The Nature and Purpose of Randomness

Mark Shelhamer
The Johns Hopkins University
School of Medicine
Baltimore, MD USA

A Sense of the Problem

- Evolution via natural selection is based on random mutations.
- How can we be the end result of God's master plan if we are the product of random chance?

Perspective

- Sometimes random is not really random
  - Chaotic dynamics
  - Sometimes it is lack of understanding (Kalman)
- Randomness is not intuitive
- There are, however, processes that truly are random
  - Timing of radioactive decay (Hot Bits)

Perspective

We appreciate the beauty and elegance of physical laws, and also mathematical laws, which offer powerful explanations of the physical world and demonstrate its underlying order.

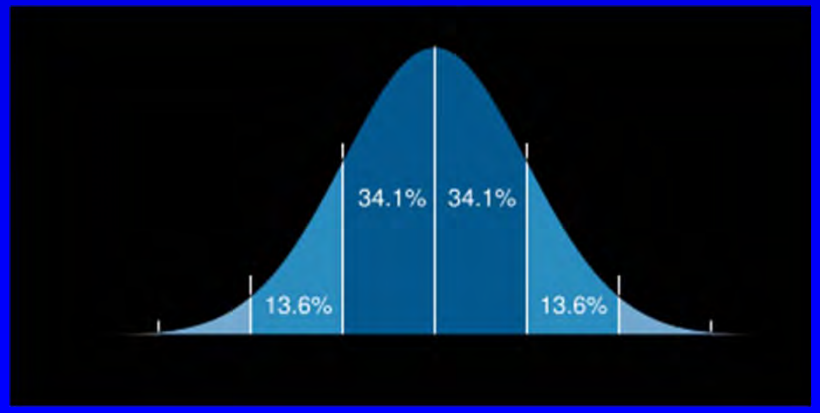
There are rules governing randomness as well, and these too are beautiful and orderly.

Misunderstanding of probability may be the greatest of all impediments to scientific literacy.

– Stephen Jay Gould

I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the law of frequency of error. It reigns with serenity and complete self-effacement amidst the wildest confusion. The larger the mob, the greater the apparent anarchy, the more perfect is its sway. It is the supreme law of unreason.

–Francis Galton



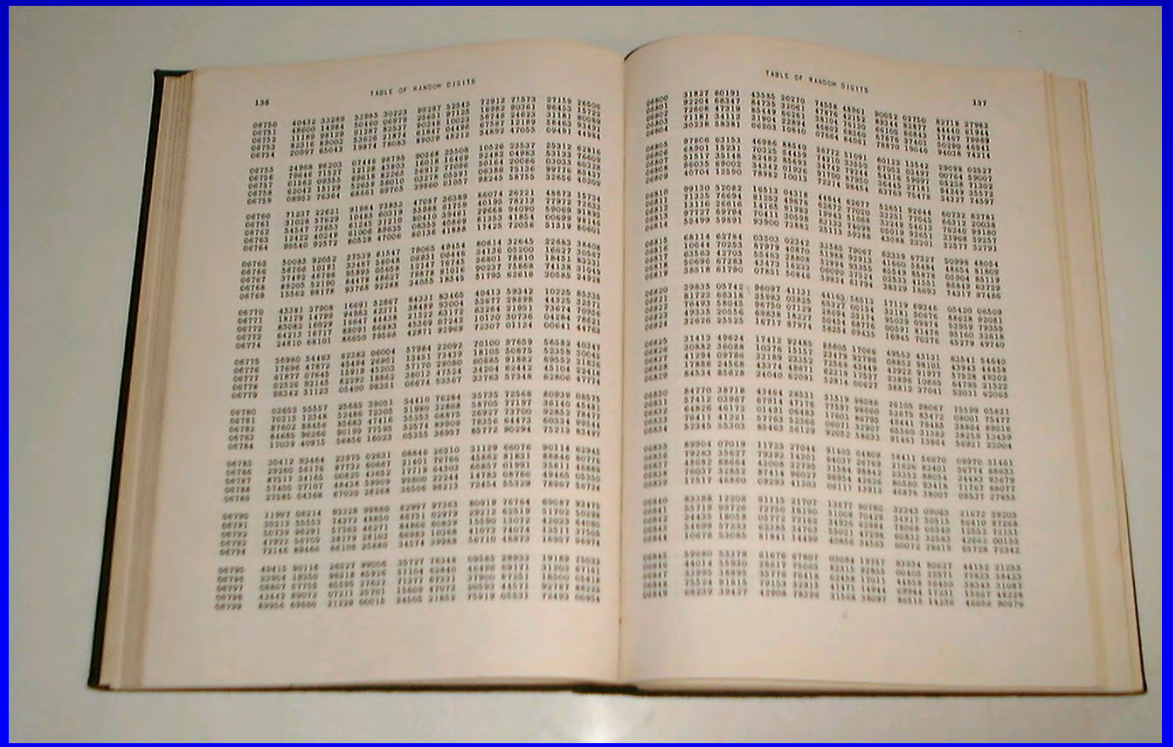
http://en.wikipedia.org/wiki/Image:Standard_deviation_diagram.svg

