Understanding of COMPLEXITY:

An Interdisciplinary Studies and a Unified Concept: SCALING

Y.M. WONG

LAFAYETTE COLLEGE

2/24/2012

Agenda

- Why?
- Intro
- Definition
- Examples and Data
  - Scaling
  - Chaos
  - Organization

Why?

- A modern trend in Physics research
  - Emergence versus Reductionism
- More and Different: Notes from a Thoughtful Curmudgeon (Anderson)
- The Quark and the Jaguar: Adventures in the Simple and the Complex (Gell- mann)
- Sharing a unified view of the underlying of Interdisciplinary Studies of Macroscopic Systems
  - Physics/engineering
  - Biology
  - Medicine
  - Economic
  - Geology
  - Ecology

1600-2000 Route

- Reductionism or Analysis (Different)
  - Physical science (Particle physics)
    - Mountain to water to
    - molecule to atom to nucleus to quark
  - Biological science
    - Elephant to man to
    - heart to cell to
    - protein to DNA

2000 to 2050^{+} Route

- Synthesis (More)
  - Physical science
    - Atom to Condensed Matter or Statistical Mechanics
    - Equilibrium or non-equilibrium
  - Biological
    - Schrodinger's "What is Life?"
    - Molecules to DNA (Replication?)
    - To virus, bacteria to
    - Diseases, Immune system, Cancer

8 Eightfold Ways to Complexity (Santa Fe Institute: www.santafee.edu)

- Mathematics: Turing, von Neumann (x)
- Information Theory: (x)
- Nonlinear Dynamics
  - Dynamic maps, critical points, chaos etc
- Random manifolds:
  - Broken ergodicity, spin glass, neural nets
- Self Organized Criticality (SOC)
  - Turbulence, avalanche, forest fire, epidemics
- Artificial Intelligence (x)
- Wetware: Brain, human (real stuff)
- Complex Adaptive System (CAS): Darwin's Evolution(?)

P.W. Anderson (1994)

Physics Precursors to Complexity Theory

- Equilibrium Statistical Mechanics
  - $S = k_B \log W$
  - Partition function and Thermodynamic functions
  - Phase transitions
    - Critical exponents, $\alpha, \beta, \gamma, \nu$
    - Scaling hypothesis
    - Renormalization Group (?)
- Non-equilibrium Stat. Mech.
  - Liouville, Boltzmann, diffusion equations
  - Correlation functions and Structural Factor
  - Stochastic Processes and Probability
  - Fractal Geometry and Processes

Q: To Scale or Not to Scale?

