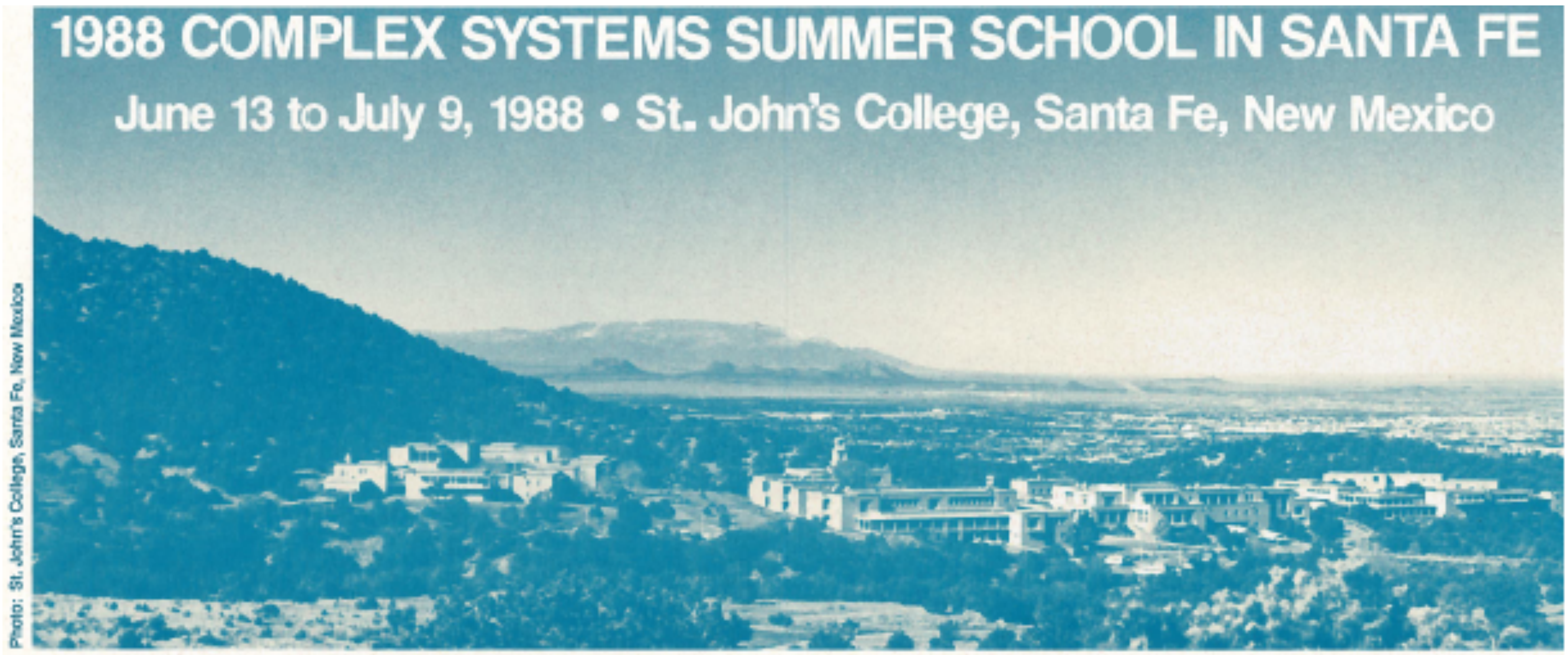
"…And here's how it all began" *:
Reflections on the first SFI Summer School



* With apologies to The Eagles, "Hell Freezes Over"

David K. Campbell, Boston University July 8, 2018

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Prolog: Axioms for Lecturers

- Kac Axiom: "Tell the truth, nothing but the truth, but NOT the whole truth."
- Weisskopf Axiom: "It is better to uncover a little than to cover a lot."
- But we all tend to follow the Rubbia lemma: "the more, the merrier"
- TTN: What was the remark?

"Faster"

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An aside based on DK's comments yesterday

- A slight rephrasing of DK's comments on reduction(ism) vs. "emergence", which could also be called "constructivism".
- Key article, first real explanation is by another founding member of SFI: Philip Anderson, "More is Different" Science 177 393-396 (1972 !!).

> The main fallacy in this kind of thinking is that the reductionist hypothesis does not by any means imply a "constructionist" one: The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. In fact, the more the ele-

- This is the essence of "emergence": new phenomena at very scale. I urge you all to find and read this paper.

The Players: Faculty

Summer School Staff

GUEST LECTURERS:

Doyne Farmer
Los Alamos National Laboratory
Ziaul Hasan
University of Arizona
Erica Jen
Los Alamos National Laboratory
Y. C. Lee
Los Alamos National Laboratory and University of Maryland
Bruce McNaughton
University of Colorado, Boulder
Richard Palmer
Duke University
George Papcun
Los Alamos National Laboratory
Rick Riolo
University of Michigan
Elizabeth Ann Stanley
Los Alamos National Laboratory

FACULTY:

Experiments on Hydrodynamic Instabilities and the Approach to Chaos
Guenter Ahlers, Physics, University of California, Santa Barbara
The Economy as a Complex Adaptive System
W. Brian Arthur, Food Research Institute, Stanford University
Introduction to Nonlinear Dynamics
David Campbell, Center for Nonlinear Studies, Los Alamos National Laboratory
Mechanisms in Evolutionary Biology
Marcus Feldman, Biological Sciences, Stanford University
Introduction to Classifiers
John Holland, Computer Science and Engineering, University of Michigan
Logic of Life
Stuart Kauffman, Biochemistry and Biophysics, University of Pennsylvania
Spatial and Temporal Organization of Morphogenetic Fields
Jay Mittenthal, Anatomical Science, University of Illinois, Urbana
Neural Networks and Cognition
Lynn Nadel, Psychology, University of Arizona
Dynamics of Patterns: A Survey
Alan Newell, Mathematics, University of Arizona
Adaptation in the Space of Cellular Automata
Norman Packard, Physics, University of Illinois, Urbana
Glasses and Spin Glasses
Dan Stein, Physics, University of Arizona
Chemical Reactions in Complex Systems
Peter Wolynes, Chemistry, University of Illinois, Urbana

The Players: (Selected) Students

- Total of 57 students attended, mostly still graduate students
- Can't include everybody but here are some familiar names, as listed at the time: Mr. Richard Bagley, Mr. Aviv Bergman, Mr. Philippe Binder, Dr. Lloyd Demetrius, Mr. Wentian Li, Mr. Seth Lloyd, Mr. Ronnie Mainieri, Mr. John Miller, Ms. Sarah Ann Scholfield, Mr. Nicholas Tufillaro, Mr. David Wolpert, Ms. Kornelija Zgonc
- Mostly from physics and math backgrounds, some medical, some social scientists

Here's what they had to cope with

A real palimpsest

Santa Fe Inst.
June 1999

D. Campbell
I.1

INTRODUCTION TO "NONLINEAR SCIENCE"

dkcampbell@lanl.gov

5 LECTURES

I. OVERVIEW OF "NONLINEAR SCIENCE":
PARADIGMS OF "CHAOS," "SOLITONS", AND "PATTERNS":
BASIC CONCEPTS OF DYNAMICAL SYSTEMS

II. "CHAOS", I : ITERATED MAPS

III. "CHAOS", II : LOW-DIMENSIONAL FLOWS

IV. "SOLITONS" : INTEGRABILITY IN HIGH-DIMENSIONAL FLOWS.

V. "PATTERNS" : SPATIALLY INHOMOGENEOUS STATES IN, e.g., REACTION-DIFFUSION EQUATIONS

SCHEDULE

LECTURES: M, Tu W, Th, F 9-10^{30}

SCHEDULED DEMOS : Th, 2^{30}-4 MAP COMPUTER DEMO
FLOW COMPUTER DEMO AND B-Z REACTION DEMO

UNSCHEDULED DEMOS : ad lib.

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Here's what they had to cope with

SANTA FE 6/88 93.I.8 D CAMPBELL

LECTURE 2: DYNAMICAL SYSTEMS I: BASIC CONCEPTS AND EXAMPLES

PROBLEM: THERE ARE WHOLE BOOKS ON SUBJECT; INDEED, BOOKS ON SINGLE WORDS eg, "BIFURCATIONS" -- INTRODUCED BELOW.

DEF: CHUTZPAH: ATTEMPT TO SURVEY DYNAMICAL SYSTEMS IN 2 LECTURES

UNIQUE SOLUTION -- DUE TO MARK KAC --

"TO TELL THE TRUTH, NOTHING BUT THE TRUTH, BUT NOT THE WHOLE TRUTH."

DEF: DYNAMICAL SYSTEM: SOMETHING THAT CHANGES IN TIME ACCORDING TO A WELL-DEFINED RULE: NO CHANGE IS A LIMITING CASE: FOR NOW, WORK WITH CONTINUOUS TIME SYSTEMS

ADD HUMAN IMPACT HERE

HAMILTONIAN SYS. (CONSERVES ENERGY) $\frac{d^2\theta}{dt^2} + \frac{g}{l}\sin\theta = 0$

SIMPLE PENDULUM

DISSIPATIVE SYS. (DOES NOT CONSERVE ENERGY) $\frac{d^2\theta}{dt^2} + \alpha\frac{d\theta}{dt} + \frac{g}{l}\sin\theta = \Gamma\cos\omega t$

DAMPED, DRIVEN PENDULUM

adidas

Outline of Rest of Talk

- Intuition on ***linear*** versus ***non-linear***
- Why interest in nonlinear science ?
- Paradigms of nonlinearity: from concept to practicality
- Chaos and Fractals
- Solitons and Coherent Structures
- Patterns and Complex Configurations
- Summary and Conclusion

Intuition on *Linear* versus *Non-Linear*

Mathematically

Linear *versus* Non-Linear

- Can add two separate solutions to form new solution: superposition principle => systematic methods for solving linear problems, independent of apparent complexity: break into small "simple" pieces and add solutions together

- Can *not* add together solutions to form new solution: failure of superposition => must solve nonlinear system *in toto*

- $(a+b)^2 = a^2+2ab+b^2$
  $\neq a^2+b^2$

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Intuition on *Linear* versus *Non-Linear*

Physically

Linear *versus* Non-Linear

Linear

- Smooth, regular motion in space/time and as function of parameters
- Response in proportion to stimulation
- Initial pulses/lumps (typically) spread and decay (dispersion)

Non-Linear

- Transitions from smooth motion to erratic "chaotic" motion, "random" behavior
- Self-sustaining oscillations, response can *differ* from stimulation
- Highly coherent, stable localized spatial structures

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Nonlinear Dynamical Systems

Def: **Dynamical system**: a system that changes in time, e.g., a pendulum, a flower, or the **human heart**

Your heart is a nonlinear, dissipative (*i.e.*, energy is not conserved) dynamical system. Normally, the heart has self-sustained oscillations (≈70/minute). Rate can change with stress, but (more or less) returns to a

Limit Cycle Attractor

Unfortunately, there is another stable motion for heart: no beating at all, or a

Fixed Point Attractor

TTN: What is this called clinically? A: Death

But many other motions are possible ("atrial fibrillations," "Wenkebach oscillations"): some of these cardiac arrhythmias have very complex behavior in time, maybe a

Strange Attractor

(Hallmark of dissipative deterministic chaos)

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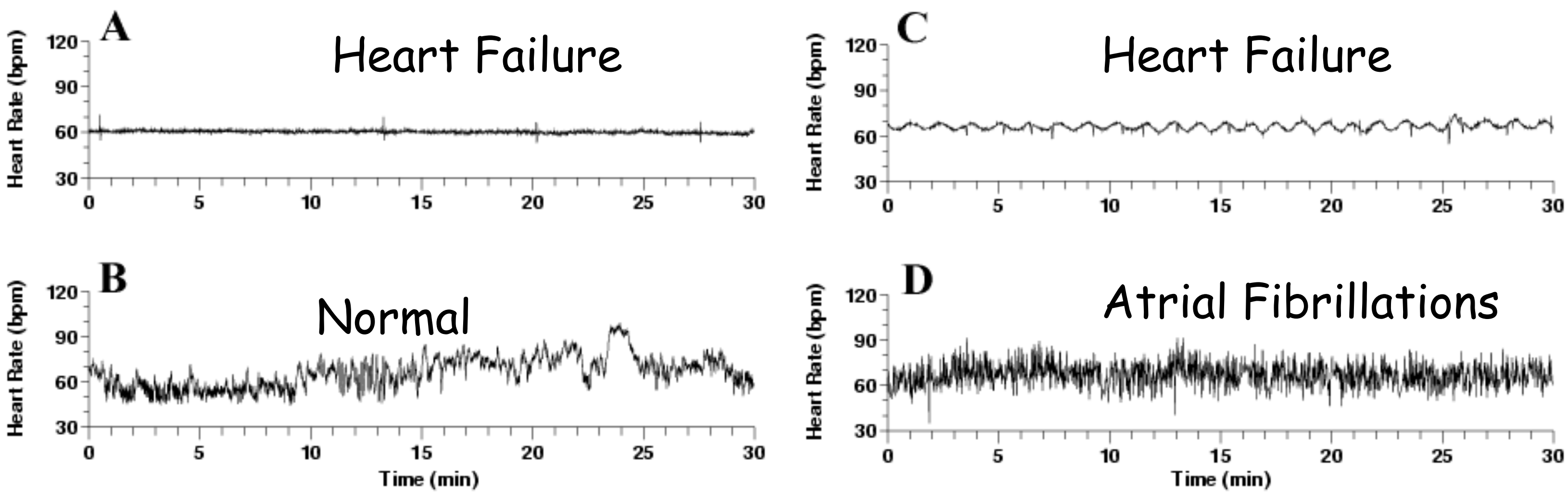
TTN: Which is the healthy heart pattern?

