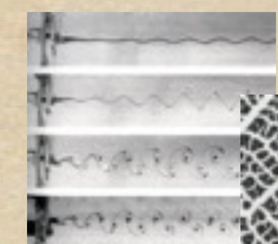
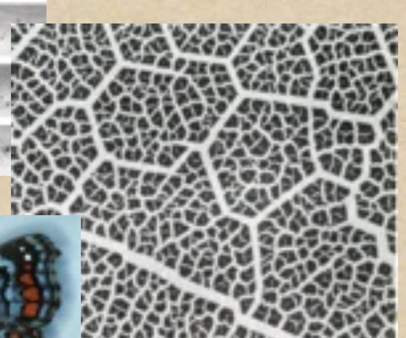
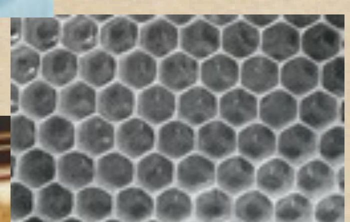
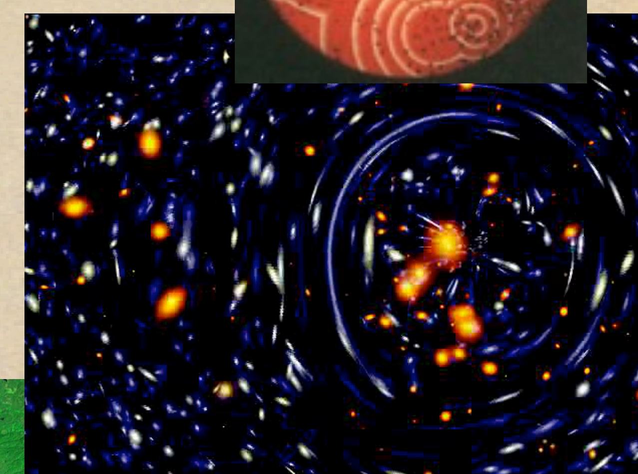
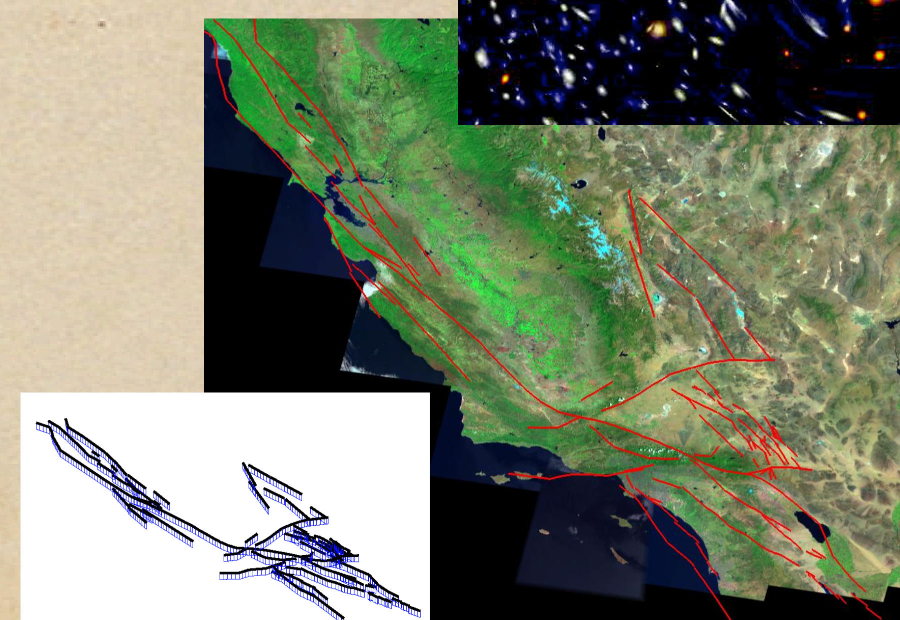
Nonlinear Physics—
Modeling Chaos & Complexity











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Mechanism Revived

- Deterministic chaos
  - Nature actively produces unpredictability
- What is randomness?
- Where does it come from?
- Specific mechanisms:
  - Exponential divergence of states
  - Sensitive dependence on parameters
  - Sensitive dependence on initial state
  - ...

