Course Overview for PoCS

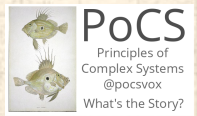
Last updated: 2022/08/29, 21:23:54 EDT

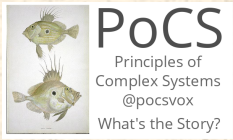
Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 300, 303, & 394, 2022–2023| @pocsvox

Prof. Peter Sheridan Dodds | @peterdodds

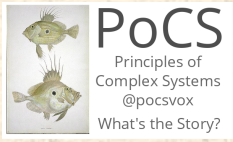
Computational Story Lab | Vermont Complex Systems Center
Santa Fe Institute | University of Vermont





These slides are brought to you by:



These slides are also brought to you by:

Special Guest Executive Producer

On Instagram at pratchett_the_cat

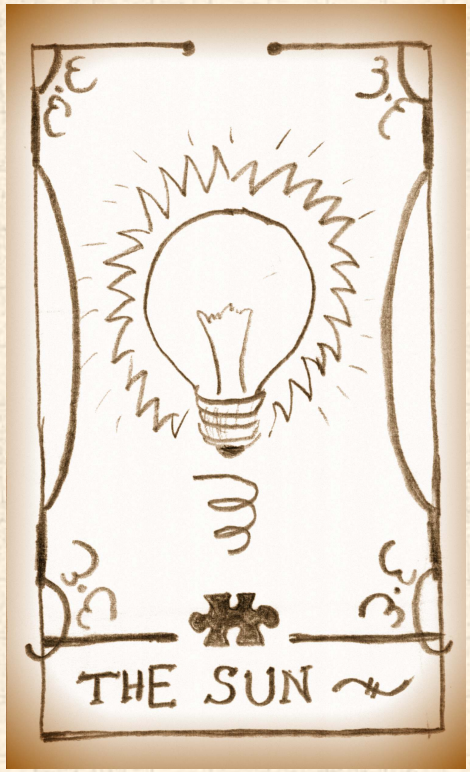
Outline

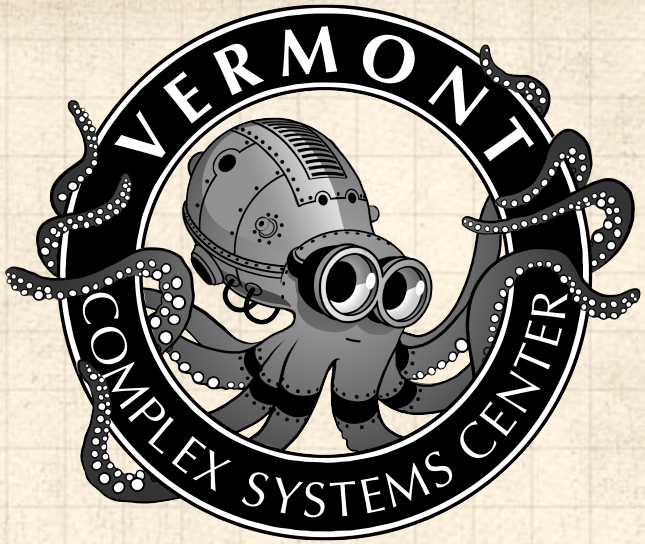
Orientation

- Course Information
- Centers, Books, Resources
- Topics
- Narrative Arc
- Tarot Cards
- Projects

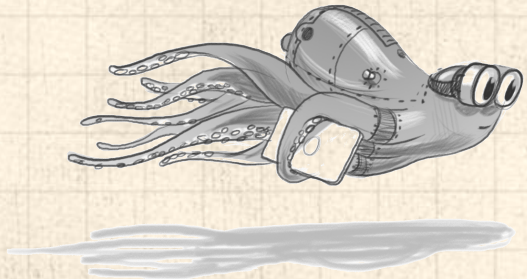
References

What's the John Dory?





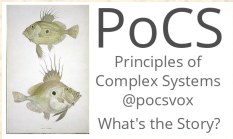
Describe | Explain | Create | Share | Ethos: Play



vermontcomplexsystems.org

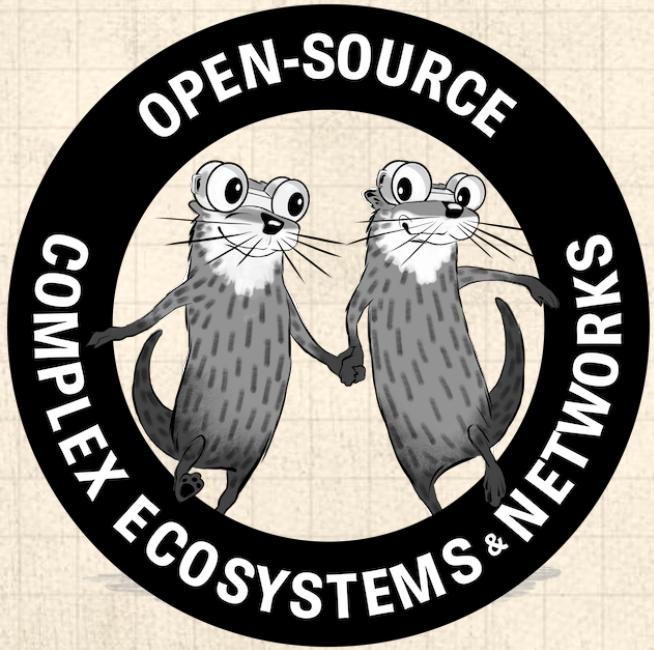
Vermont Complex Systems Center (2006–):