Space and Time: $e^{-x/L}$ *and* $e^{-t/\tau}$ *or* $e^{-i\omega_n t}$

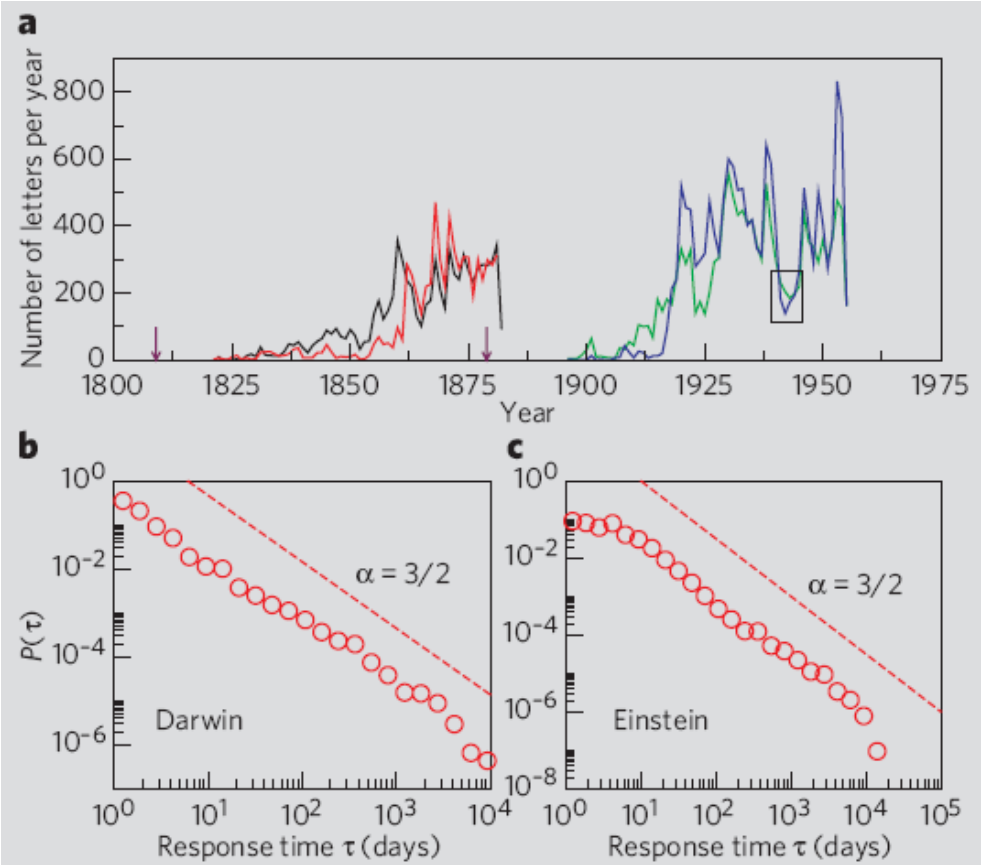
Linearity:

$$\psi(t) \equiv \sum_{n=0}^{N<\infty} a_n(t) e^{i\omega_n t}$$

Fractional Power Law:

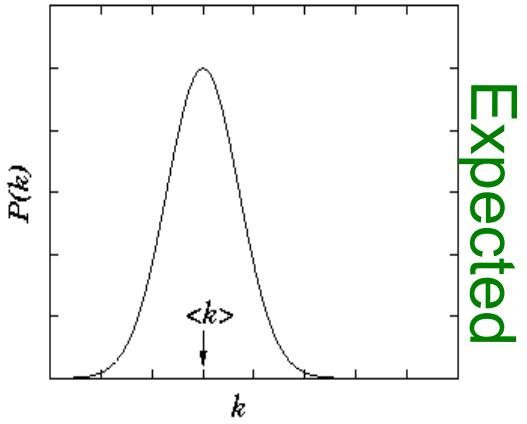
$$\frac{1}{t^{1+\alpha}} = \sum_{n=0}^{\infty} a_n e^{i\omega_n t} \quad \textit{meaningful?}$$