A. L. Goldberger *et al.*, *Proc. Nat. Acad. Sci. (USA)* **99** suppl1: 2466 (2002)



Variability in heart rate is key to ability to adapt to different situations, stresses; typical of nonlinear biological oscillators

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Why the Interest in Nonlinear Science?

- "Non-elephants?" (Ulam)—Study of everything? No!
- Rapid progress from "synergetic" interactions of:
  1. "Experimental Mathematics" including interactive graphics
  2. High precision measurements of natural phenomena, interdisciplinary
  3. New analytic methods (IST, Nonlinear stability)
- This "tripartite methodology" has *not* led to completely systematic approach *but* to recognition of several "paradigms" reflecting common (*universal* ?) features of nonlinear systems: three *"foundational"* paradigms

<u>Deterministic Chaos/ Fractals</u>	<u>Solitons/Coherent Structures</u>	<u>Patterns/Complex Configurations</u>
Apparently random behavior in deterministic systems/structure on all scales	Persistent, localized spatial structures	Formation of complex spatial patterns and dynamical competition to select among them

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Two more recent Paradigms

- Adaptation/Evolution/Learning: nonlinear systems that can modify behavior in response to environmental changes; exhibit emergence, self-organizing behavior
- Networks: interacting nonlinear systems: nonlinear systems on graphs (*e.g.*, hub-spoke, long connection, random, …)

These form the bridge between "Nonlinear Science" and what we now call "Complexity" or "Complex Systems."

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Deterministic Chaos and Fractals

Seemingly random beha those obeying
Newton's Laws

Very non-intuitive at fir iew (Laplace)

Cliché Henri Manuel.

From *exact* knowledge c dge of final state:
True, *BUT*, exact knowl xperiment. Hidden
assumption has been l conditions follow
roughly the same fin

This is ems

Sensi ons

Familiar caré)

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Essence of Chaos

- Sensitivity to initial c … est error grows exponentially in time … lled “Lyapunov exponent” **λ** and for … n is chaotic
- Geometrical essenc … retching” (by e^{λ}) and “folding” (so that mo … a finite region). Exactly like a baker … *ant* or *mille feuille* pastery: rolling it ou … nd folding it over (“folding”!)

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Chaos in the "Standard Map"

- Chaos in energy-conserving (non-dissipative) systems: There can be *no* attractors, as phase space volume is conserved. Instead, "Cantor dust" of wandering orbits (see images below)
- Simple example: the "Standard Map" : two-dimensional area-preserving

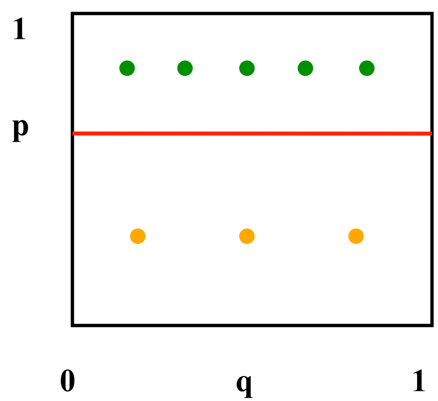
k is nonlinearity parameter

(Mod 1) $$p_{n+1} = p_n - k(/2\pi) \sin 2\pi\, q_n$$

$$q_{n+1} = q_n + p_{n+1}$$

NB: n+1 necessary for area preserving (Hamiltonian) map

- For $k=0$ (*i.e. no* nonlinearity) $p_{n+1} = p_n = p_0$, $q_{n+1} = q_n + p_0$. so the momentum is conserved and q just "wraps around" unit square (torus):



$p_0 = 4/5,\ q_0 = 0.1$

$p_0 = 1/\sqrt{2},\ q_0 =$ arbitrary

$p_0 = 1/3,\ q_0 = 0.5$

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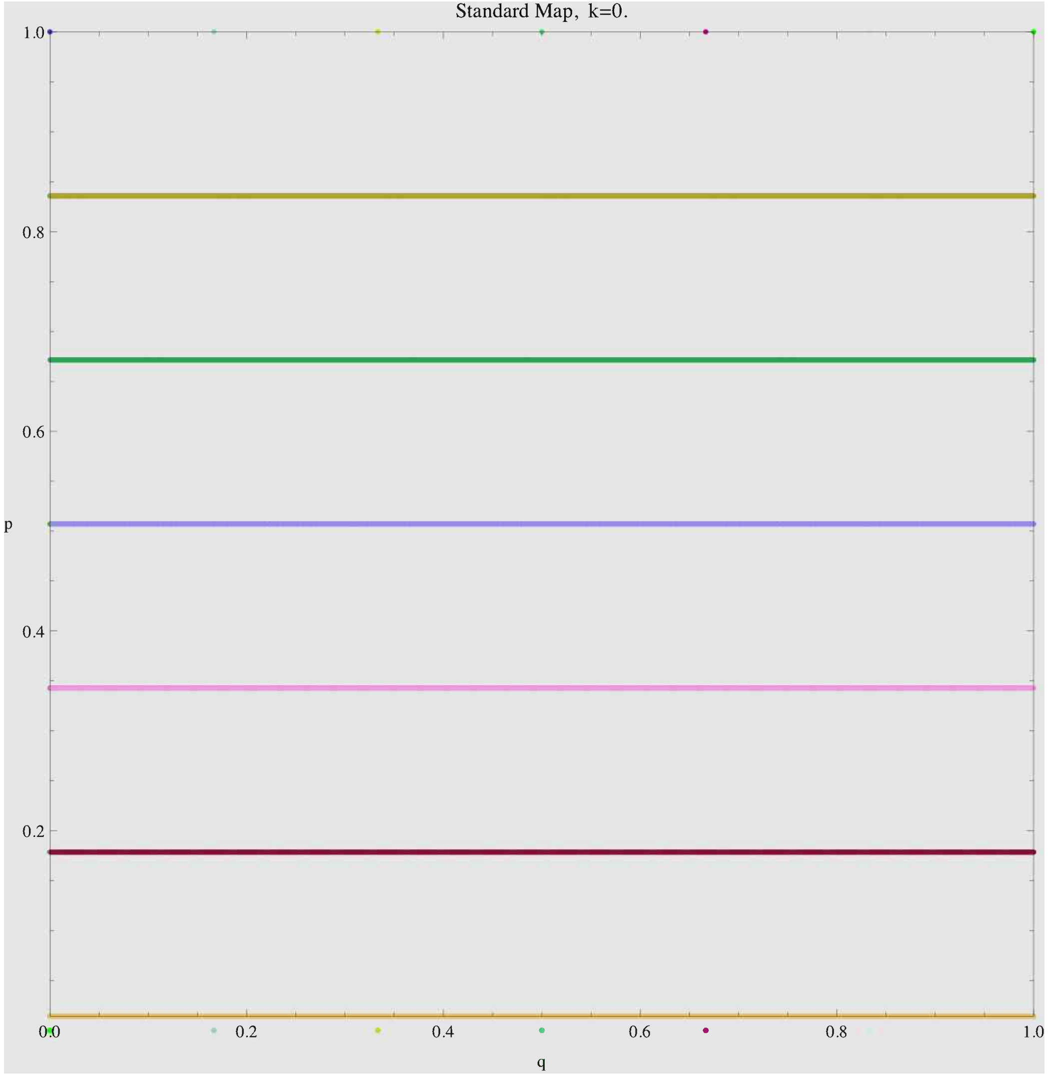
K=0: no nonlinearity; orbits are everywhere smooth and regular



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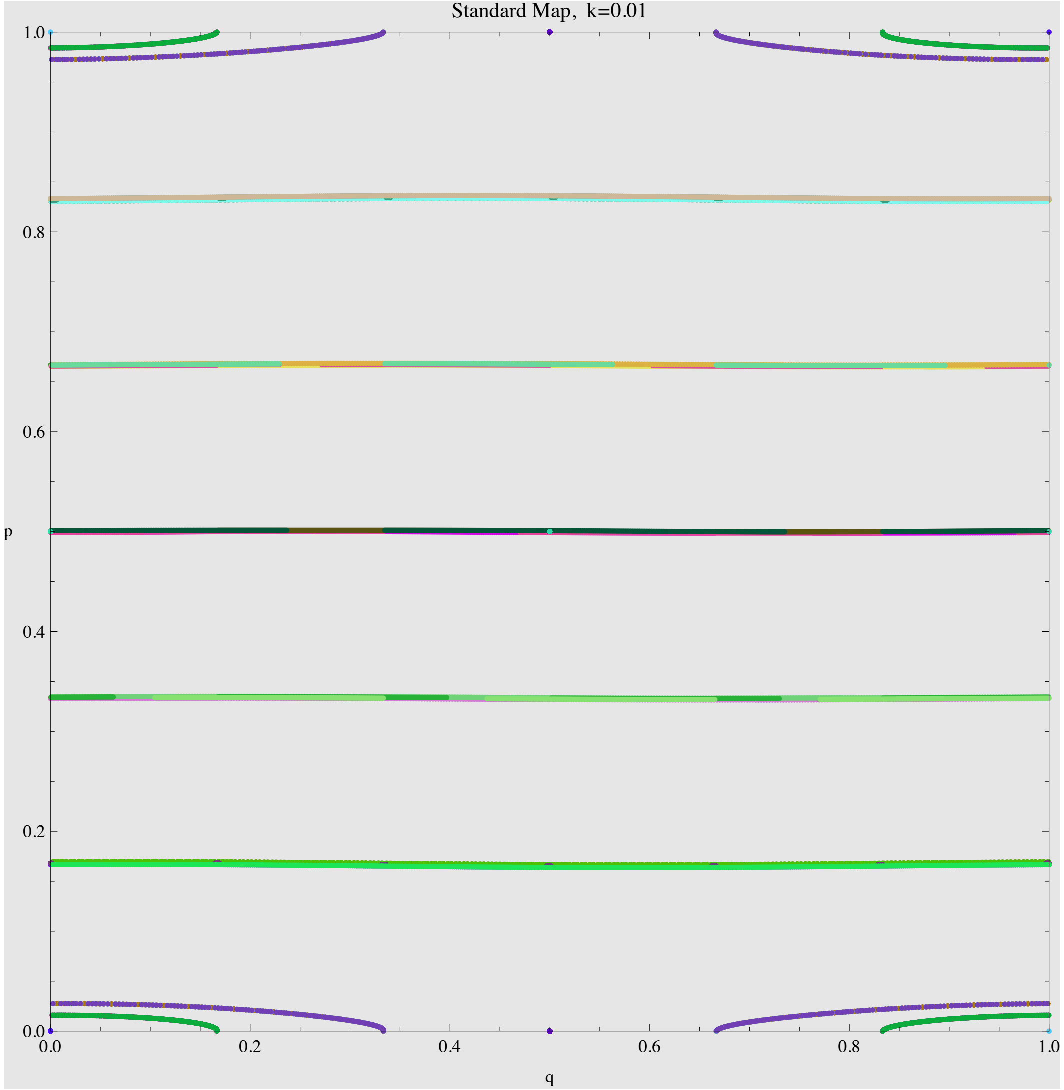
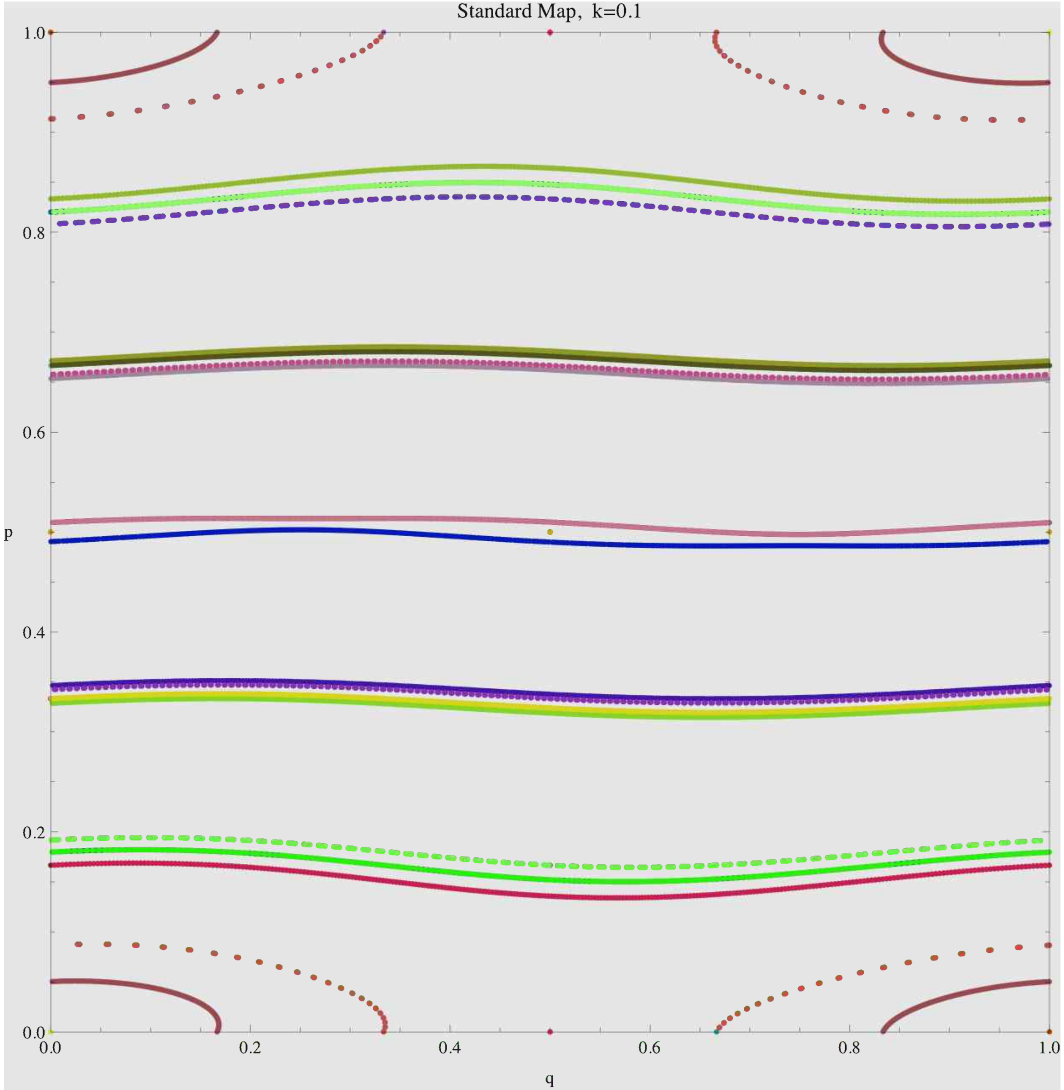
K=0.01: very weak nonlinearity already distorts orbits around q=1/2 unstable fixed point