Randomness is not Intuitive

Humans are bad at generating randomness

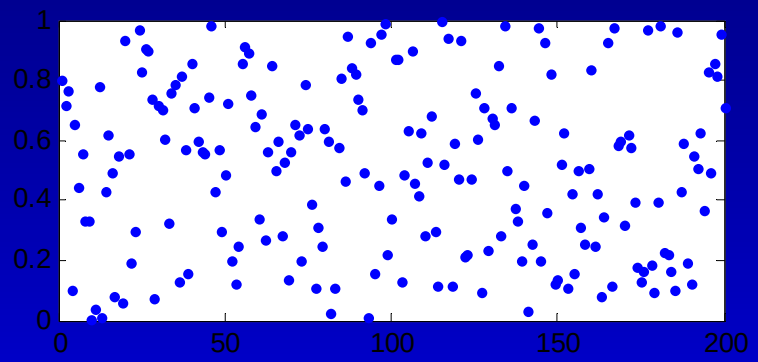
- tendency to alternate
- tendency to neglect extreme values

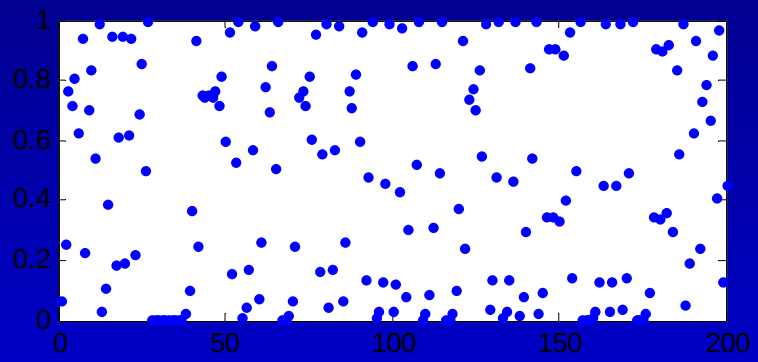
Fortunately, there are reliable sources of randomness