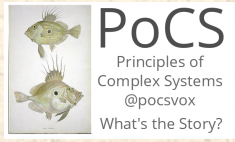
- Diverse research and teaching portfolio ($>$ 400 papers in 2010–2015).
- Funding from many sources: NSF, NIH, DARPA, Microsoft, MITRE, Computer Associates, MassMutual, Google, foundations.
- Regular global press coverage: NYT, BBC, WaPo, NatGeo, ...
- Conferences: "Big Data, Big Stories", "Big Scale, Big Fail", "Prediction: the Next Big Thing", NetSci 2019, ALife 2020.
- Fully developed educational platform in Complex Systems and Data Science.
- Complex Networks Winter Workshops in Quebec City ("Canoe")
- Faculty hires of true Complex Systems scholars.
- Numerous NSF CAREER awards (including PECASE).
- Connecting Graduate and Undergraduate Students across campus (SCRaPS).
- Paper Shredder, Research Jam, and ComplexiTea.
- Talkboctopus



Major support:

- MassMutual Center for Excellence in Complex Systems and Data Science
  vermontcomplexsystems.org/partner/MMCOE/
- University of Vermont-Google Open-Source Complex Ecosystems And Networks (OCEAN)
  vermontcomplexsystems.org/partner/OCEAN/





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
- Complex Networks
- Climate
- Biology
- Ecology
- Geomorphology
- Space
- Complex Fluids
- (Smart) Power Grids
- Critical infrastructure
- Defense
- Public Policy
- Health and Medicine
- ~~Brainz~~ Brains
- Neuroscience
- Food systems
- Epidemiology
- Pandemics
- Organizations
- Economics
- Wealth inequality
- Financial Systems

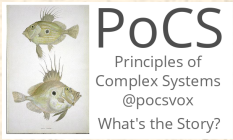
Leveling up—Scaffolded educational mission:

- Data Science Undergrad.
- Graduate Certificate in Complex Systems and Data Science
- Fall, 2015–: MS in Complex Systems and Data Science
- Fall, 2018–: PhD in ~~The Study of Interesting Things~~ Complex Systems and Data Science

All the words: http://vermontcomplexsystems.org.

Graduate Certificate in Complex Systems (and Data Science):

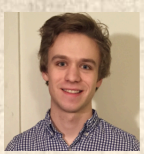
- Principles of Complex Systems is one of three core requirements for UVM's five course Certificate of Graduate Study in Complex Systems.
- Prof. Laurent Hebert-Dufresne's "Modelling Complex Systems" (CSYS/CS 302).
- Prof. Jim Bagrow's "Data Science I" (STAT 287)
- The Sequel to PoCS:
  "Complex Networks" (CSYS/MATH 303).
- But really it's the PoCSverse:
  Principles of Complex Systems Vols. 1 and 2



Framing (funfully):

Science = Area of study + Instruments of study

- Stars and Telescopes = Astronomy
- Rocks and Hammers = Geology
- Water and Partial Differential Equations = Fluid Dynamics
- Brains and Giant Imaging Machines = Neuroscience
- People and Deception = Social Psychology
- Mathematics and Mathematics = Pure mathematics
- Mind and Mind = Psychotherapy, Insight meditation, ...
- Complex Systems + Data Science = Postdisciplinary Systems Science