K=0.1: weak nonlinearity distorts orbits further



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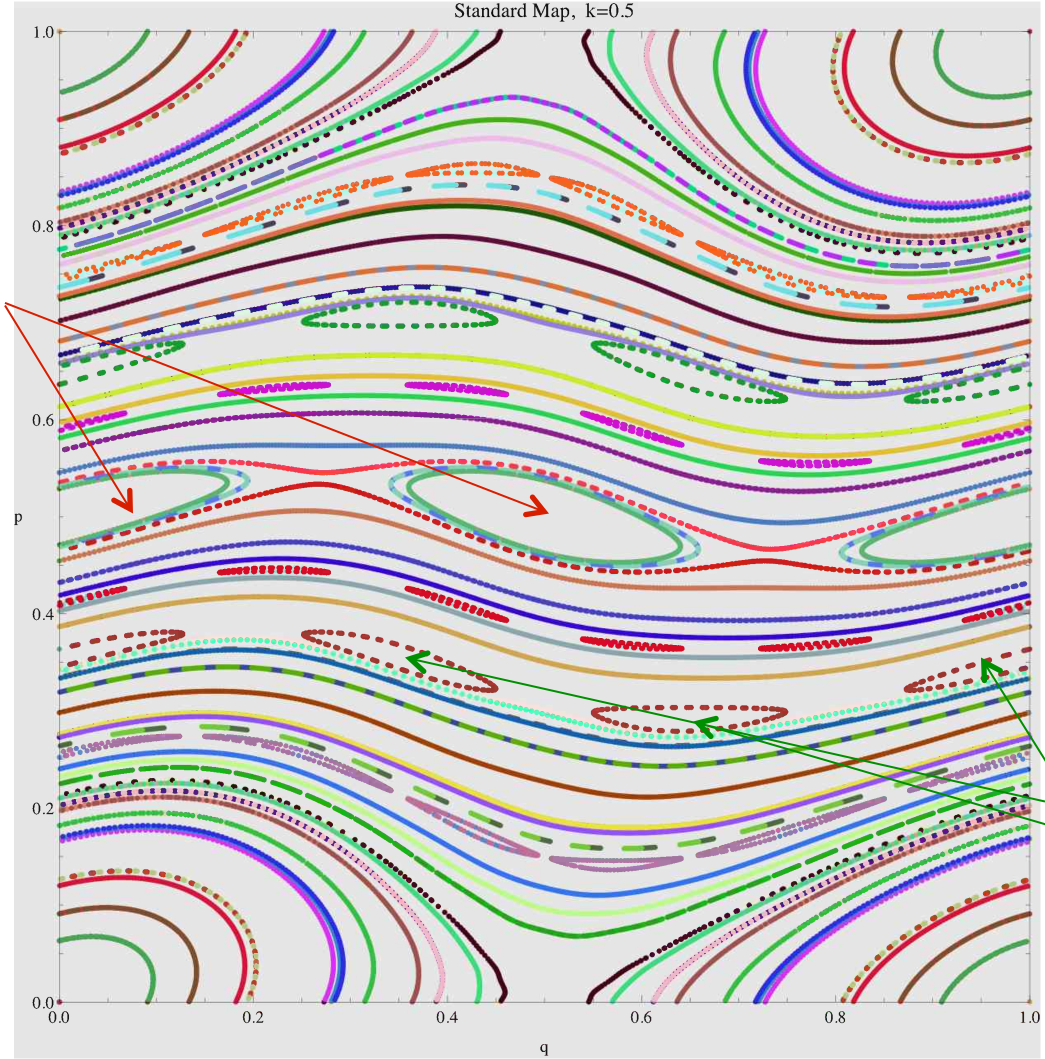
K=0.5: Observe the "islands" of regular motion: some "straight line" orbits are broken up into closed paths

"Island" of regular motion of period 2



"Island" of regular motion of period 3

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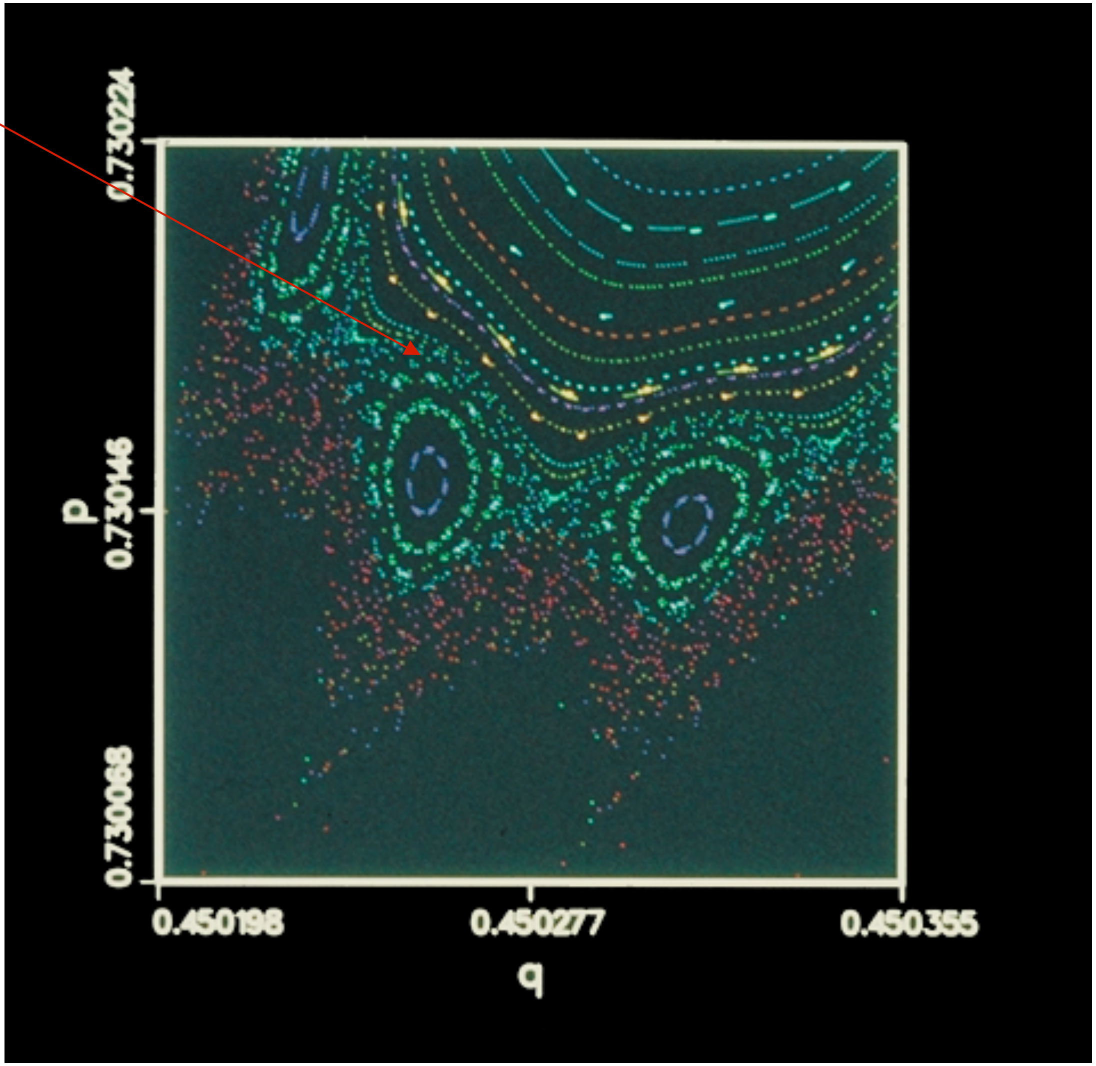
Structure of Chaos in Standard Map

For ***k*** = 1.1

Expand small region

Mixture of regular and irregular motion on all scales, "chaos all the way down"

Implications for solar system (Laskar), orbits of asteroids, motion of Pluto's moons!



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Practical Chaos

- Practical Chaos
  - Systems in nonlinear regime can show much more interesting behavior than in linear regime
  - Importance of chemical oscillations for reactive control, pattern selection, etc.
  - Nonlinear systems in chaotic regime are even more interesting
- Chaotic Control/Controlling Chaos
  - Intuition: chaotic motion "explores" much of the "space" of the system. Further, chaotic regime is filled with unstable fixed points and periodic orbits. Central idea of (one form of) chaotic control is to :
  - 1) identify a desired unstable motion in that is in/near some region visited by chaotic system and then
  - 2) alter the "parameters" of the system to try to stabilize this already existing orbit (pointer demo)
- Chaos => Flexibility
  - N.B.: Chaos may be desirable for: enhanced mixing in chemical reactions and/or spreading out/distributing wear

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Pluto's chaotic moons

See M. R. Showalter and D. P. Hamilton, "Resonant Interactions and chaotic rotation of Pluto's small moons,: Nature 522 45-49 (2015) : Image credit NASA

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Interlude: Nonlinear Dynamics in Chemistry

Chemical Oscillators

- Theoretical possibility of nonlinear oscillations in chemical reactions pointed out by J. Lotka, *Journal of Physical Chemistry* **14**, 271 (1910)! Requires at least two coupled autocatalytic reactions => coupled, first order, nonlinear ODE's
- Experimentally first reported by W.C. Bray, Journal of the American Chemical Society **43**, 1262 (1921)! In iodic acid/hydrogen peroxide system, rate of oxygen evolution varies periodically
- BUT: Idea of oscillations extensively criticized, even declared impossible!
- One of the strongest statements made by D.M. Shaw and H.O. Pritchard, Journal of the American Chemical Society **72**, 1403 (1968):
  - Hidden assumption in "proof" of no oscillations is linearization around equilibrium: if nonlinear deviations, no problem!
- Let's check this out in the laboratory: Briggs-Rauscher demo

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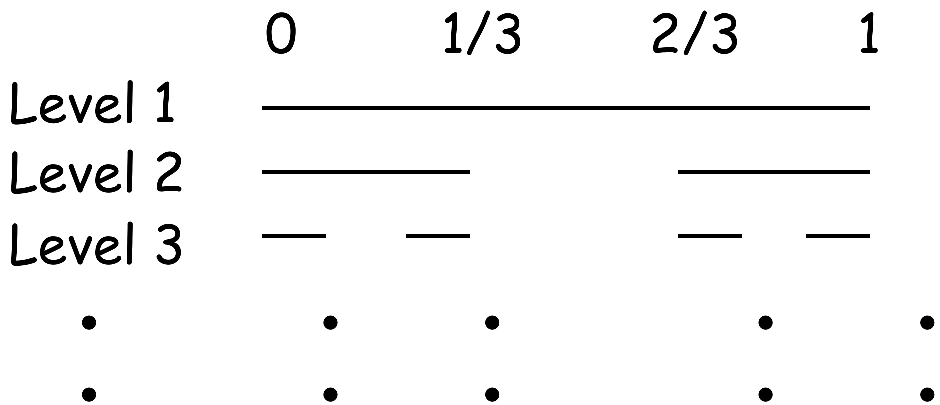
Fractals

"Fossils of Chaotic Motion"

- Def: Fractals: geometrical objects with "non-trivial" structure *on all scales*: typically "self-similar" (i.e., same non-trivial structure on all scales) and with "fractional" dimension
- Example: Cantor Set