Example 1: Letter

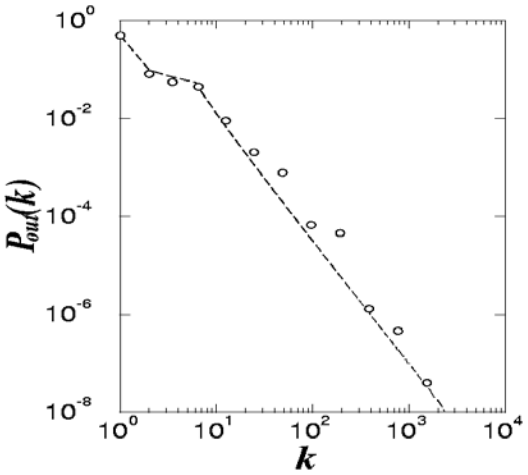


Darwin and Einstein's behavior

Example 2: Network



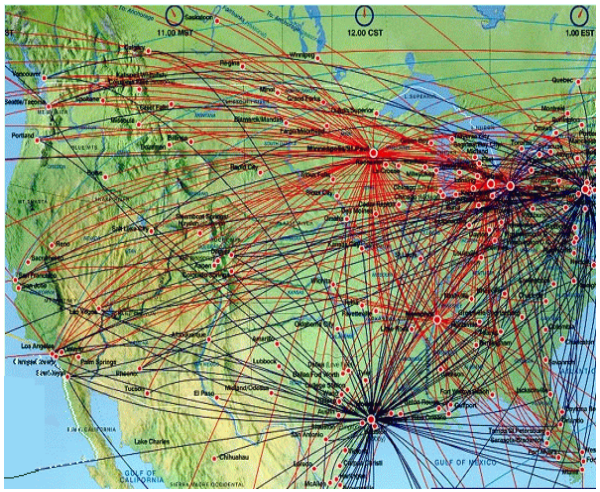
Expected

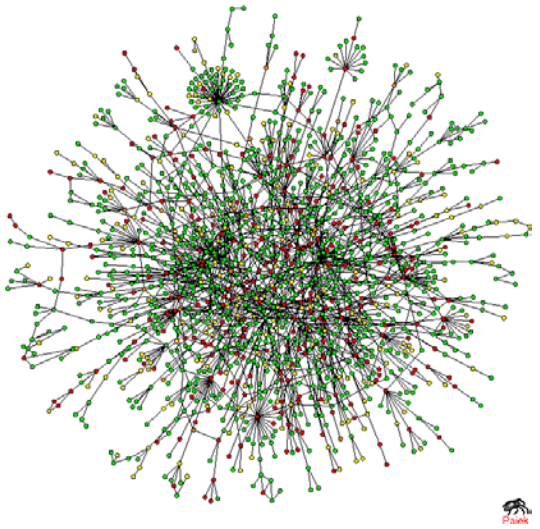


Found

$P(k) \sim k^{-\gamma}$