Michael Arnold


Jane Adams


Todd DeLuca


Sophie Hodson


Sandhya Gopchandani

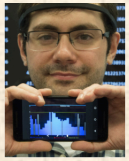

Anne Marie Stupinski


Summer Jiang


Chris Danforth Peter Dodds


Tyler Gray


Aaron Schwartz


Eric Clark


Ben Emery

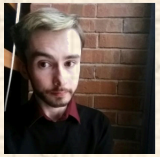

David Dewhurst


Colin Van Oort


Laura Jennings


Abby Ross Northfield Mount Hermon School


Chris Fusting Data Science Consultant


Ryan Gallagher Northeastern PhD student


John Ring


Lindsay Ross


Brendan Whitney


Henry Mitchell


Sarah Howerter


Kayla Horak U of Wisconsin

Computational Story Lab ++;
compstorylab.org


Nick Allgaier Psychiatry Res Asst Prof


Dilan Kiley Chobanian Group


Tom McAndrew Cardiovascular Research Foundation


Emily Cody Data Scientist Adobe

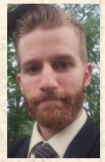

Morgan Frank MIT Media Lab PhD Student


Cathy Bliss UVM Lecturer


Mark Ibrahim Data Scientist Insight


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


Eitan Pechenick Maine School of Science & Math

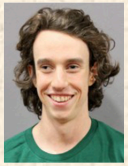

Andy Reagan Data Scientist MassMutual

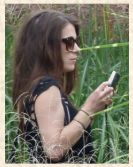

Sven McCall Maps, Apple


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 U Washington Postdoc

Paul Lessard Colorado PhD Student

Suma Desu Apple Data Scientist

Mike Foley Northeastern PhD student

Darcy Glenn Climate Science UC London, MS student

Lindsay Van Lier VCHIP

Funding: NSF, NIH, NIDA, NASA, MITRE, James S. McDonnell Foundation, ONR, DARPA, MassMutual, Google, Computer Associates; [YOUR WONDERFUL FUNDING AGENCY HERE]

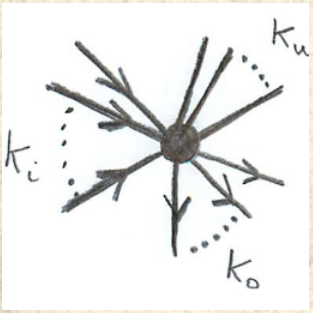
Computational Story Lab ++;

Outside

Inside the Lab that's Quantifying Happiness

by Rowan Jacobsen, August 2017.
(Reprinted in UVM Quarterly, 2018.)

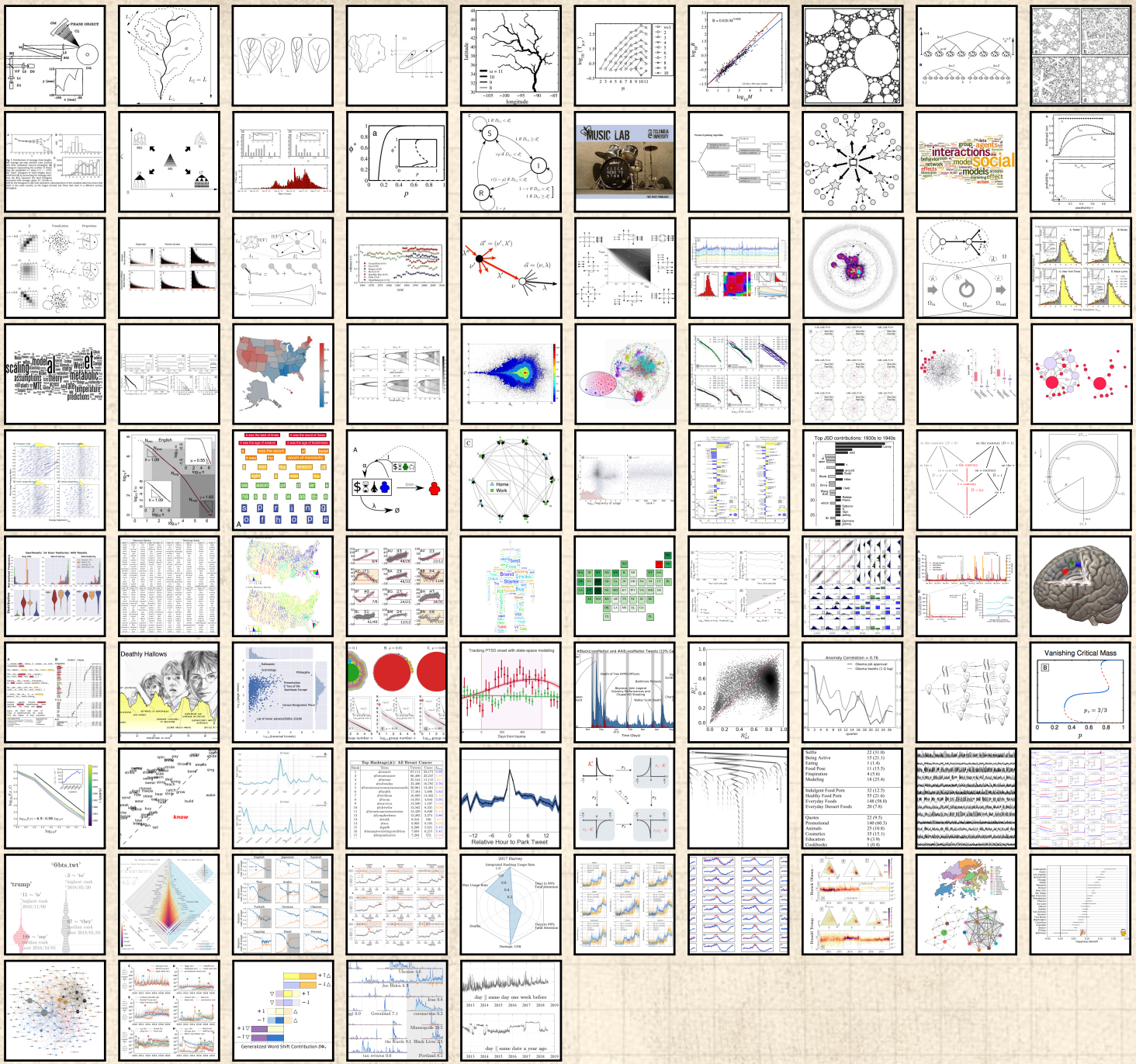
Courses:



- 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

Computational Story Lab ++;



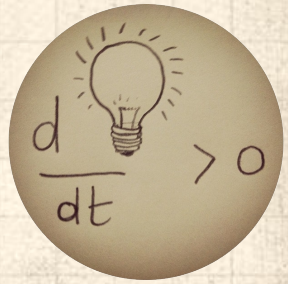
PoCS
@pocsvox

What's the John Dory?

Orientation

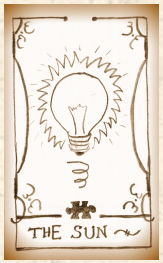
- Course Information
- Centers, Books, Resources
- Topics
- Narrative Arc
- Tarot Cards
- Projects

References



Basics:

- Instructor: Prof. Peter Sheridan Dodds
- Lecture room and meeting times:
  Perkins 003, 10:05 am to 11:20 am
- Office: (in theory) The Ether and/or Innovation, fourth floor
- email: peter.dodds@uvm.edu
- Course Website:
  https://pdodds.w3.uvm.edu/teaching/courses/2022-2023pocsverse
- Course Twitter handle: @pocsvox

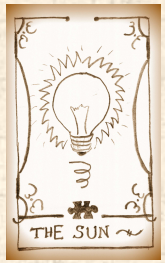


Potential paper product:

- The Syllabus.

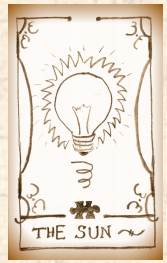
Office hours:

- TBD,
  The Ether and/or Innovation, fourth floor



Exciting details regarding these slides:

- Three servings (all in pdf):
  1. Fresh: For in-class Deliveration.
  2. On toast: Flattened for page-turning joy.
  3. Freeze-dried: Pack-and-go, 3x3 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. #totallynormal

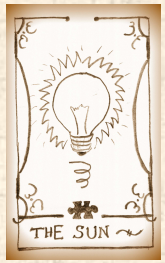


More super exciting details:

- We use Open Sans and make math look good:

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

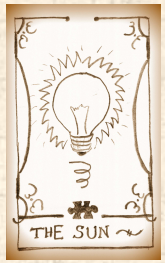
- Still working towards putting the course on Github/Gitlab
- And finishing writing the books ...



Yet more super exciting details:

- This is Season 18 of Principles of Complex Systems, Vols. 1, 2, & 3D.
- In-person lectures will be called Stories (a more elevated framing than “Streams of consciousness”)
- Slide-specific curated episodes are online, and are broken into clips.
- Goal for all in-person lectures: Record with ScreenFlow, curate, send to Youtube.
- Office hours will run over Teams and be recorded.
- Some new clips may be recorded in a pretend studio.
- All lectures are bottle episodes.
- Other tropes will be involved.

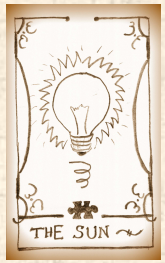
- Last season’s Episodes are here.



Wonderful foundational support for PoCS Vol. 1, ~~CoNKS~~ ~~CocoNuTs~~ PoCS Vol. 2, and PoCS Vol. 3D, 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 also said nice things about PoCS

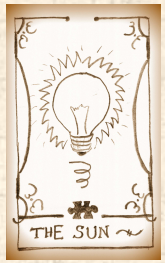


Team PoCS

Microsoft Teams + Slack

- Teams = main place for discussions about all things PoCS including assignments and projects.
- Slack = main place for students and faculty in Complex Systems and Data Science to talk about everything.
- Teams—Automatic if enrolled in the course.
- Slack—Once invited, please sign up here: https://csdsgrads.slack.com/
- Very good: Install Microsoft and Slack apps on laptops, tablets, phone, cats, dogs. Nothing will go wrong.
- Everyone will behave wonderfully.

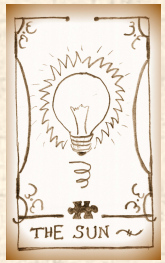
Microsoft Teams slack



Grading breakdown:

- Assignments (75%)—All assignments will be of equal weight and there will be 10 ± 1 of them.
- Projects/talks (24%)—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.

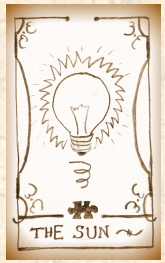
  Details: 8% for the first talk, 8% for the final talk, and 8% for the written project.
- General attendance/Class participation (1%)—Everyone is expected to behave well.



