics:

### Sociotechnical Systems:

- Biological and social spreading models
- Schelling's model of segregation [13]
- Granovetter's model of imitation [8]
- Collective behavior and Synchrony
- Global cooperation from bad actors
- Global conflicts from good actors
- Stories (Homo Narrativus)
- The Sociotechnocene





## Schedule in detail:

| Week # (dates) | Tuesday | Thursday |
|---|---|---|
| 1 (8/29 and 8/31) | Overview; Fundamentals: The Complexity Manifesto | Scaling |
| 2 (9/05 and 9/07) | Power-law size distributions | Zipf's law; Fundamentals: Data, Emergence, Limits to Understanding |
| 3 (9/12 and 9/14) | Projects; Power-law mechanisms: Randomness | Power-law mechanisms: Variable Transformation |
| 4 (9/19 and 9/21) | Power-law mechanisms: The Rich-Get-Richer | Power-law mechanisms: Optimization |
| 5 (9/26 and 9/28) | Robustness and Fragility | Fundamentals: Statistical Mechanics Language evolution |
| 6 (10/03 and 10/05) | Robustness vs. SOC | Complex networks: Introduction Basics and Examples networks Small-world networks |
| 7 (10/10 and 10/12) | Complex networks: Key Properties Generalized random | Complex networks: Small-world networks |
| 8 (10/17 and 10/19) | Complex networks: Scale-free networks | Project presentations† |
| 9 (10/24 and 10/26) | Project presentations† | Complex networks: Scale-free networks |
| 10 (10/31 and 11/02) | Complex networks: Scale-free networks | Contagion: Introduction |
| 11 (11/07 and 11/09) | Contagion | Biological Contagion |
| 12 (11/14 and 11/16) | Social Contagion | Social Contagion |
| 13 (11/21 and 11/23) | Thanksgiving | Thanksgiving |
| 14 (11/28 and 11/30) | Voting and Success | (Away: Quarterology) |
| 15 (12/05 and 12/07) | Stories | The Big Story |

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

## Topics:

### Large-scale social patterns:

- Movement of individuals
- Cities
- Happiness
- Twitter

### Collective decision making:

- Wisdom and madness of crowds
- Systems of voting
- The role of randomness and chance
- Success inequality: superstardom





## Postcards from the Course:





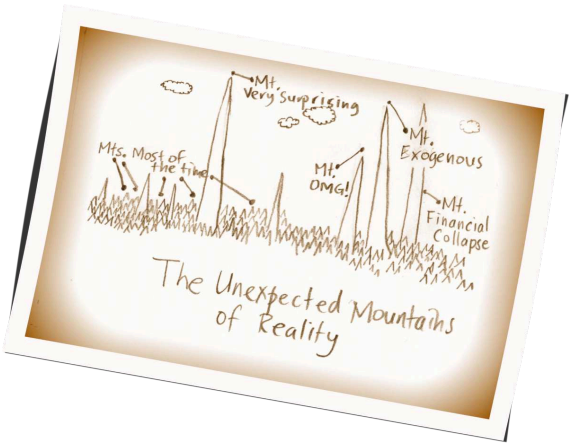

### Season's Narrative Arc (or Places We Will Go):

- Overview of Complex Systems with bonus Manifesto.
- Thread of Understanding Sociotechnical Systems.
- Allometric scaling in complex systems.
- Size distributions of system elements:
  - Power-law size distributions.
  - Description and Mechanisms of Becoming.
- Robustness of Complex Systems.
- Complex networks—how system elements are connected:
  - Structure, Growth Mechanisms, Processes on Networks.
  - Social Contagion, Voting, Fame and Fate, Stories.
- Complexification: The Theory of Anything and the Rise of Algorithms





## Postcards from the Course:



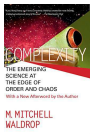
## Postcards from the Course:






## Popular Science Books:

Historical artifact:



"Complexity: The Emerging Science at the Edge of Order and Chaos"
by M. Mitchell Waldrop (1993). [16]

Shout-out: Dr. Andrew P. Morokoff, MBBS PhD FRACS D.Thau (Bug)





## Projects

- Semester-long projects, teams.
- Develop proposal in first few weeks.
- May range from novel research to investigation of an established area of complex systems.
- Two talks + written piece.
- Usage of the VACC is encouraged (ability to code well = super powers).
- Massive data sets available, including Twitter.
- Possible: Work with Twitter data and Story Lab on socially meaningful problems.
- 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.

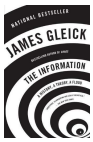




## Popular Science Books:

"Simply Complexity: A Clear Guide to Complexity Theory"
by Neil F. Johnson (2009). [9]

"Complexity: A Guided Tour"
by Melanie Mitchell (2009). [12]

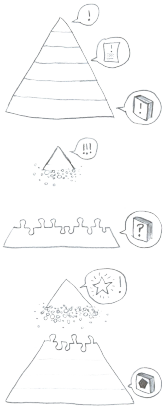


"The Information: A History, A Theory, A Flood"
by James Gleick (2011). [6]





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



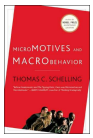
- 1 to 3 word encapsulation = a soundbite = a buzzframe,
- 1 sentence, title,
- few sentences, a haiku,
- a paragraph, abstract,
- short paper, essay,
- long paper,
- chapter,
- book,
- ...