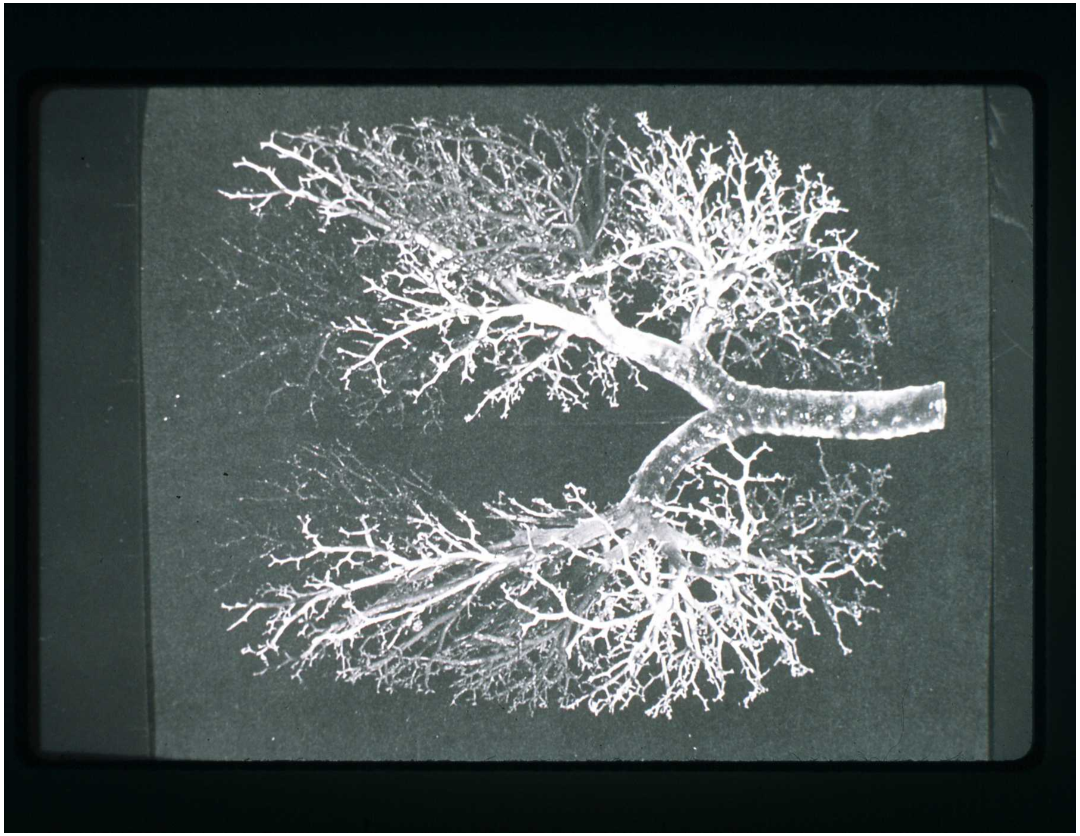


Resulting Cantor set formed as n-> ∞ has "fractal" dimension "between" a point and a line):

$D_F = \ln 2 / \ln 3 \sim 0.63...$

Fractals in the real world

Human lung



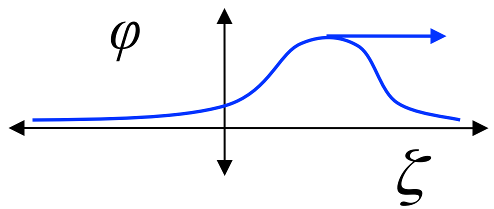
Fractals in the real world

Romanesco broccoli : credit
https://www.flickr.com/photos/paulmccoubrie/6792412657/

Solitons and Coherent Structures

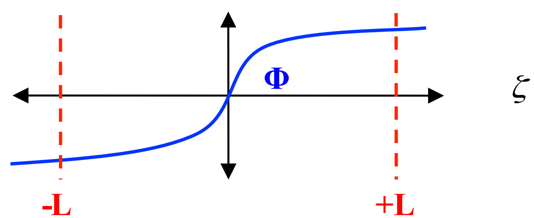
Consider continuum, wave-like motion, 1 space dimension

Def: ***Solitary Wave***: localized, traveling wave



$$\phi\left(\zeta = x - \mathrm{v}t\right)$$

NB: Different states allowed for $\zeta \to \pm\infty$



Localized since $\dfrac{\mathrm{d}\phi}{\mathrm{d}\zeta} = 0$ for $|\zeta| > L$

Def: ***Soliton***: Solitary wave that preserves *exactly* its amplitude, shape and velocity after collisions with all other waves.

Historical observation

Along a Scottish Canal, August 1834
(Reinactment 1995)

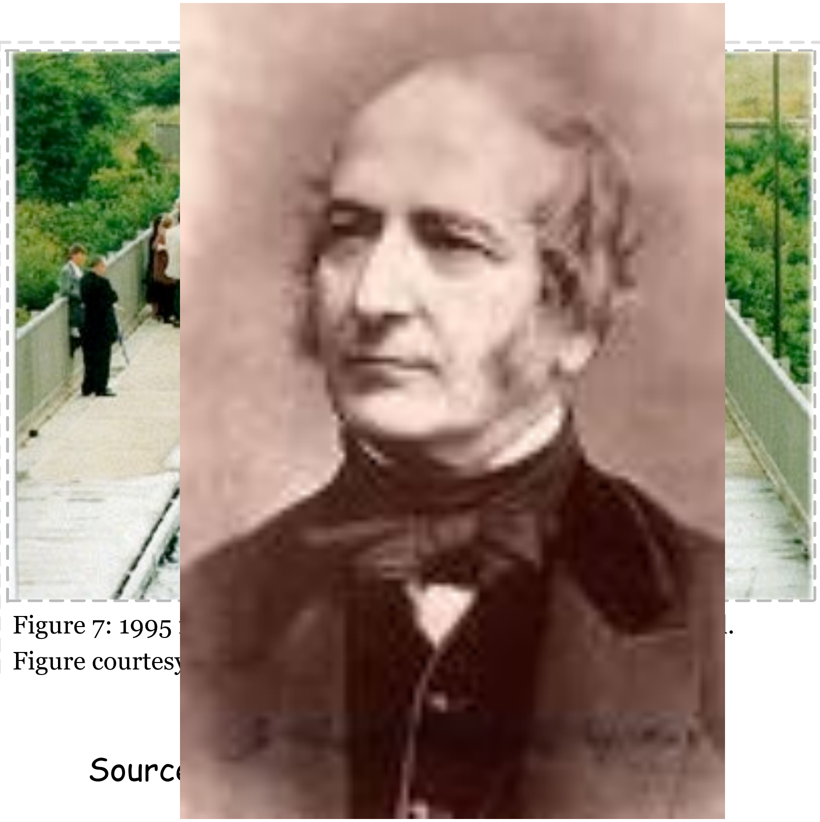


Figure 7: 1995 ...

Figure courtesy ...

Sourc...

John Scott-Russell, Scottish civil engineer and naval architect

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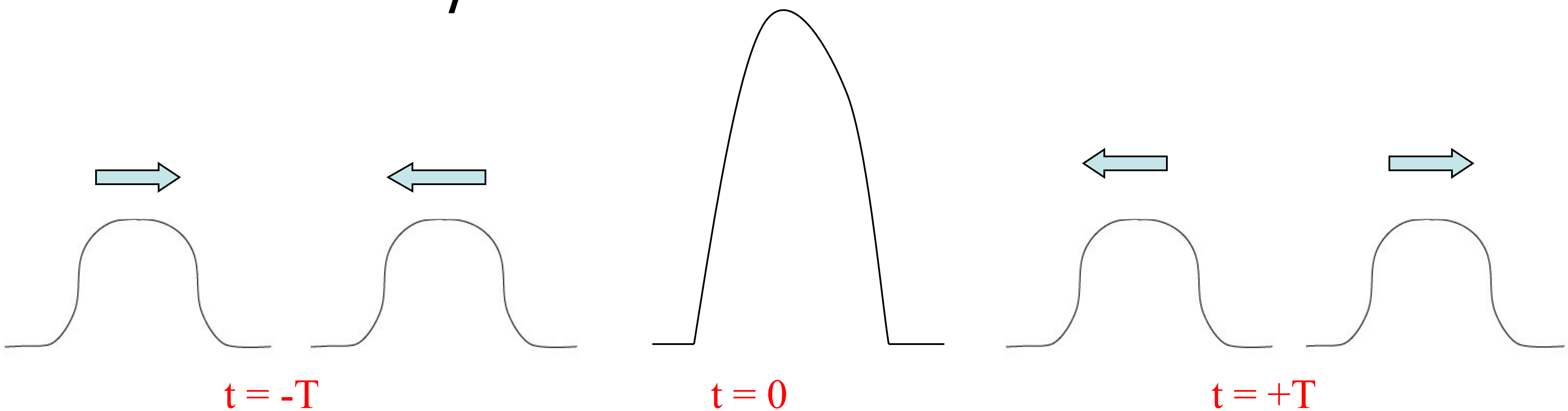
Where do Solitons Lurk?

- Linear, dispersionless wave equations have (trivial) solitons

Linear $\phi_{tt} - c^2\phi_{xx} = 0$ Dispersionless $\omega(k) = k$

By *superposition*

$$\phi \equiv e^{-(x-ct)^2} + e^{-(x+ct)^2}$$



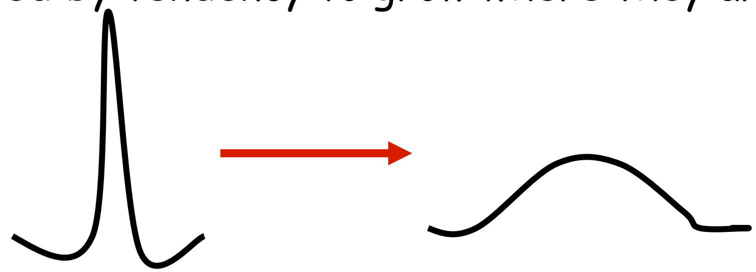
BUT ALSO: (some!) nonlinear, dispersive equations also have solitons ➔

VERY BIG SURPRISE!

Intuition behind Solitons

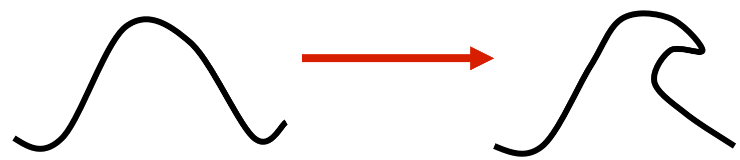
- In nonlinear systems, the "natural" tendency of waves to "spread out" (disperse) can be balanced by tendency to grow where they are already large and "break:"
  - Dispersion: (e.g., u_{xxx})

    $0=u_t+u_{xxx}$



  - Nonlinearity: (e.g., uu_x)

    $0=u_t+uu_x$



  - Combined effects lead to Korteweg-de Vries equation, with soliton solution

$$u_t+uu_x+u_{xxx}=0$$

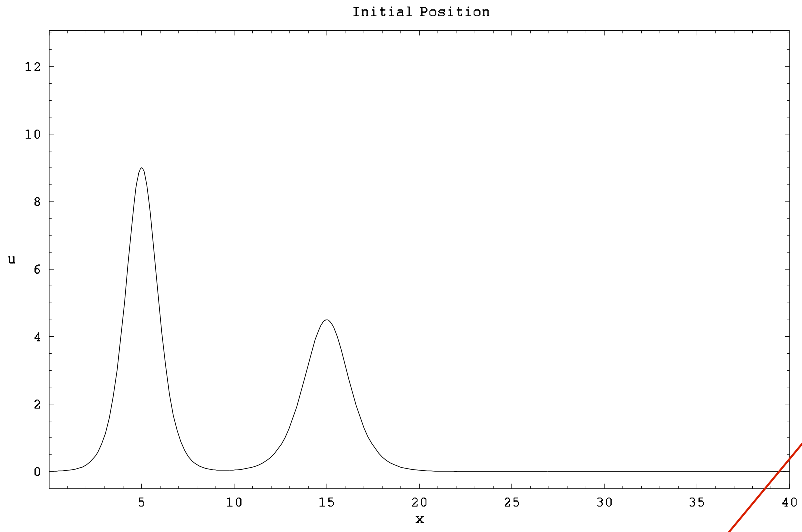
$$u_{sol}(x,t)=3v\,\mathrm{sech}^2\left(\sqrt{v}/2\right)[(x-vt)]$$