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.

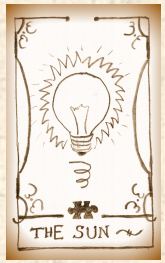


Important things:

1. Classes run from Tuesday, August 31 to Thursday, December 9.
2. Add/Drop, Audit, Pass/No Pass deadline—Monday, September 13.
3. Last day to withdraw—Monday, November 1 (Sadness!).
4. Reading and Exam period—Saturday, December 11 to Friday, December 17.

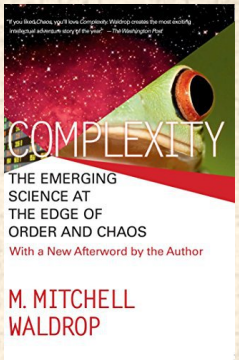
Do check the course Twitter account, @pocsvox, for updates regarding the course (part of the course site).

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.



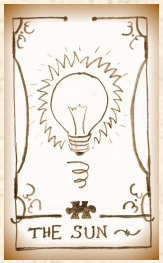
Popular Science Books:

Historical artifact:

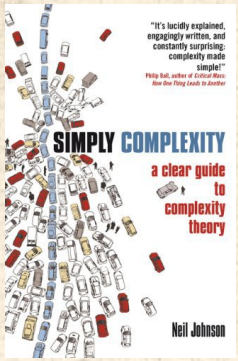


"Complexity: The Emerging Science at the Edge of Order and Chaos"
by M. Mitchell Waldrop (1993). [16]

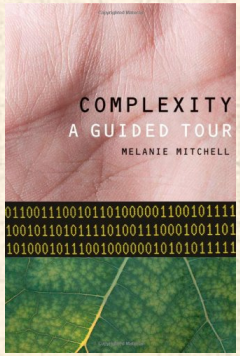
Shout-out: Dr. Andrew P. Morokoff, MBBS PhD FRACS D.Thau (Bug)



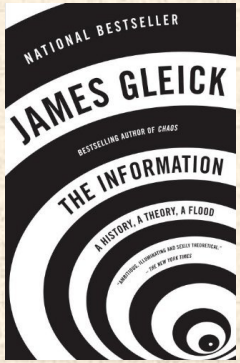
Popular Science Books:



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

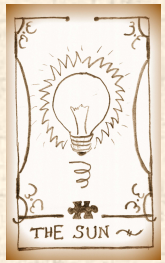


"Complexity: A Guided Tour"
by Melanie Mitchell (2009). [12]

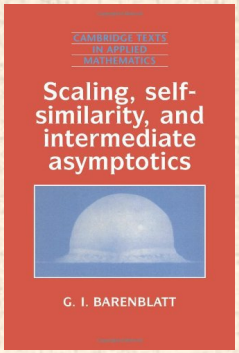


"The Information: A History, A Theory, A Flood"
by James Gleick (2011). [6]

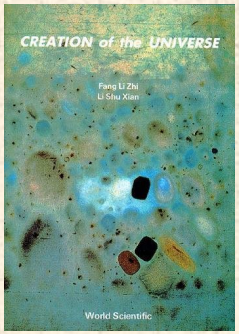
What's the John Dory?



Books on Complexification:

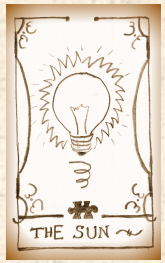


"Scaling, self-similarity, and intermediate asymptotics"
by G. I. Barenblatt (1996). [3]

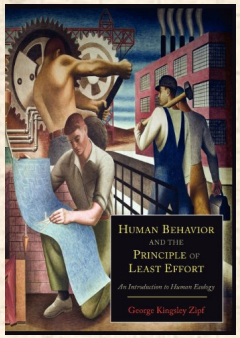


"Creation of the Universe"
by Zhi and Xian (1989). [17]

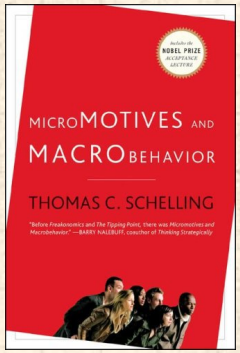
See Freeman Dyson's The Key to Everything.