Brief History of Chaos

- Discovery of Chaos:
  - 1890s, Henri Poincaré
  - Invents Qualitative Dynamics
- Dynamics in 20th Century
  - Develops in Mathematics (Russian & Europe)
  - Exiled from Physics
- Re-enters Science in 1970s
  - Experimental tests
  - Simulation
- Flourishes in Mathematics:
  - Ergodic theory & foundations of Statistical Mechanics
  - Topological dynamics
  - Catastrophe/Singularity theory
  - Pattern formation/center manifold theory
  - ...

Discovering Order in Chaos

- Problem:
  - No "closed-form" analytical solution for predicting future of nonlinear, chaotic systems
  - One can prove this!
- Consequence:
  - Each nonlinear system requires its own representation
- Pattern recognition: Detecting what we know
- Ultimate goal: Causal explanation
  - What are the hidden mechanisms?
- Pattern discovery: Finding what's truly new

Major Roadblock to the Scientific Algorithm

- No "closed-form" analytical solutions
- Baconian cycle of successively refining models broken
- Solution:
  - Qualitative dynamics: "Shape" of chaos
  - Computing

Logic of the Course

- Two parallel themes
- Conceptual:
  - Deterministic Chaos: Emergence of randomness
  - Self-organization: Emergence of order
  - Complex systems: Balance of order & chaos
- Tools:
  - Building: Programming
  - Uses: Exploration & analysis

How to do this?

- Mathematics of dynamical systems
- Computing methods:
  - Numerical simulation
  - Interactive visualization

Goals

- Comfortable with state space
- Understand geometric mechanisms
  of unpredictability
- Measure the degree of chaos and order
- Build your own exploration tools

Demos?

- Lorenz chaotic attractor
- Map lattice
- Spin system

The Holodeck is Here!

KeckCAVES

- Sensory Immersive Environment
- 10' x 10' x 8' Room
- Three Walls + Floor:

  Each a stereoscopic

  projection screen

KeckCAVES ...

- User View:
  - LCD Shutter Glasses
  - One user's head is tracked

- Users Interaction:
  - Wand
  - Position & Orientation
  - Buttons

KeckCAVES ...

- Movie: User Manipulates Protein
- http://keckcaves.org/

Applications (a few) (Projects?)

- Physics:
  - Solid state: Bose-Einstein condensates, Charge-density waves, ...
  - Astronomy
  - Cosmology
- Chemistry:
  - Molecular dynamics
  - Reaction kinetics
  - Chemical oscillators
- Biology:
  - Population dynamics
  - Ecology
  - Evolution
  - Neurodynamics
- Social sciences:
  - Market dynamics
  - Game interactions
- Engineering:
  - Mechanical systems
  - Electrical circuits
  - Fluid turbulence
  - Oscillations in Internet traffic through-put
- Health:
  - Epidemics
- ...

Prerequisities

- Interest in modeling some dynamical phenomenon
- Mathematics:
  - Vector calculus
  - Linear algebra
  - Lower division Math, Physics, or CS courses
- Programming:
  - Experience with C/C++, Java, or ...
  - We will use Python
- Preferred environment:
  - Laptop with Python v. 2.6 running

Why Python?

- Open source & free!
- Hierarchy of programming structures:
  - Procedural (like C/Fortran)
  - Object oriented (like C++/Java)
  - Functional programming (like Haskell/Lisp)
- Interpreted, not compiled:
  - Easy to test code, interactive
  - Scriptable (like Perl)
  - Can be slow!
- Excellent libraries: OS, numerical, WWW, parallel, ...
- Wide range of tools available:
  - Development: e.g., Eclipse IDE
  - WWW

Organization: Two tracks

- Parallel Theme I:
  Forms of Randomness, Order, & Intrinsic Instability
  - Qualitative Dynamics
  - Continuous-time ODEs and discrete-time maps
  - Bifurcations
  - Stability, Instability, and Chaos
  - Quantifying (In)Stability

Organization: Two tracks ...

- Parallel Theme II:
  Tools for Exploring Chaos and Complexity
  - Modeling methods
  - Programming
  - Simulation
  - Graphics
  - Interaction

Organization: Two tracks ...

- Each week:
  - Theory first (Tuesday)
  - Then Lab: Code up ideas (Thursday)
- Field trip (May/June)
  - Sensory Immersive Environments
  - KeckCAVES tour

Who are we?