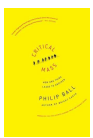


## On complex sociotechnical systems:

"Human Behaviour and the Principle of Least-Effort"
by G. K. Zipf (1949). [17]



"Micromotives and Macrobehavior"
by Thomas C. Schelling (1978). [14]



"Critical Mass: How One Thing Leads to Another"
by Philip Ball (2004). [2]

## It's all about algorithms (stories):

"The Engine of Complexity: Evolution as Computation"
by John E. Mayfield (2013). [10]

"On the Origin of Stories: Evolution, Cognition, and Fiction"
by Brian Boyd (2010). [5]

"The Storytelling Animal: How Stories Make Us Human"
by Jonathan Gottschall (2013). [7]





## Relevant online courses:

- Melanie Mitchell (Santa Fe Institute): Introduction to Complexity
- Lada Adamic (Facebook): Social Network Analysis
- Principles of Complex Systems and Complex Networks

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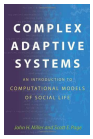
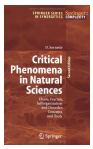
What's the John Dory?
Orientation
Course Information
Topics
Narrative Arc
Postcards from the Course
Tarot Cards
Projects
Centers, Books, Resources
References



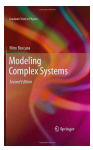
## A few textbooky books:




"Complex Adaptive Systems: An introduction to computational models of social life"
by John H. Miller and Scott E. Page and John H. Miller and Scott E. Page (2007). [11]




"Critical Phenomena in Natural Sciences"
by Didier Sornette (2003). [15]




"Modeling Complex Systems"
by Nino Boccara (2004). [4]

Eventually: "Principles of Complex Systems"

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## Centers:

- Santa Fe Institute (SFI)
- New England Complex Systems Institute (NECSI)
- Michigan's Center for the Study of Complex Systems (CSCS)
- Northwestern Institute on Complex Systems (NICO)
- Also: Indiana, Davis, Brandeis, University of Illinois, Duke, Warsaw, Melbourne, ...,
- Vermont Complex Systems Center


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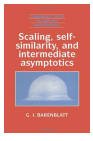
## Books on scaling:




"Scaling, self-similarity, and intermediate asymptotics"
by G. I. Barenblatt (1996). [3]

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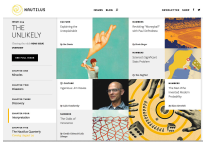
## Other inputs:

- Complexity Digest: http://www.comdig.org https://twitter.com/@cxdig



- Nautilus Magazine: http://nautil.us/
- Aeon: http://aeon.co/

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## References I


[1] P. W. Anderson.
More is different.
Science, 177(4047):393–396, 1972. pdf

[2] P. Ball.
Critical Mass: How One Thing Leads to Another.
Farra, Straus, and Giroux, New York, 2004.

[3] G. I. Barenblatt.
Scaling, self-similarity, and intermediate asymptotics, volume 14 of Cambridge Texts in Applied Mathematics.
Cambridge University Press, 1996.

[4] N. Boccara.
Modeling Complex Systems.
Springer-Verlag, New York, 2nd edition, 2004.






## References II


[5] B. Boyd.
On the Origin of Stories: Evolution, Cognition, and Fiction.
Belknap Press, 2010.

[6] J. Gleick.
The Information: A History, A Theory, A Flood.
Pantheon, 2011.

[7] J. Gottschall.
The Storytelling Animal: How Stories Make Us Human.
Mariner Books, 2013.

[8] M. Granovetter.
Threshold models of collective behavior.
Am. J. Sociol., 83(6):1420–1443, 1978. pdf






## References III


[9] N. F. Johnson.
Simply Complexity: A Clear Guide to Complexity Theory.
Oneworld Publications, London, UK, 2009. pdf

[10] J. E. Mayfield.
The Engine of Complexity: Evolution as Computation.
Columbia University Press, New York, 2013.

[11] J. H. Miller and S. E. Page.
Complex Adaptive Systems: An introduction to computational models of social life.
Princeton University Press, Princeton, NJ, 2007.






## References IV


[12] M. Mitchell.
Complexity: A Guided Tour.
Oxford University Press, New York, NY, 2009.
pdf

[13] T. C. Schelling.
Dynamic models of segregation.
J. Math. Sociol., 1:143–186, 1971. pdf

[14] T. C. Schelling.
Micromotives and Macrobehavior.
Norton, New York, 1978.

[15] D. Sornette.
Critical Phenomena in Natural Sciences.
Springer-Verlag, Berlin, 2nd edition, 2003.






## References V


[16] M. M. Waldrop.
Complexity: The Emerging Science at the Edge of Order and Chaos.
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[17] G. K. Zipf.
Human Behaviour and the Principle of Least-Effort.
Addison-Wesley, Cambridge, MA, 1949.