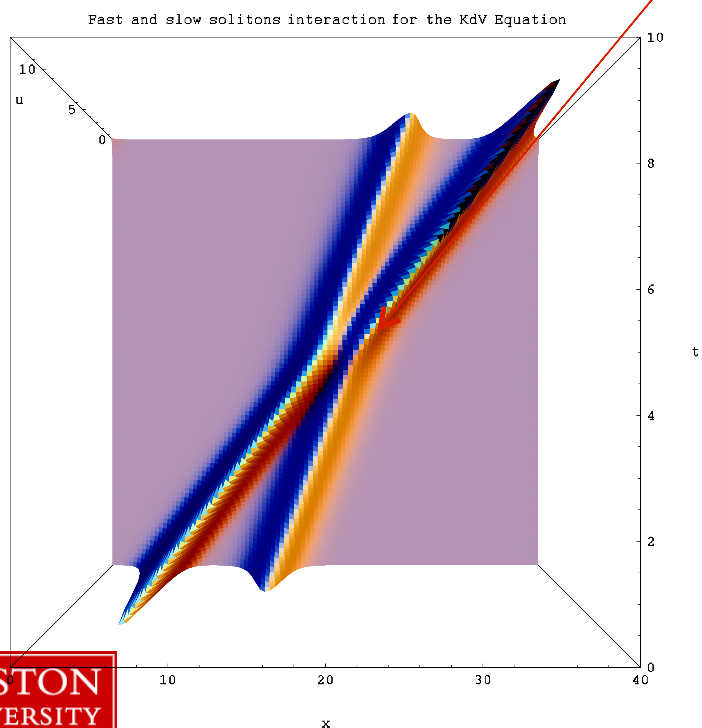
KdV Soliton collision: V_l = 3,V_s=1.5

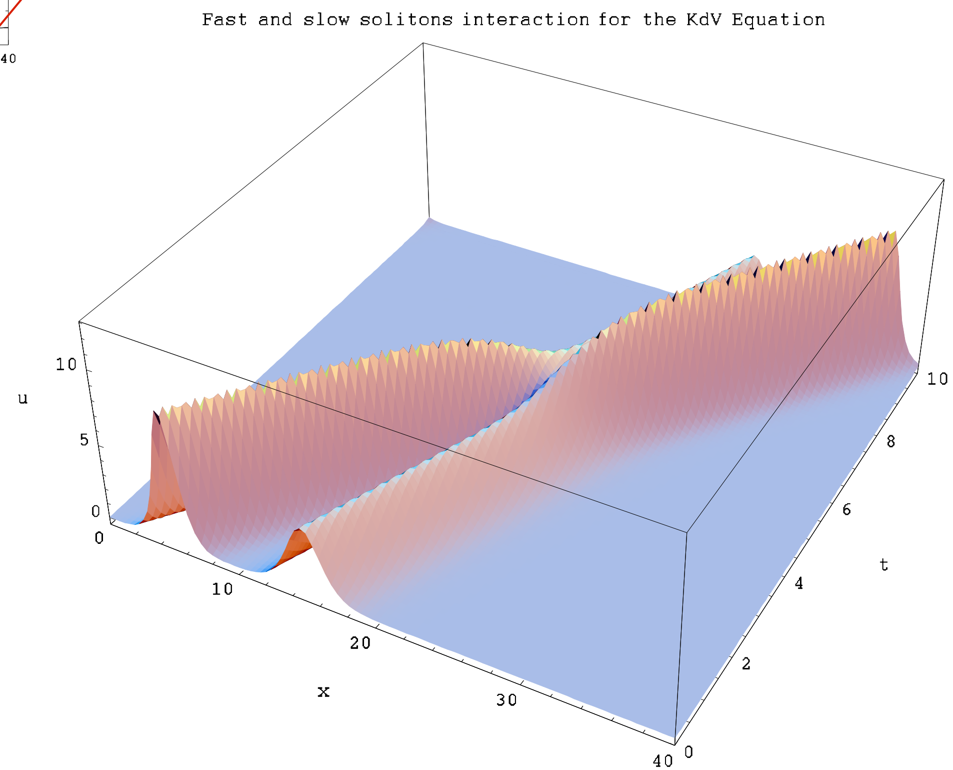
$u_t+uu_x+u_{xxx}=0$

TTN: What do you notice here?

A. Phase shift/time delay







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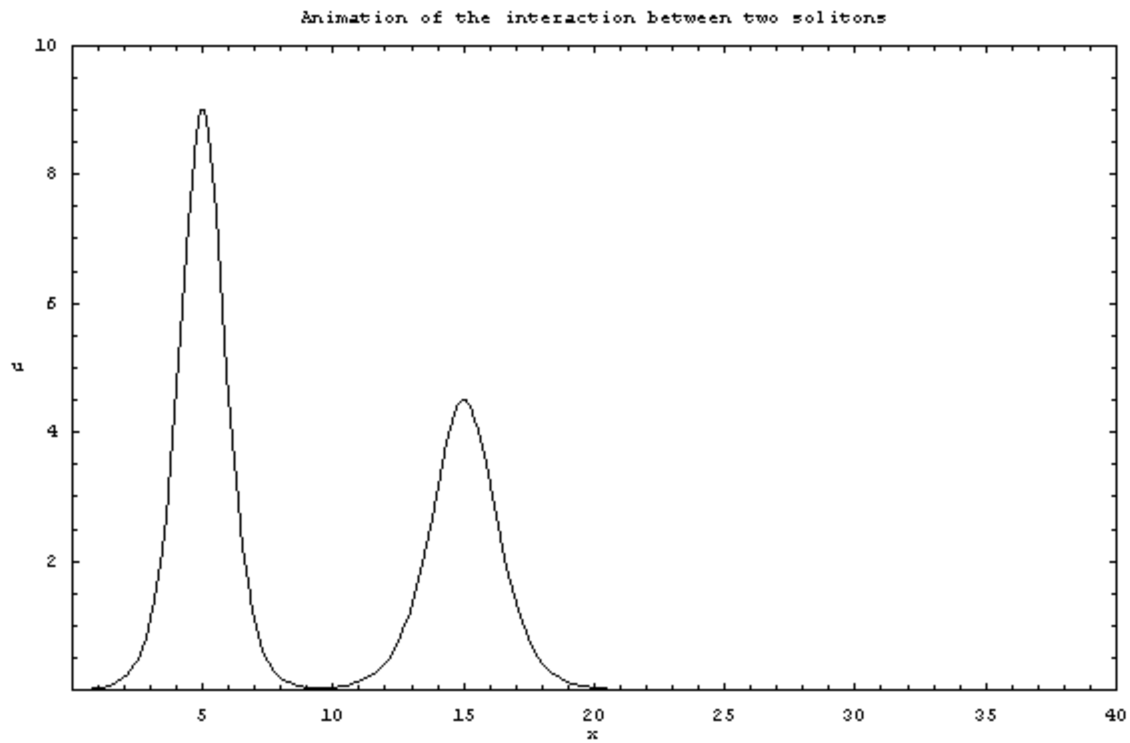

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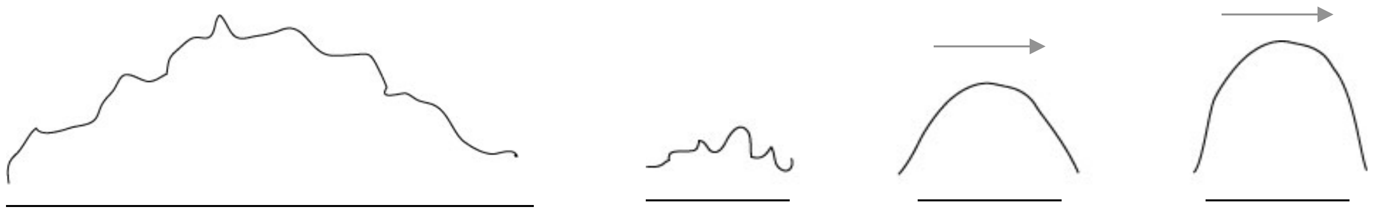
Why are Solitons so Special?

1. That they exist at all in nonlinear equations is amazing; expect nonlinearity would destroy, particularly in view of our experience with low-dimensional dynamical systems.
2. Solitons—more generally, coherent structures—can dominate asymptotic form of solution.



Random Junk t = 0 Separated Solitons $t = T >> 0$

3. Many physical systems are well-approximated by soliton equations: novel starting point for perturbation theory.

KdV: Water waves, plasma motions, nonlinear lattices

NLSE: Self-focusing in laser/plasma, laser/fiber optic interactions, self-trapping in solids

SG: Domain walls in magnetic materials, Josephson transmission lines, model relativistic quantum field theory, key renormalization group equation

Why are Solitons so Special?

4. Conversely, soliton-like excitations are observed and studied widely in nature: in physics, for instance, "Skyrmions" in nuclear and condensed matter physics, "monopoles" in particle physics, cavitons in atmosphere, vortices in fluids, *etc.*

5. Deep mathematical structure
   - Infinite dimensional, completely integrable systems
   - Group theoretic/algebraic structure of conservation laws:
   - Kac – Moody algebras, Strings
   - Inverse spectral transformation/Painlevè test

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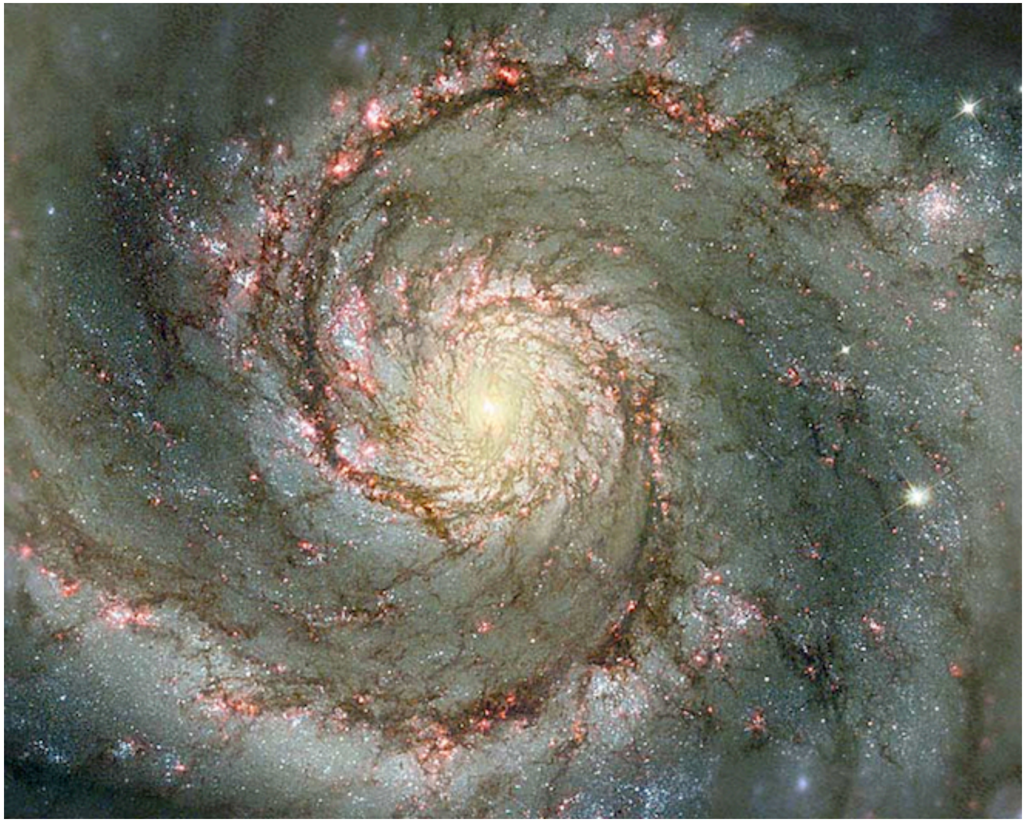
Coherent Structures in Nature

In natural world, don't expect exact soliton behavior: more general concept of ***coherent structures*** – persistent, localized spatial structures in extended nonlinear systems--is relevant.

Coherent Structures are observed on all scales in nature

- Galaxies 170,000 light years



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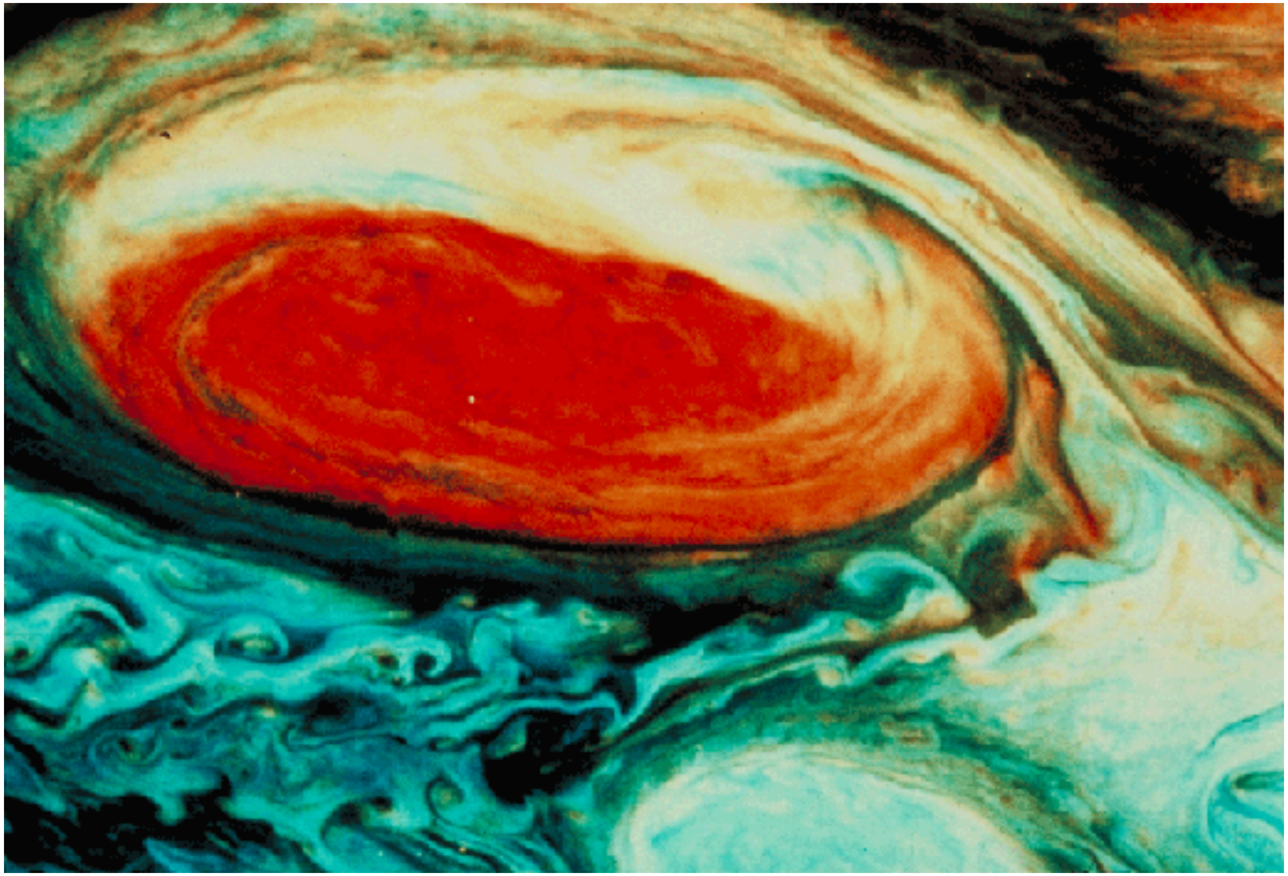
Coherent Structures in Nature