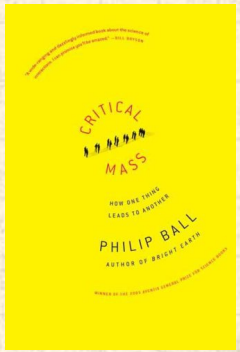
On complex sociotechnical systems:



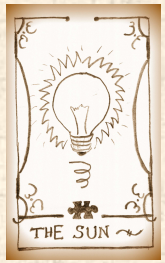
"Human Behaviour and the Principle of Least-Effort"
by G. K. Zipf (1949). [18]



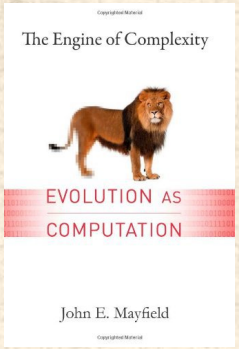
"Micromotives and Macrobehavior"
by Thomas C. Schelling (1978). [14]



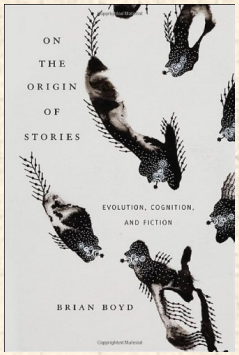
"Critical Mass: How One Thing Leads to Another"
by Philip Ball (2004). [2]



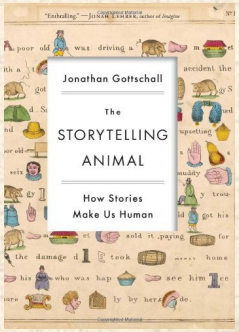
It's all about algorithms (stories):



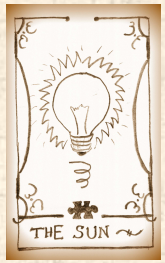
"The Engine of Complexity: Evolution as Computation"
by John E. Mayfield (2013). [10]



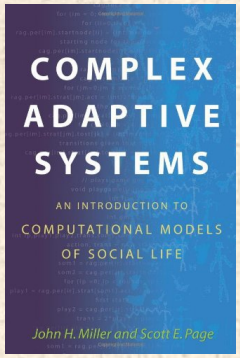
"On the Origin of Stories: Evolution, Cognition, and Fiction"
by Brian Boyd (2010). [5]



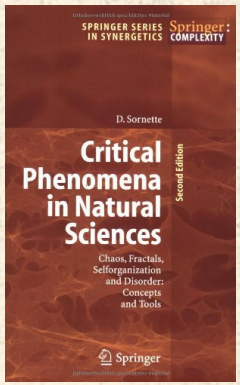
"The Storytelling Animal: How Stories Make Us Human"
by Jonathan Gottschall (2013). [7]



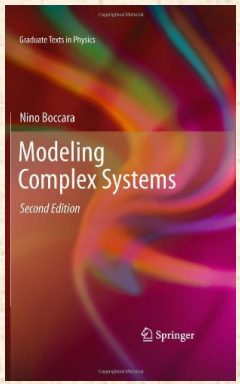
A few textbooky books (dated):



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

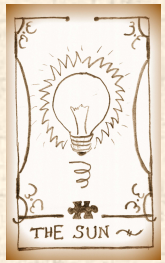


"Critical Phenomena in Natural Sciences"
by Didier Sornette (2003). [15]



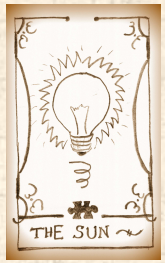
"Modeling Complex Systems"
by Nino Boccara (2004). [4]

Eventually: "Principles of Complex Systems"



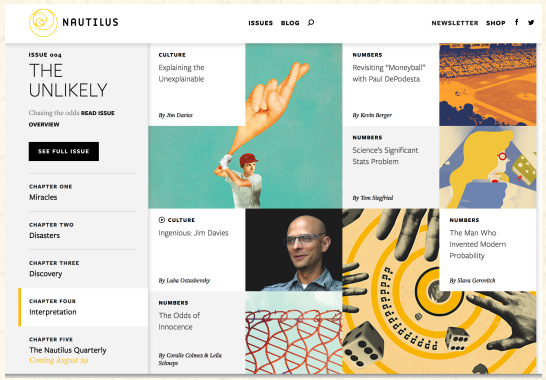
Centers:

- Santa Fe Institute (SFI)
- Networks Institute at Northeastern
- Northwestern Institute on Complex Systems (NICO)
- MIT Institute for Data, Systems, AND Society
- New England Complex Systems Institute (NECSI)
- Michigan's Center for the Study of Complex Systems (CSCS)
- Some Data Science groups (highly variable)
- Also: Indiana, Davis, Brandeis, University of Illinois, Duke, Warsaw, Melbourne, ...,
- Us!!!: Vermont Complex Systems Center



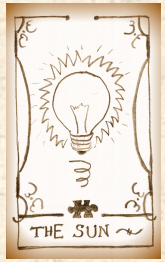
Other inputs:

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



- Nautilus Magazine:
  http://nautil.us/

- Aeon: http://aeon.co/
- Quanta Magazine:
  https://www.quantamagazine.org/

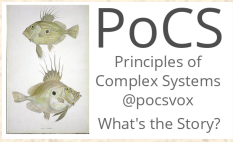


The nature of PoCS:

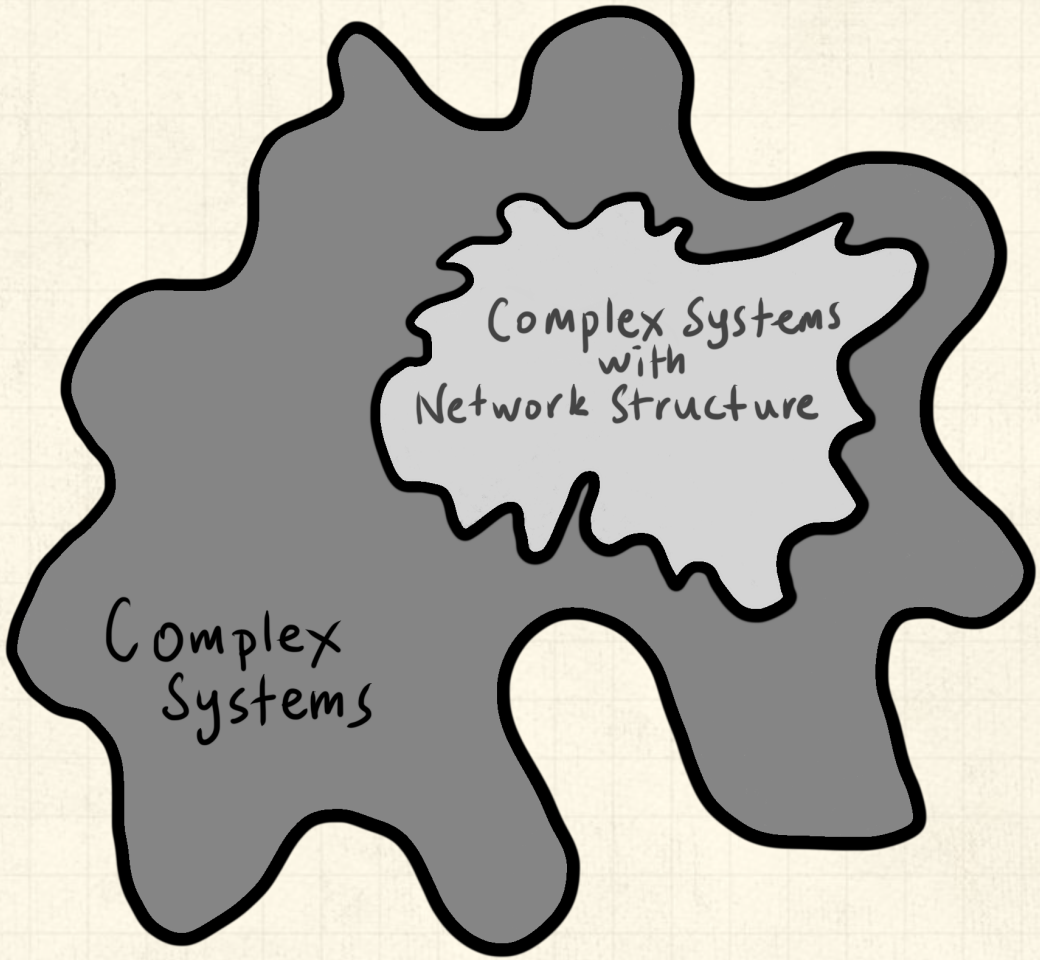
- Transitional from standard coursework to research-focused work. #alittlescary

Major themes:

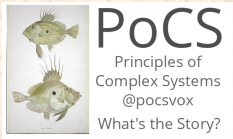
- The Complexity Manifesto;
- Complex Systems ≡ Modern, Normal Science;
- Roles and limits of Data, Theory, and Experiment;
- Emergence;
- Universality and Accidents of History;
- Structure and Stories: Micro-to-macro Mechanisms;
- Elements: Scaling, Surprise, Networks, Robustness, Failure, and Spreading.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



Complex Systems are the Big Story:

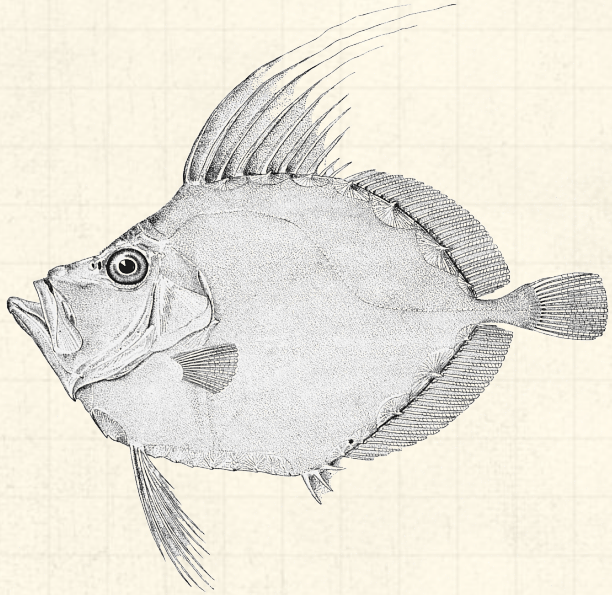


- Only a bit networky: Fluids-at-large (the atmosphere, oceans, ...), organism cells, ...