- Me: JPC
- Assistant: Benny Brown
- You: (Please fill out questionnaire.)
    - Interests
    - Background
    - Abilities

Course logistics

- Course Website:

  cse.ucdavis.edu/~chaos/courses/nlp/

- Readings: Assignments on website
- Homework: Assignments on website

  Assigned first 2/3s of quarter

- Project:

  Remaining 1/3, presentation, written report, working code

- Grading:
  - 30% homework + 30% lab + 40% project

Staying in touch

- Course Website:

  cse.ucdavis.edu/~chaos/courses/nlp/

- Email

  chaos@cse.ucdavis.edu & brown@cse.ucdavis.edu

- Office hours

  JPC: Wednesday 3-4 PM

  BB: TBD

Materials

- Books

[NDAC] Nonlinear Dynamics and Chaos: with applications to physics, biology, chemistry, and engineering, S. H. Strogatz, Addison-Wesley, Reading, Massachusetts (2001). **2001 Printing is Important!**

[Python] Learning Python, M. Lutz, Fourth Edition, O'Reilly & Associates (2009).

- [NLP] Nonlinear Dynamics Reader

cse.ucdavis.edu/~chaos/courses/nlp/Reader.html

- Lecture Notes online

Software

- Goal: Learn via Analytical, Numerical, Coding
- Previous programming?
- Python Tools & Development:
  - Python v. 2.6
  - Suggested packages:
    - Numerical: NumPy, SciPy, & ScientificPython
    - Graphics: matplotlib & MayaVi & PyGlet
    - Images: PIL & ImageMagick
    - Development: iPython and others
  - See course web pages for configuration help:

    cse.ucdavis.edu/~chaos/courses/nlp/Software/

    Enthought Python Distribution 6.1: Windows, Linuses, & Mac

Who has what?

- Fill out questionnaire
- Laptop?
- OS:
  - Windows?
  - OS X?
  - Linux?

Nonlinear Physics:
Modeling Chaos and Complexity

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Spring 2008
WWW: http://cse.ucdavis.edu/~chaos/courses/nlp/

Questionnaire

1. Name: ____________________
2. Graduate or Undergraduate (circle one)
   17 **6**
3. Email address: ____________________
4. Major/Field: ____________________
5. What programming language(s) have you used?
   (circle all appropriate)
   C or C++ or Java or Fortran or Python or Perl or Other ________
   17 21 7 4 10 5
6. What level of programming experience do you have?
   (circle one)
   Little or Moderate or Extensive
   5 11 10
7. Are you familiar with Unix? Yes or No (circle one)
   19 6
8. Do you have a laptop? Yes or No (circle one)
   21 3
9. Which OS(es) does it run?
   (circle all appropriate)
   Windows or OS X or Linux
   15 7 5
10. Do you have a desktop machine? Yes or No (circle one)
    16 9
11. Which OS(es) does it run?
    (circle all appropriate)
    Windows or OS X or Linux
    12 2 6

PHY	**10**
APM	**7**
CS	**2**
MAT	**1**
ApSci	**1**
MAE	**1**
Civil	**1**
Econ	**1**
?	**1**

Matlab	**5**
Lisp	**3**
LabView	**2**
Haskell	**2**
C#	**2**
ASM	**2**
Basic	**2**
SQL	**1**
Lua	**1**
Ruby	**1**
Pascal	**1**
IDL	**1**

Tasks: Done by Thursday

- Get your machine(s) running Python 2.6
- Computer lab:
    - 2118 Math Sciences Bldg
    - Currently testing installation
- Get your computing lab account:

  Instructions on course website.
- Familiarize yourself with Linux/Unix:

  See tutorials on course website.

Reading To Do

- NLP articles:
  - Lem "Odds"
  - "Chaos", Scientific American
- NDAC:
  - Chapters 1 & 2

Homework 0

- Find three (3) examples of unpredictability that you encounter directly over the weekend.
- For each, be prepared to discuss:
  - Where did you encounter it?
  - What was your interaction?
  - Why do you consider it unpredictable?
  - What effect did its unpredictability have on you?
  - What aspects would you expect to be able to predict?
  - How would you model it?
- For each example write paragraph summarizing answers.

Math computer lab: 2118 MSB

Thursdays we meet there, not in 185 Physics.

OS is Linux: Who needs help with Unix/Linux?

Create your account, go to

http://www.math.ucdavis.edu/comp/class-accts

Use virtual course number MAT 998Z.