Red Spot of Jupiter 4×10^7 m



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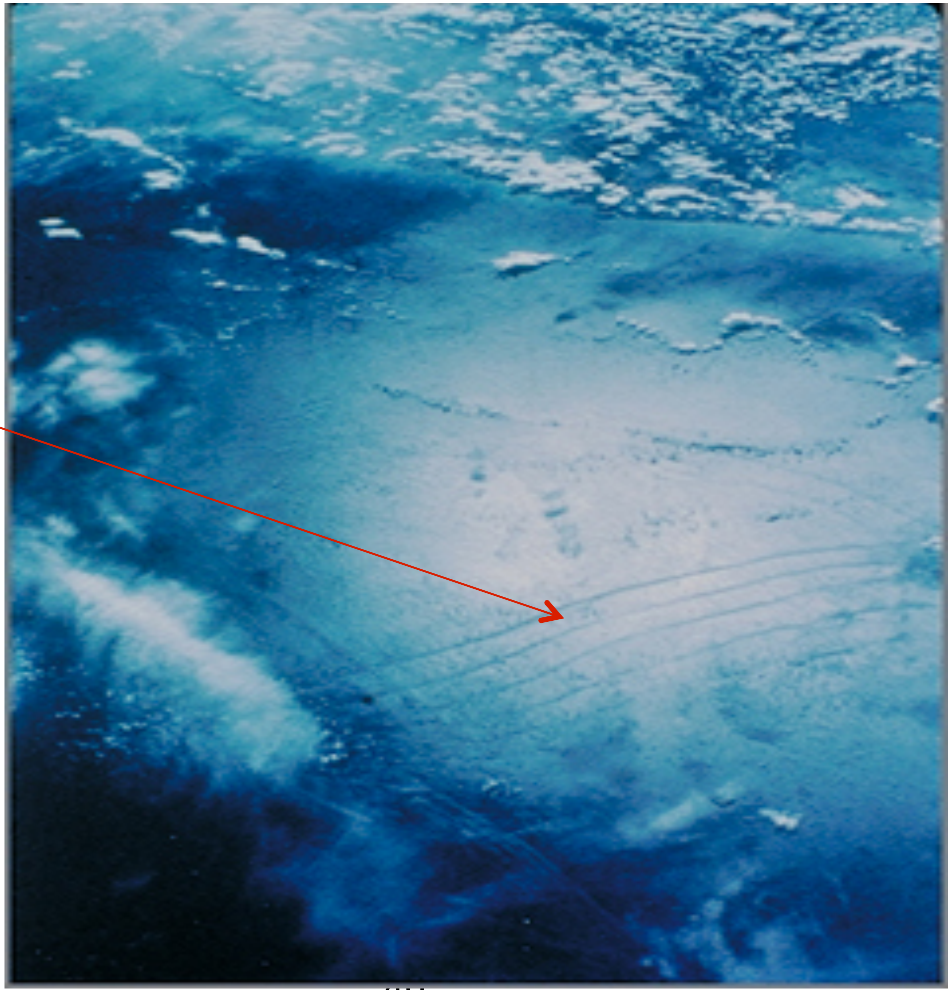
Coherent Structures in Nature

Earth Ocean Waves--Apollo - Soyuz image 10^5 m → 10^2 m



Note train of wave fronts ~ KdV solitons

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Coherent Structures in Nature

Earth Ocean Waves--Tsunamis 10^5 m → 10^2 m

Coherent Structures in Nature

Earth Ocean Waves—Waves on a beach 10^5 m → 10^2 m

Note phase shift from interaction like KdV

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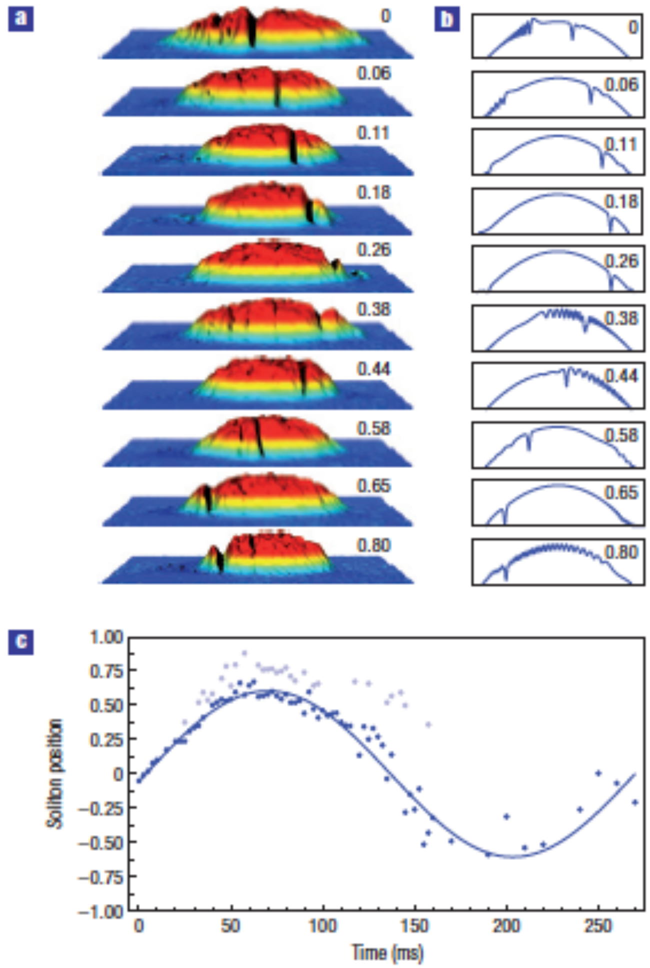
Coherent Structures in Nature

Bose-Einstein condensates 10^{-6} m



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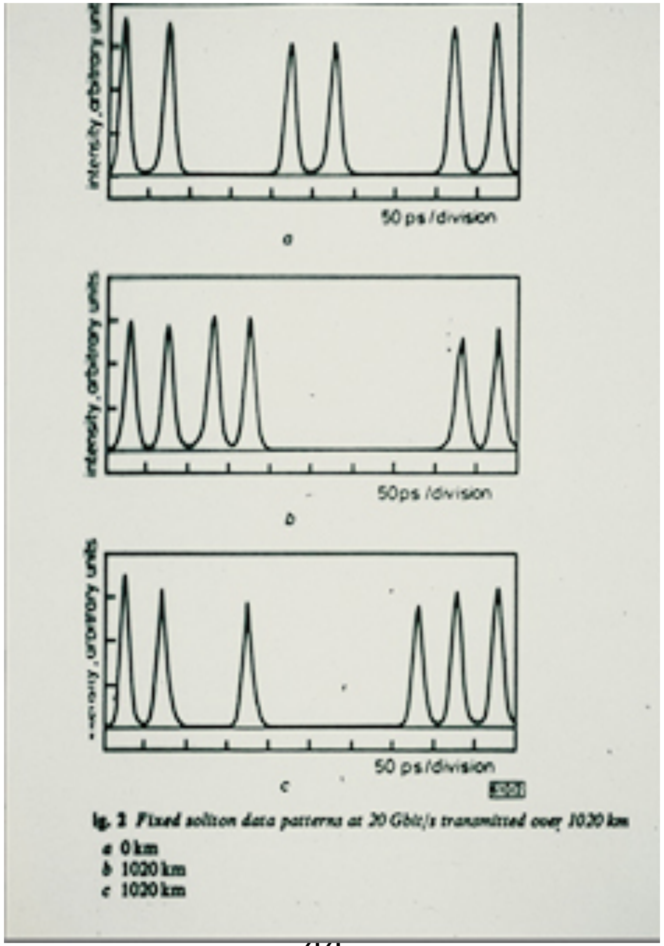
Coherent Structures in Nature

Pulses in optical fibers

10^{-6} m wide 10^{-3} m long



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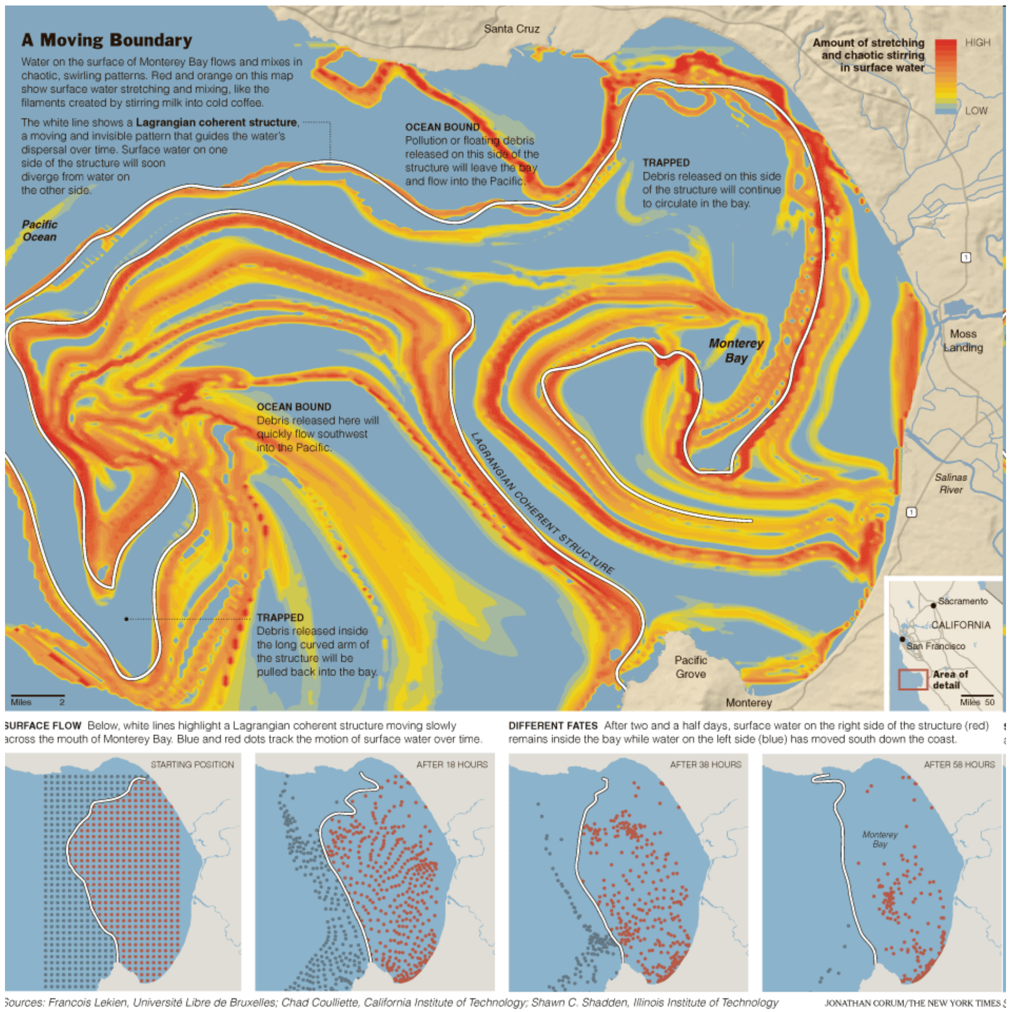
Practical Solitons/Coherent Structures

- Solition optical communications
  - Paradigm: Balance of dispersion with nonlinear index of refraction ("Kerr effect") in a glass (SiO_2) fiber
- Practicality:
  - Low loss optical fiber (<1dB/km)
  - Appropriate laser frequency to allow (small) nonlinear effects to balance dispersion
  - Reliable, cheap, low-power amplification mechanism (erbium doped sections of fiber)
- Bottom line:
  - All optical system, glass fiber, erbium doped sections every 20-50km. Solitions of 10-20ps duration and ~20mw can be used to send 10-20Gbit/s rate. Rates of 300 Gbit/s possible with "sliding guiding filtering" and "wavelength division multiplexing (WDM)!
  - Utilized in fiber cables in Europe and US

