# Principles of Complex Systems

CSYS/MATH 300 (14509); University of Vermont, Spring 2013

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**Basic stuff:**

**Instructor:** Prof. Peter Dodds.
**Lecture room:** 102 Perkins
**Meeting times:** Tuesday and Thursday, 11:30 am to 12:45 pm
**Office:** Farrell Hall, second floor, Trinity Campus.
**E-mail:** peter.dodds@uvm.edu
**Office hours:** 1:00 pm to 4:00 pm, Wednesday.
**Course website:** http://www.uvm.edu/∼pdodds/teaching/courses/2013-01UVM-300
**Source material:** Journal papers and book excerpts.
**Suggested text:** No official textbook.

**If instructor's permission is required:** Students are asked to please send a short email describing their interests (and their 950 student number) to Prof. Dodds at pdodds@uvm.edu.

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**Synopsis:**

Many of the problems we face in the modern world revolve around comprehending, controlling, and designing multi-scale, interconnected systems. Networked systems, for example, facilitate the diffusion and creation of ideas, the physical transportation of people and goods, and the distribution and redistribution of energy. Complex systems such as the human body and ecological systems are typically highly balanced, flexible, and robust, but are also susceptible to systemic collapse. These complex problems almost always have economic, social, and technological aspects.

So what do we know about complex systems? My basic aim in this introductory, interdisciplinary course is to impart knowledge of a suite of theories and ideas and tools that have been evolved over the last century in the pursuit of understanding complex systems. We'll touch on everything from physics to sociology, from randomness to cities to language. Throughout the course, we'll maintain a focus on (1) real small-scale mechanisms that give rise to observed macro phenomena, (2) scaling phenomena, and (3) complex networks, allowing us to explore how seemingly disparate systems connect to each other—the phenomenon of universality—and, just as importantly, where tempting analogies break down.

The course is a 3 credit course and is aimed at graduates and advanced undergraduates.

**Potential topics:**

(Note: this list is undoubtedly incomplete, in no particular order, and subject to change; more detailed treatments of many of the topics that follow will appear in the advanced courses.)

1. Measures of complexity
   (a) The poles of randomness and order
   (b) Basic notions of entropy and information theory
2. Scaling phenomena
   (a) Zipf's law
   (b) Non-Gaussian statistics and power law distributions
   (c) Sample mechanisms for power law distributions
   (d) Organisms and organizations
   (e) Scaling of social phenomena: crime, creativity, and consumption.
   (f) Renormalization techniques
3. Multiscale complex systems
   (a) Hierarchies and scaling
   (b) Modularity
   (c) Form and context in design
4. Complexity in abstract models
   (a) The game of life
   (b) Cellular automata
   (c) Chaos and order—creation and maintenance
5. Integrity of complex systems
   (a) Generic failure mechanisms
   (b) Network robustness
   (c) Highly optimized tolerance: Robustness and fragility
   (d) Normal accidents and high reliability theory
6. Complex networks
   (a) Small-world networks
   (b) Scale-free networks
7. Collective behavior and contagion in social and sociotechnical systems
   (a) Percolation and phase transitions
   (b) Disease spreading models
   (c) Schelling's model of segregation
   (d) Granovetter's model of imitation
   (e) Contagion on networks
   (f) Herding phenomena
   (g) Cooperation
   (h) Wars and conflicts
8. Large-scale Social patterns
   (a) Movement of individuals
9. Collective decision making
   (a) Theories of social choice
   (b) The role of randomness and chance
   (c) Systems of voting

(d) Juries
(e) Success inequality: superstardom

10. Information
    (a) Search in networked systems (e.g., the WWW, social systems)
    (b) Search on scale-free networks
    (c) Knowledge trees, metadata and tagging

**Prerequisites:** Familiarity with the following would be good but not completely necessary: standard calculus, differential equations, difference equations, linear algebra, and statistical methods.

**Computing:** Proficiency in coding (C, Matlab, perl, python) will be beneficial (and indeed necessary) for certain projects but is not required.

**Textbooks:** There is no specific textbook for the class. The course will draw on material from a wide range of sources and will provide students with book excerpts and journal papers as appropriate to supplement lecture notes.

The following is a list of some of the books that will provide source material (none of these need be purchased):

- "Critical Phenomena in Natural Sciences" by Didier Sornette,[1]
- "Critical Mass: How One Thing Leads to Another" by Philip Ball,[2]
- "Modeling Complex Systems" by Nino Boccara,[3]
- "Complex Adaptive Systems: An Introduction to Computational Models of Social Life," by John Miller and Scott Page[4],
- "Micromotives and Macrobehavior" by Thomas Schelling,[5]
- "Social Network Analysis" by Stanley Wasserman and Katherine Faust,[6]
- "Handbook of Graphs and Networks" by Stefan Bornholdt and Hans Georg Schuster.[7]

**Grading breakdown:**

1. **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. Projects may take the form of novel research, investigation of an established area of complex systems, or both. Graduate students already pursuing appropriate research topics are welcome to use the class as a venue to present their work.