Hub
within hub
within hub
…….



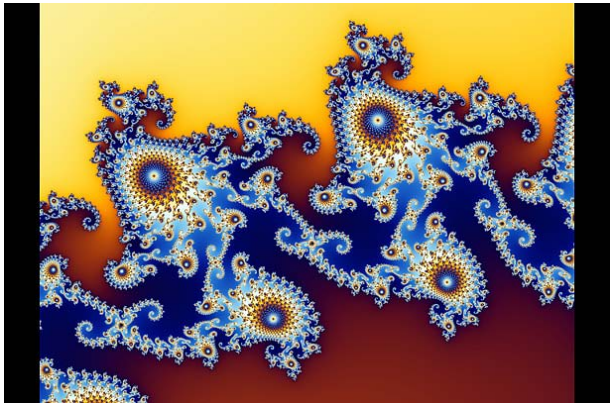


Example 3a: Fractal Geometry of Nature

What is the coastal length of Britain?

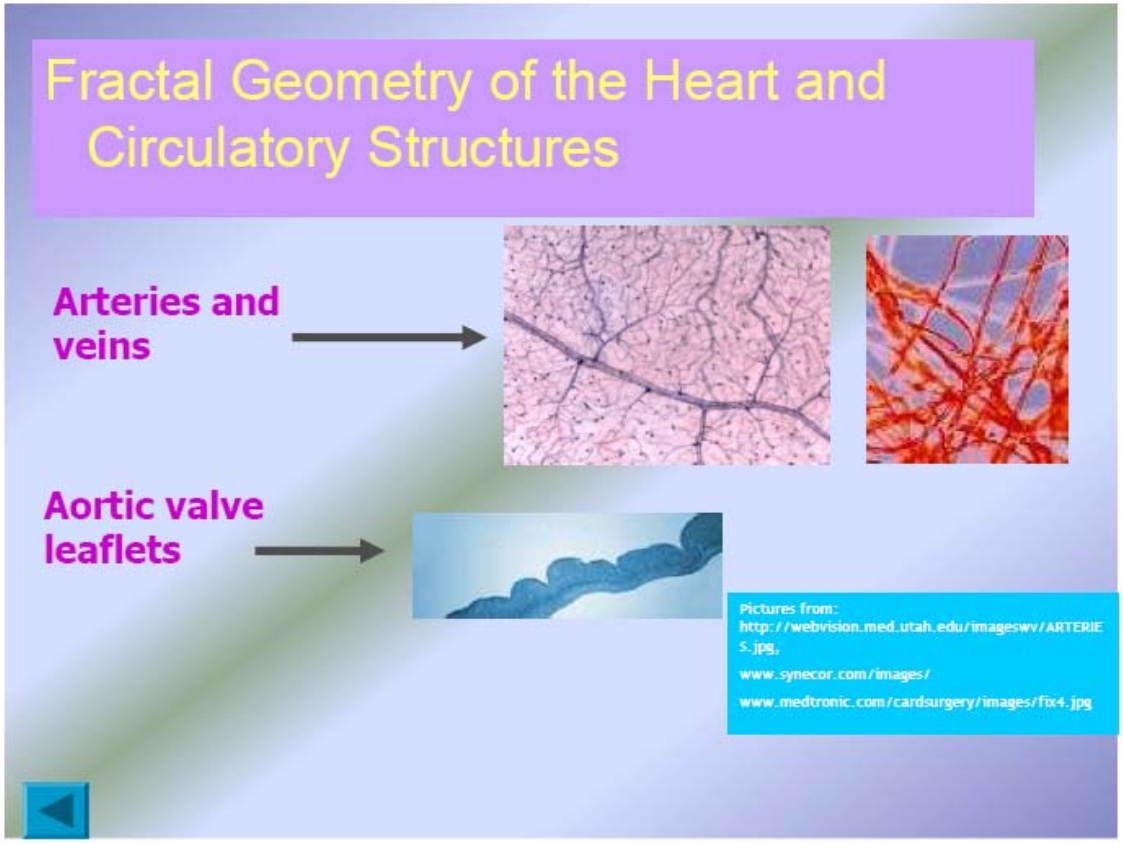
Unit = 200 km -> length = 2400 km (approx.)