Practical Solitons/Coherent Structures: LCS

Controlling pollution in Monterey Bay



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Practical Solitons/Coherent Structures

Cleaning up Deep Water Horizon Oil Spill

Practical solitons? Surfin' the Severn River

Patterns and Complex Configurations

- Patterns and complex configurations arise in spatially extended nonlinear systems from instabilities of homogeneous state. Metaphorically, competition between coherent structures and chaotic dynamics
  - Kelvin-Helmholtz instability in counter-flowing fluids—entrapment of boundary
  - Rayleigh-Benard Convection Experiments
  - Targets and spirals in chemical reactions (Belusov-Zhabotinskii) and in slime mold colonies
  - Turing patterns
    - In chemical reactions
    - In zebra fish

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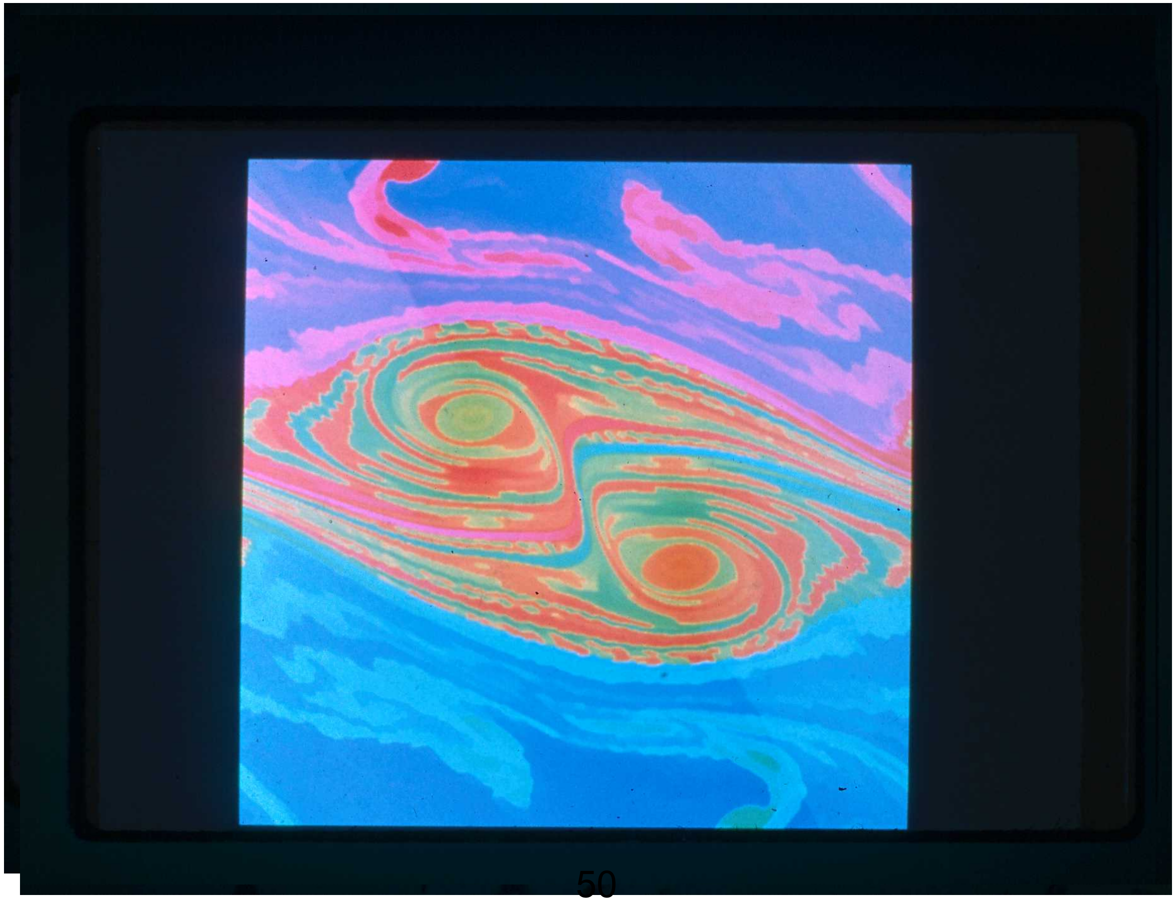
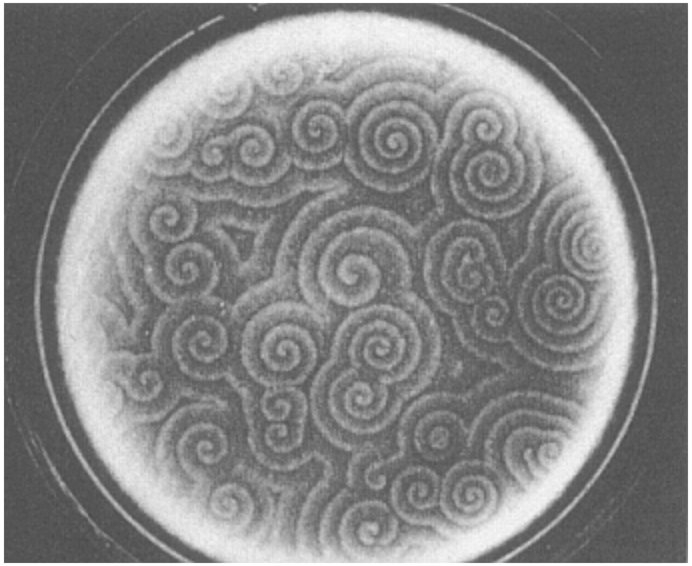
Patterns: Kelvin Helmholtz Instability

Two counter flowing fluids (upper =pink, lower = greenish blue) boundary colored yellow: note "chaotic" stretching and folding of boundary and emergence of coherent structures (vortices) (Simulation: P. Woodward)

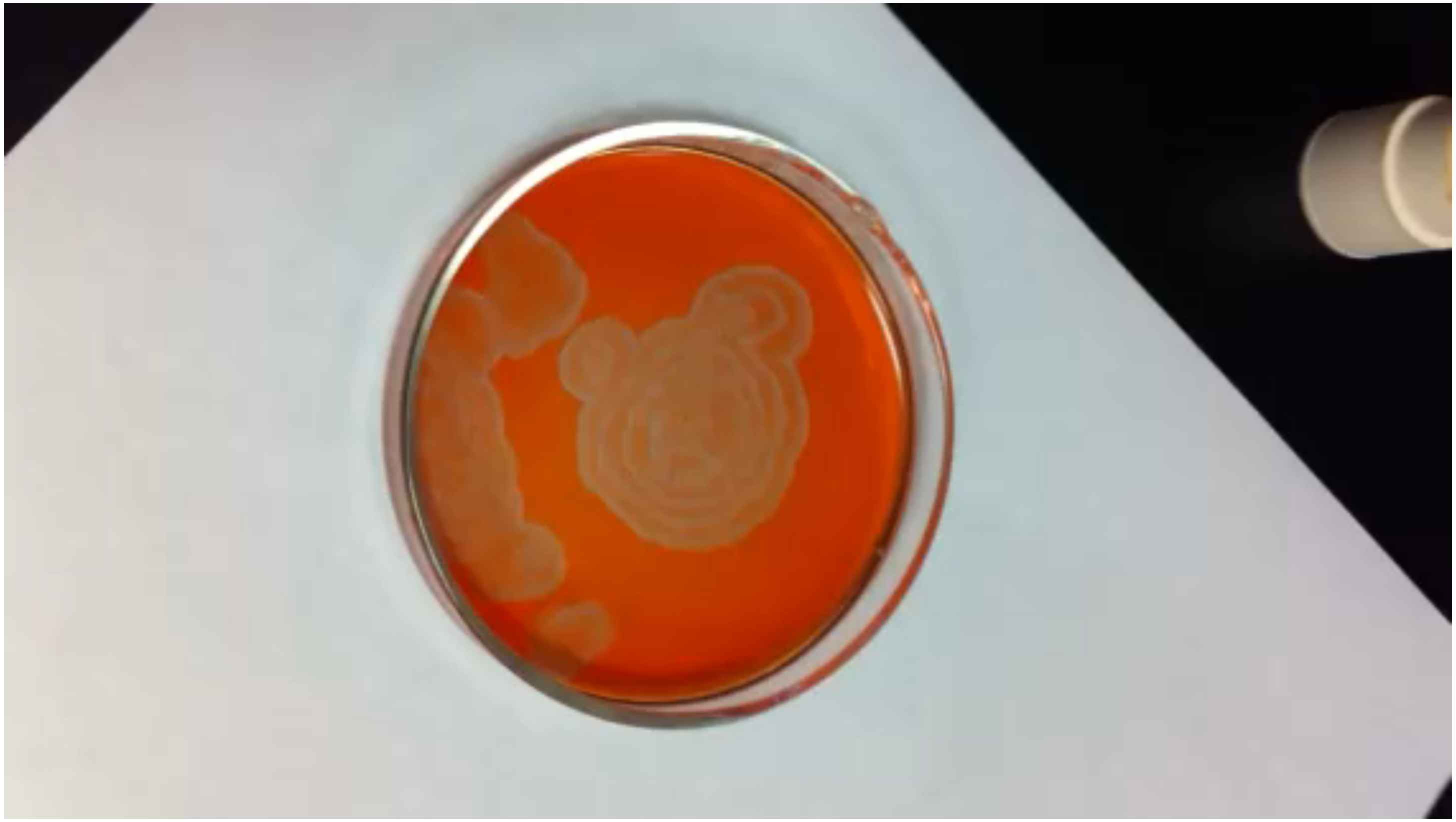


Patterns: Chemical Reactions and Slime Mold

Striking similarity between target and spiral patterns formed in Belusov-Zhabotinsky chemical and in slime mold (dictyostelium discoideum)



Dynamics of Belusov-Zhabotinskii Patterns



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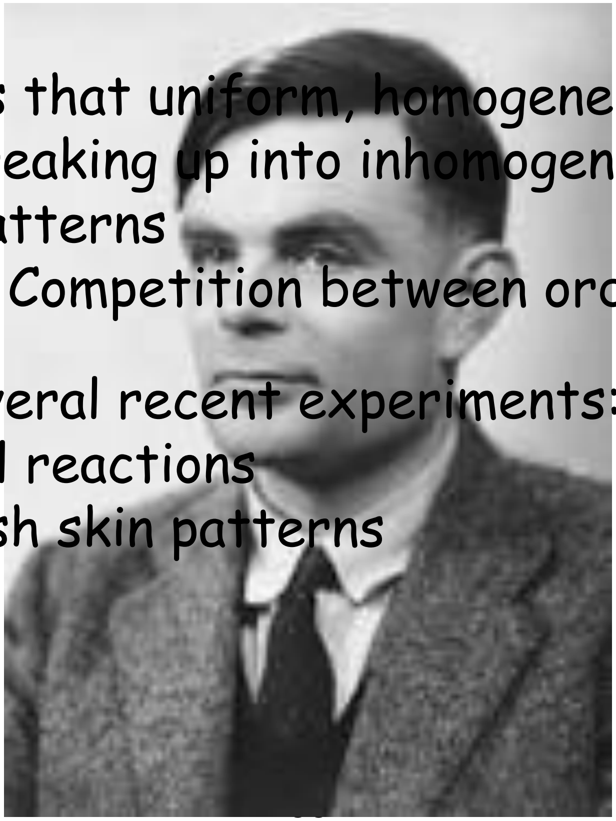
Turing Patterns

In 1952, Alan Turing proposed a "Chemical Basis for Morphogensis," involving reaction-diffusion equations to explain emergence of patterns

Essential idea is that uniform, homogeneous space can be unstable into breaking up into inhomogeneous, variegated structures => patterns
Metaphorically: Competition between order and chaos

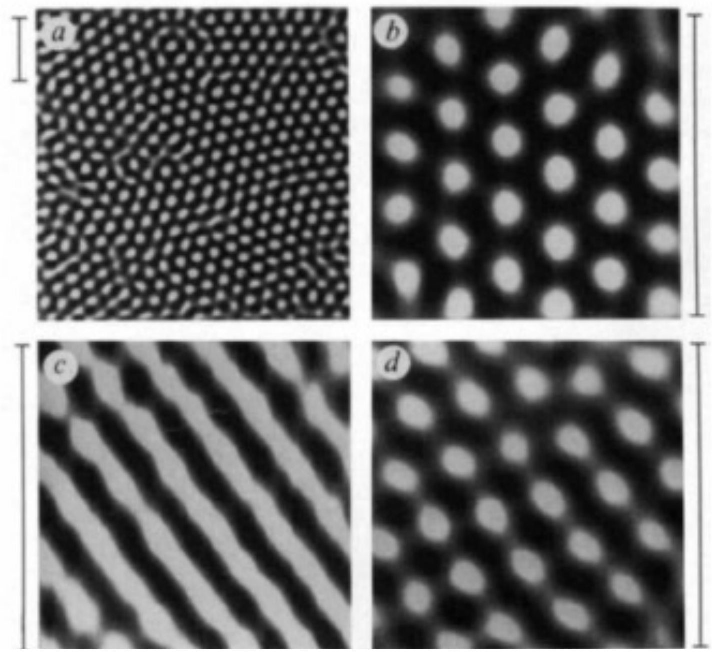
Observed in several recent experiments: give two examples:

- Chemical reactions
- Zebra fish skin patterns



Turing Patterns

Turing patterns in chemical traveling waves (Ouyang and Swinney)



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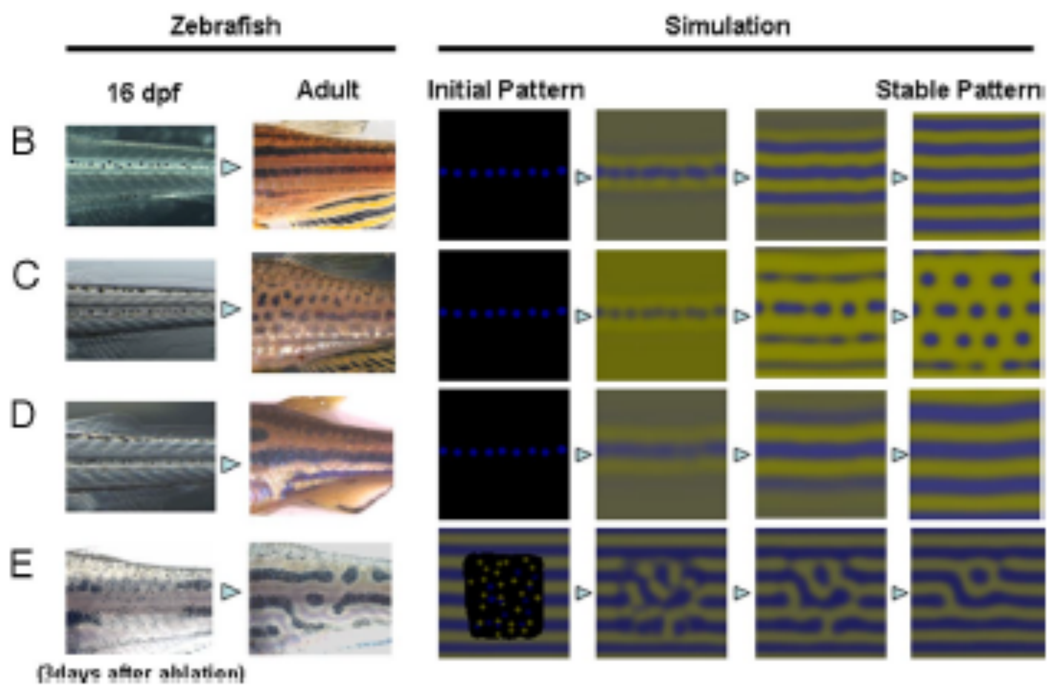
Turing Patterns

Patterns in Zebra fish (Nakamasu et al. PNAS 106 8429-8434 (2009)



Interaction network between pigment cells in zebrafish possesses properties necessary to form Turing patterns. Modifying cells with laser treatment can lead to different patterns

Practical Patterns

"Practical patterns" exist almost everywhere, from nanostructures in materials science through morphogenesis in biology to geological formations, networks, and economics: they are an important form of "emergent" behavior and underlie much of the behavior of complex real world systems.

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Summary and Conclusions

What have we learned in this whirlwind introduction to nonlinear science?

- That linear phenomena are routine and predictable and often not relevant to real world because **nonlinearity** comes in to saturate/modify/limit linear behavior; **paradigms of nonlinear science**
- That nonlinear phenomena can produce incredible irregularity: **deterministic chaos** and sensitive dependence on initial conditions
- That **fractals**, objects with similar, non-trivial structure on all scales, are naturally produced by chaotic dynamics and occur in many natural systems
- That nonlinear phenomena can also produce remarkable order and regularity, **solitions and coherent structures**, observed in nature on all scales
- That **patterns and complex configurations** *emerge* in typical extended nonlinear systems and are basis for structure observed in natural world

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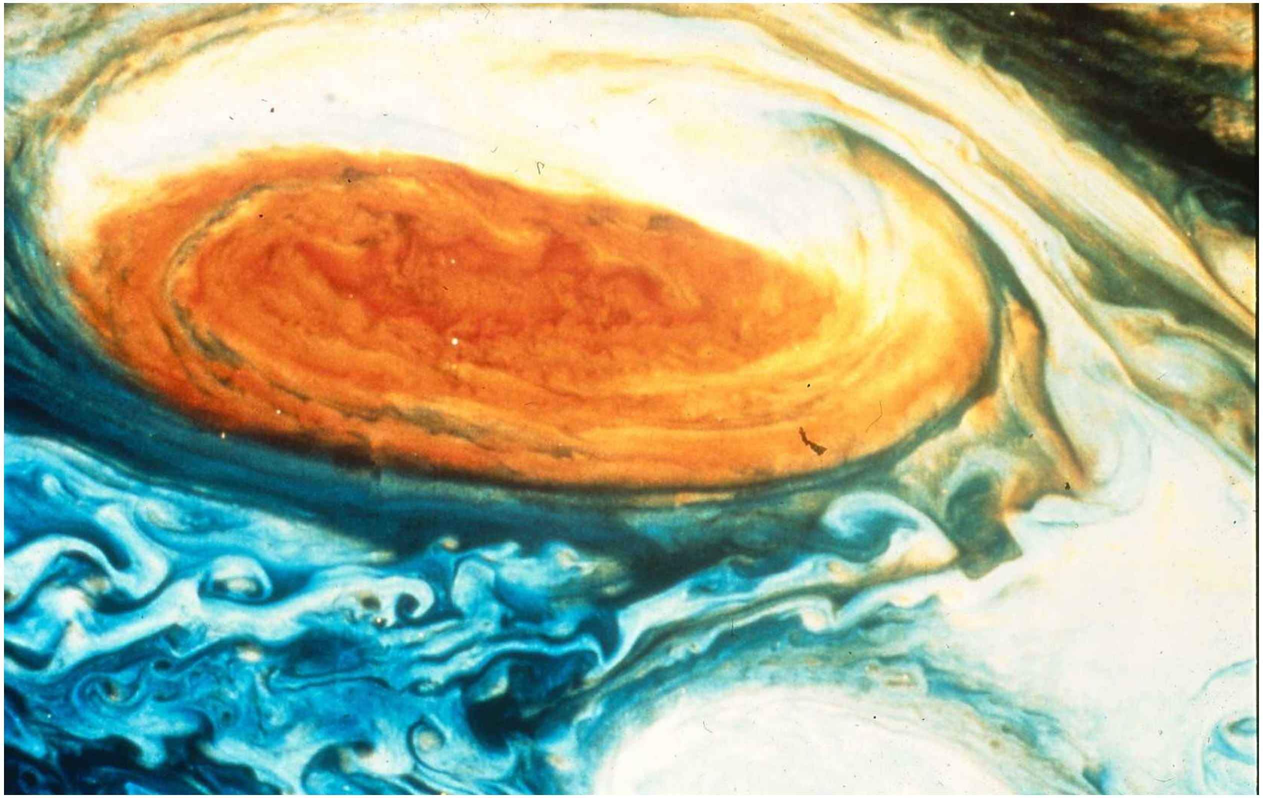
Concluding Image

- Close with one image that sums up this introduction to nonlinear science concisely (and beautifully !)



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Thank You !

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Dedicated to the memories of

- Peter Carruthers
- George Cowan
- John Holland
- David Pines
- Alfred Hübler

All of whom played key roles in the creation and sustainability of the SFI Complex Systems Summer School

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TUCSON, ARIZONA 85721 USA

COLLEGE OF ARTS AND SCIENCES
FACULTY OF SCIENCE
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BUILDING #81
(602) 621-6820

August 30, 1987

INTERNAL MEMORANDUM

SUBJECT: 1988 COMPLEX SYSTEMS SUMMER SCHOOL

The time has come to formally organize the summer school we have discussed previously. As you may know, the Santa Fe Institute has reserved St. John's College facilities from June 27 to July 22 for this purpose. These dates may prove inconvenient; earlier dates are being explored.

1. FORMAT OF THE SCHOOL. We propose that there be eight courses of five lectures each. The five lectures are to be stretched over two weeks. In addition there will be two or three research lectures each week, and possibly some overview and public lectures relevant to the school. In general, the model of the Theoretical Advanced Study Institute (TASI) is appropriate, and encouraged by NSF sources. TASI 1987 was actually held in Santa Fe, sponsored by Los Alamos. About sixty graduate students participated. We should anticipate wider participation, including researchers wishing to change fields.

2. DOCUMENTATION OF THE SCHOOL. Special attention will be given to assuring first class pedagogical content of the proceedings since we hope that the lectures will in many cases actually define the newly forming topics in complexity. The school is intended to exist on a continuing basis, providing thereby a standard reference as the science of complexity develops. Several publishing option are available.

3. FINANCIAL SUPPORT. Besides agency support (NSF has already been contacted) we can no doubt find other sponsors. One such is NATO, if their constraints are not too constricting. We recommend that the administrative functions of the School be managed by the Santa Fe Institute, since its staff is available and its bureaucracy relatively undeveloped. Perhaps there should be a registration fee to be waived for legitimate students.

4. INSTITUTIONAL SPONSORS. For many reasons it makes sense to involve the US research institutions most active in pursuing complexity research. The following come to mind:

University of Arizona	University of Illinois
University of Michigan	University of New Mexico
University of Texas	California Institute of Technology
Santa Fe Institute	Los Alamos National Laboratory

5. GOVERNANCE. Since we hope that the School will be a unique and ongoing activity, some care must be given to its decision making apparatus. We recommend three bodies:

Executive Committee. A core of this could be the SFI Regional Council, although broader representation is needed.

Advisory Committee. This might have significant international representation.

Organizing Committee. This is of course the group doing the real work of putting together a given year's program. The following names came to mind as a representative organizing committee: D. Campbell, J. Holland, J. Hopfield, S. Kauffman, A. Newell, D. Rumelhart, M. Scully, D. Stein, H. Swinney, S. Wolfram. Hopefully from this group we can select a czar to run the School.

6. FEEDBACK. Your instant attention is required due to the timetable.

Peter Carruthers PC

David Pines

Aspen, Colorado

August 22, 1987

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TUCSON, ARIZONA 85721 USA

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September 20, 1987

MEMO TO: Complexity Summer School Organizers

FROM: Peter Carruthers PC

SUBJECT: Committee Membership and School Lecturers

Following the Science Board meeting last Saturday I managed to discuss next summer's school with many of the board members. We were so efficient that I can already provide a provisional set of lecturers and topics. An asterix by a name indicates tentative acceptance subject to scheduling constraints. An asterix next to a topic means that I have invented it before consulting the speaker.

Weeks 1-2

D. Campbell* Introduction to Nonlinear Dynamics

M. Feldman* Mechanisms in Evolutionary Biology*

J. Holland*/R. Riolo Introduction to Classifiers/Genetic Algorithms. The latter would be the "lab" part of this course.

S. Kauffman* Logic of Life*

D. Rumelhart Topics in Cognition

Weeks 3-4

A. Newell Pattern Formation*

N. Packard Cellular Automata*

D. Stein* Spin Glass Phenomena and their Applications*

H. Swinney/A. Libchaber Experiments in Nonlinear Systems*

B. Arthur/J. Scheinkman Economics and Complex Systems*

Please comment on the balance in subject matter and what other speakers could or should be substituted. I will wait for a week before making further contacts.

Advisory Committee. The following names of luminaries were suggested to glorify our poster. Do we need others?

P. W. Anderson*, R. Axelrod, M. Gell-mann*, M. Eigen, H. Frauenfelder, H. Haken, A. Libchaber, D. Pines, G. Toulouse.

Steering Committee. Since the school may have already been organized I suggest lumping the executive committee and organizing committee into a Steering Committee. This committee will make decisions regarding the School. I volunteer to chair this committee for one year. Suggested members are:

K. Arrow, D. Campbell*, P. Carruthers*, M. Feldman*, S. Kaufmann*, D. McLaughlin, M. Scully, L. M. Simmons,Jr.*, H. Swinney, S. Wolfram.

If the school succeeds, the membership will be rotated.

Summer School Director.

For 1988 there was sentiment that Dan Stein should be asked to supervise the school. I have not yet asked him. David Campbell cautiously agreed to take over in 1989. // A blatant lie

Funding

At least $100,000 will be required if we support around 50 students for a month. Probably we should pay an honorarium (dispensed on receipt of the manuscript) of maybe $300 per lecture. I will draft a proposal to the NSF and DOE. Further ideas on funding sources should be forwarded instantly. Remember that the School is meant to be a national cooperative effort, hosted but not owned by the Santa Fe Institute.

Summary and Conclusions

What have we learned in this whirlwind introduction to nonlinear science?

- That linear phenomena are routine and predictable and often not relevant to real world because **nonlinearity** comes in to saturate/modify/limit linear behavior; **paradigms of nonlinear science**
- That nonlinear phenomena can produce incredible irregularity: **deterministic chaos** and sensitive dependence on initial conditions
  - That simple models can produce complicated behavior that in some cases is **universal**, e.g., $x_{n+1}=rx_n(1-x_n)$
  - That **fractals**, objects with similar, non-trivial structure on all scales, are naturally produced by chaotic dynamics and occur in many natural systems
- That nonlinear phenomena can also produce remarkable order and regularity, **solitions and coherent structures**, observed in nature on all scales
- That **patterns and complex configurations** *emerge* in typical extended nonlinear systems and are basis for structure observed in natural world

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