   A list of possible projects will be provided though individuals are encouraged and free to choose their own. Project content may range from novel research to a review of research relevant to the course. The hope here is for some work to percolate up to the level of journal publications. Students will give two brief presentations in the middle of the semester and a longer one at the end (length of talks will depend on class size). Students will also be required to hand in a report on their investigations.

   The grade breakdown will be 12% for the first talk, 12% for the final talk, and 12% for the written project.

2. **Assignments (60%)**—All assignments will be of equal weight and there will be four or five of them. Aside from correctness, clarity in thinking, writing, and presentation will be taken into account in grading.

   In general, 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.

3. **General attendance/Class participation (4%)**—it is highly desirable that students attend class, and class presence will be taken into account if a grade is borderline. Providing suggestions for the class blog will count here.

**Schedule:**

| **Week # (dates)** | **Tuesday** | **Thursday** |
|---|---|---|
| 1 (1/15 and 1/17) | Overview; Fundamentals: The Complexity Manifesto | Power-law size distributions |
| 2 (1/22 and 1/24) | Zipf's law; Fundamentals: Data, Emergence, Limits to Understanding | Power-law mechanisms: Randomness |
| 3 (1/29 and 1/31) | Power-law mechanisms: Variable Transformation; Projects | Power-law mechanisms: The Rich-Get-Richer |
| 4 (2/5 and 2/7) | Fundamentals: Self-Organization; Projects | Power-law mechanisms: Optimization |
| 5 (2/12 and 2/14) | Robustness and Fragility | HOT vs. SOC |
| 6 (2/19 and 2/21) | Fundamentals: Statistical Mechanics Complex networks: Introduction | Complex networks: Key features |
| 7 (2/26 and 2/28) | Project presentations† | Project presentations† |
| 8 (3/5 and 3/7) | Spring recess | Spring recess |
| 9 (3/12 and 3/14) | Complex networks: Generalized random networks | Complex networks: Small-world networks |
| 10 (3/19 and 3/21) | Complex networks: Scale-free networks | Complex networks: Modularity |
| 11 (3/26 and 3/28) | Contagion: Introduction | Biological Contagion |
| 12 (4/2 and 4/4) | Social Contagion | Interesting Scaling |
| 13 (4/9 and 4/11) | Interesting Scaling | Interesting Scaling |
| 14 (4/16 and 4/23) | Voting and Success | Happiness |
| 15 (4/30) | The Big Story | — |

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

Final project presentations will likely be given in the final exam period which takes place on Tuesday, May 7, 1:30 pm to 4:15 pm, 102 Perkins. .

Times may adjusted based on class size.

**Important dates:**

1. Classes run from Tuesday, January 15 to Tuesday, April 30.
2. Add/Drop, Audit, Pass/No Pass deadline—Monday, January 28.
3. Last day to withdraw—Friday, March 29 (Sadness!).
4. Reading and Exam period—Thursday, May 2 to Friday, May 10.

**Do** check your zoo account for updates regarding the course.

**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.

**Being good people:** First, in class there will be no electronic gadgetry, no cell phones, no beeping, no text messaging, etc. You really just need your brain, some paper, and a writing implement here (okay, and maybe Matlab). Those who beep in an annoying fashion will be fined one organic banana by the lecturer. Second, I encourage you to email me questions, ideas, comments, etc., about the class but request that you please do so in a respectful fashion. Finally, as in all UVM classes, **Academic honesty** will be expected and departures will be dealt with appropriately. See `http://www.uvm.edu/cses/` for guidelines.

**Late policy:** Unless in the case of an emergency (a real one) or if an absence has been predeclared and a make-up version sorted out, assignments that are not turned in on time or tests that are not attended will be given 0%.

**Grades:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| A+ | 97–100 | B+ | 87–89 | C+ | 77–79 | D+ | 67–69 |
| A | 93–96 | B | 83–86 | C | 73–76 | D | 63–66 |
| A- | 90–92 | B- | 80–82 | C- | 70–72 | D- | 60–62 |

# References


[1] D. Sornette. *Critical Phenomena in Natural Sciences*. Springer-Verlag, Berlin, 1st edition, 2003.

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

[3] N. Boccara. *Modeling Complex Systems*. Springer-Verlag, New York, 2004.

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

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

[6] S. Wasserman and K. Faust. *Social Network Analysis: Methods and Applications*. Cambridge University Press, Cambridge, UK, 1994.

[7] S. Bornholdt and H. G. Schuster, editors. *Handbook of Graphs and Networks*. Wiley-VCH, Berlin, 2003.