Unit = 50 km -> length = 3400 km



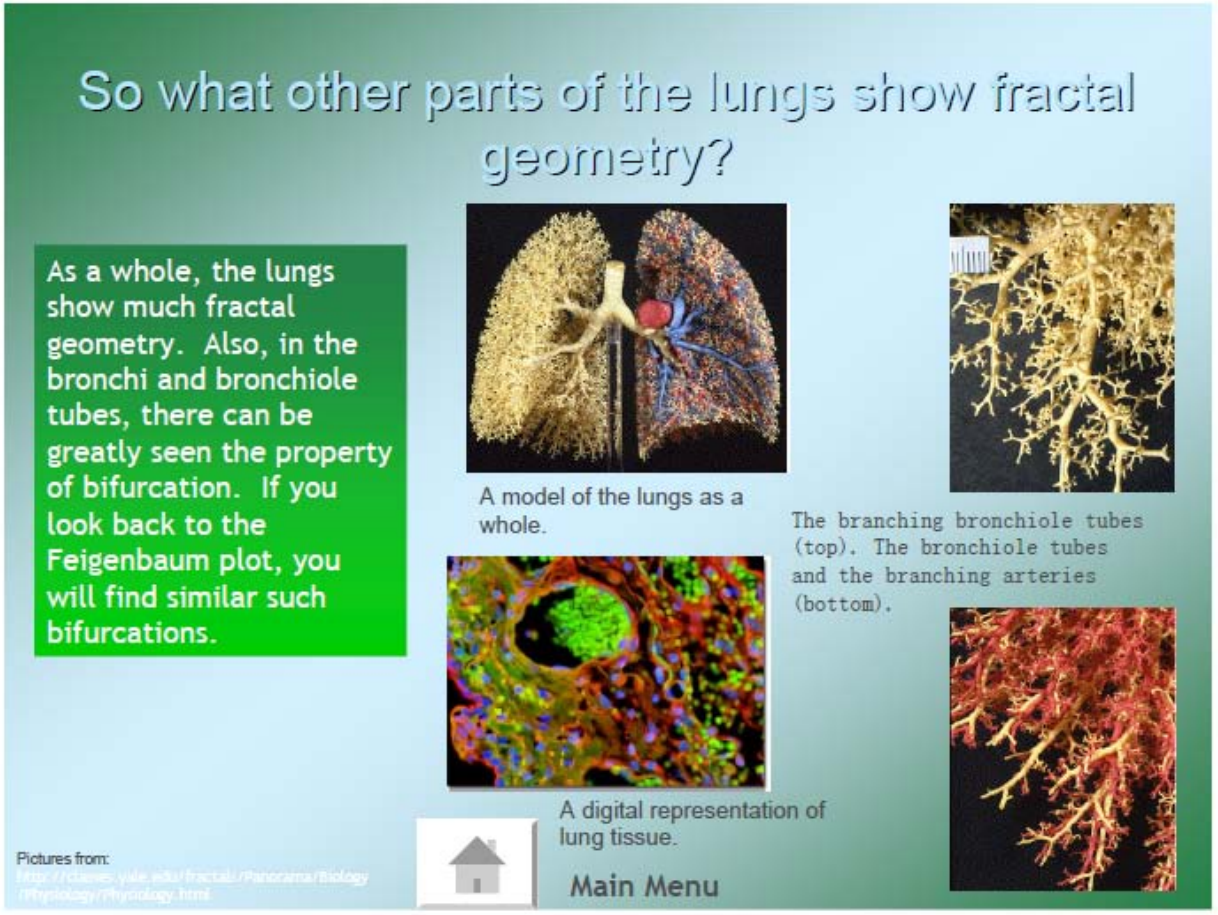
Father of Fractal: B. Mandelbrolt

Example 3b: Fractal Geometry of Nature



From webvision.utah.edu

Example 3b: Fractal Geometry of Nature



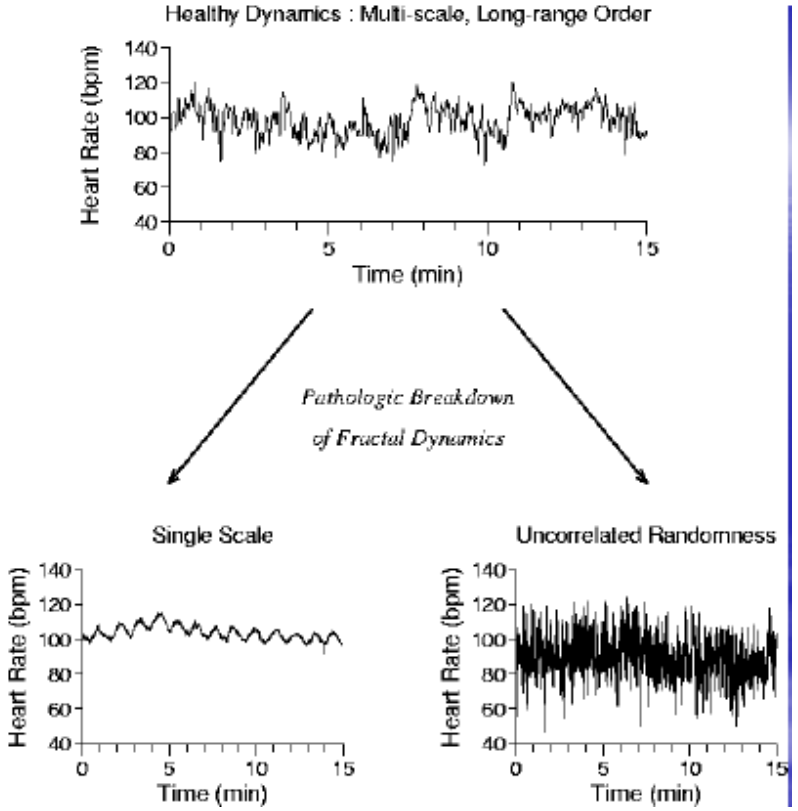
From Yale University Biology Class

Example 4: Is Chaos always Bad?

Both of these images show what happens as the heart goes out of its normal state. The bottom left graph shows a subject with heart failure. This graph has highly periodic values with little variation.

The bottom right graph shows a subject with atrial fibrillation. This heart rate is very erratic jumping from the high end of heart rate to the low end, with no particular pattern.

Goal of this interdisciplinary studies is
[1] Understand fractal nature of healthy heart
[2] Relate treatment response and loss of Fractality to Fatalities



http://www.physionet.org/tutorial.