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.
- Scaling in biology (elephants and platypuses).
- Dimensional Analysis and Renormalization.
- Power law size distributions and non-Gaussian statistics.
- The 80/20 rule, the 1%.
- Zipf's law.
- Order from randomness.
- Fundamental mechanisms for generating power law size distributions.
- The rich-get-richer mechanism.

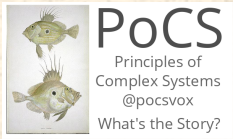
Topics:

Robustness—Integrity of complex systems:

- Generic failure mechanisms.
- Highly Optimized Tolerance (HOT): Robustness and fragility.
- How to build optimal forests.
- Minimization of risk as a driver of heterogeneous structures in complex systems.
- How to optimally locate facilities: hospitals, schools, and coffee shops.

Fundamentals of Complexity:

- Emergence: More is Different.
- Measurement and mismeasurement.
- Universality versus path dependence.
- Complexification (it all starts with gravity [17]).



Topics:

Complex networks:

- Statistical Mechanics
- Structure and Dynamics
- Phase transitions
- Random Networks
- Scale-free Networks
- Small-world Networks
- Why your friends are better than you.
- More in PoCS, Vol. 2 in the spring.

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

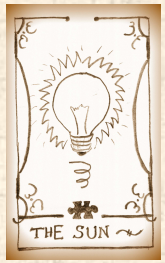
Topics:

Collective decision making:

- Wisdom and madness of crowds.
- Systems of voting.
- The role of randomness and chance.
- Success inequality.
- The paradox of unpredictable global fame.
- Bonus knowledge: How to make things spread.
- Bonus knowledge: Fate does not exist in a world of fame.

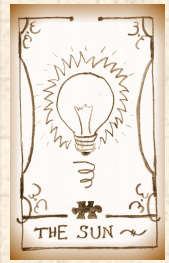
Large-scale social patterns (maybe):

- Movement
- Cities
- Happiness
- Social media

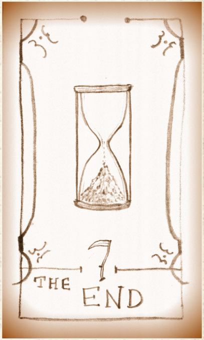


Season's Narrative Arc (or Places We Will Go):

- 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

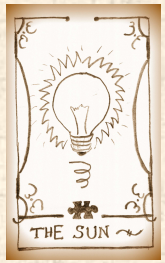



THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE DOORS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MONKS
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
THE ARKS OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
THE UNENDING PANDEMICS
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE RATIO OF GAIN
THE MECHANICS OF FAME
THE TALK OF FAME
THE STORIES CONTAGIOUS
THE JOHN DORY
THE ADJACENT NARRATIVES
THE STORYTELLERS
THE FATED ASTRAL PATH
THE PATHS OF UNIVERSALITY
THE DEPENDENT PATHS
THE TROUSERS OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
THE LANDSCAPES OF FORKING PATHS
THE NETWORKS OF BLOOD
THE TREES OF REALITY
THE ORDERS OF STREAMS
THE LAWS OF BRANCHING
THE SCALING OF BROKEN HIERARCHIES
THE BRAID OR THE BRANCH
THE LAW OF OPTIMAL FORKS
THE CHURCH OF QUARTEROLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILLSCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM SUM OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS
THE OVERCOMING OF CATASTROPHE
THE TROUBLES ILL-FORMED
THE NETWORKS OF MANY ILKS
THE CHAOS OF FETTERED CONTAGION
THE END


THE END

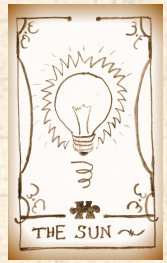
Projects

- 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.



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,
- ...



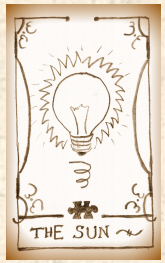
References I

[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.



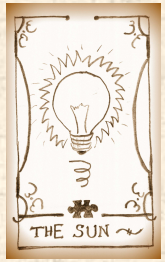
References II

[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

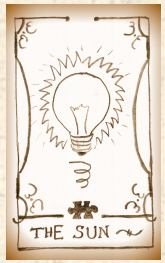


References III

[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.



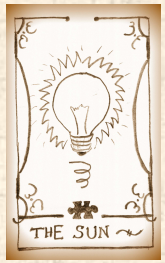
References IV

[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.
Simon & Schuster, New York, NY, 1993.

[17] F. L. Zhi and L. S. Xian.
Creation of the Universe.
World Scientific Publishing Company, 1989.

[18] G. K. Zipf.
Human Behaviour and the Principle of Least-Effort.
Addison-Wesley, Cambridge, MA, 1949.