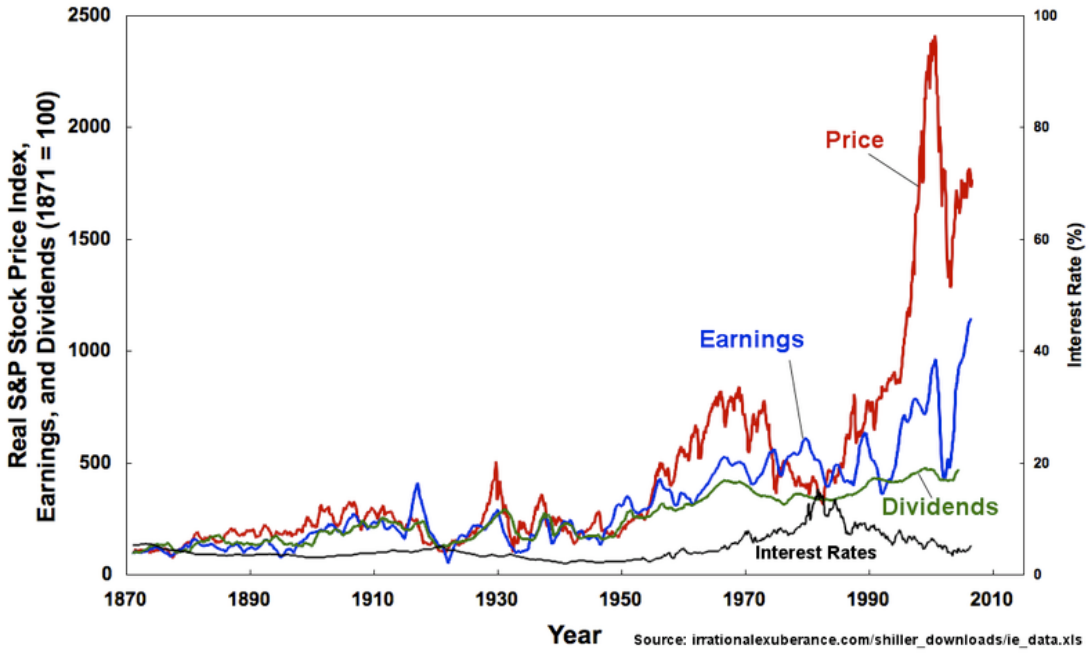
Self Organized Criticality (or Sync) in Biology

- How thousands of autonomous agents (bird or fish) can behave a single unity without a central command?
- Can one design flock of nano-robots and send them to explore humanly unreachable regions, such as Mars or internal human organs?
- Modeling of heart beat?

http://www.youtube.com/watch?v=V71hz9wNsgs&feature=related

Modeling? Stock Market?

- This field will be as tough to crack as in
  - Climate and weather forecasting
  - economic behavior
  - Social dynamics



What is a Complex system?

- Emergence
  - Broken symmetry (Anderson-Higgs Mechanism)
  - Phase transition, bifurcation: Macro behavior qualitatively different from micro individual element
- Nonlinear (N>2) interactions necessity
  - No superposition principle
  - Chaos: Sensitive to initial perturbation or IC (simple eqn -> complexity)
  - Fixed or Critical points, limit cycles, strange attractor
- Evolving, Adaptive, and Unfolding structures
  - Interconnected parts: $P_m(t|K_{mn}(t, t'|P_m(t')))$??
  - Capable to learn and change from experience
  - Modeling Darwin's Natural Selection?
- Examples:
  - Bee or ant colonies, economies or finance, weather or climate, neural network or brain, cells and protein network

More Complex System Features

- Catastrophic failure (Black swan effect)
- Boundary unclear
- History dependent or Memory
- Nested hierarchy
- Scale free networked
- Adapt, learn, survive of the fittest, …
- Apoptosis (a genetically directed process of cell self-destruction that is marked by the fragmentation of nuclear DNA, is activated either by the presence of a stimulus or removal of a suppressing agent or stimulus, and is a normal physiological process eliminating DNA-damaged, superfluous, or unwanted cells —called also *programmed cell death)*