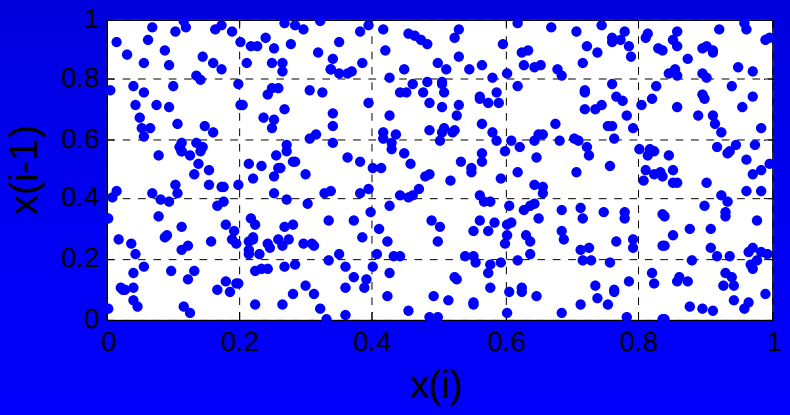


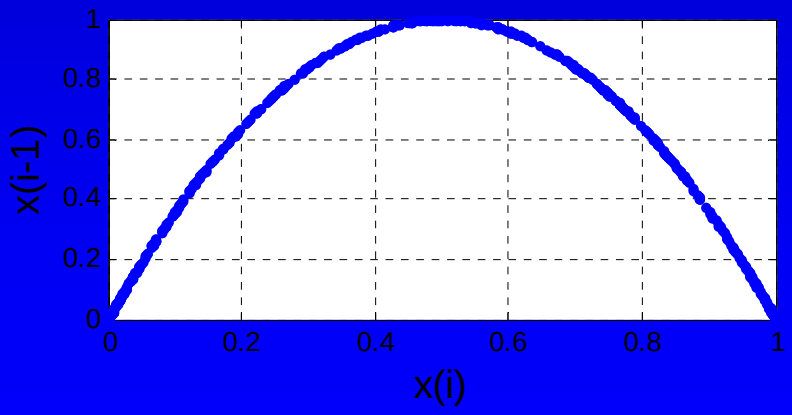
Randomness is not Intuitive

We are bad at judging randomness









Randomness is not Intuitive

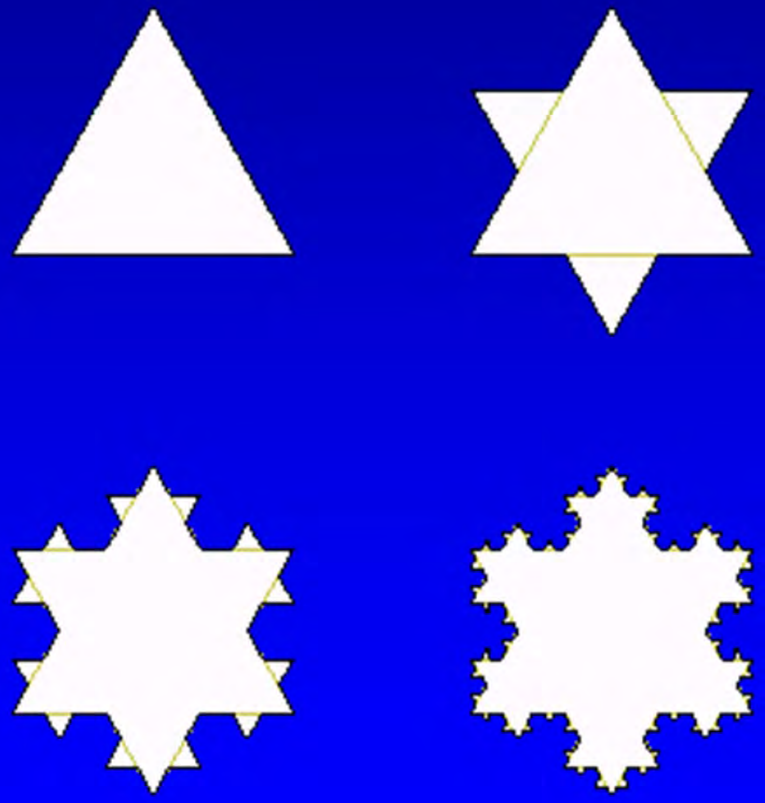
Gambling and gambler's fallacy

- bet on the next flip of a fair coin: HHHHHHHH

Entire industry built on this misunderstanding

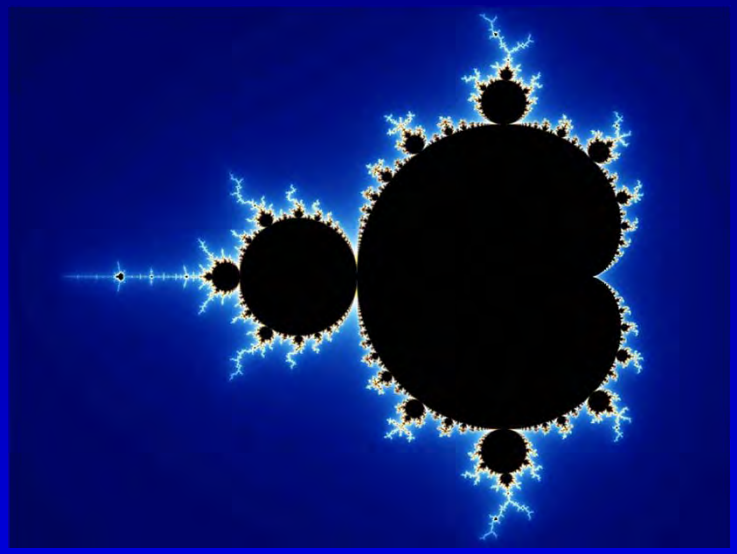
Fractals

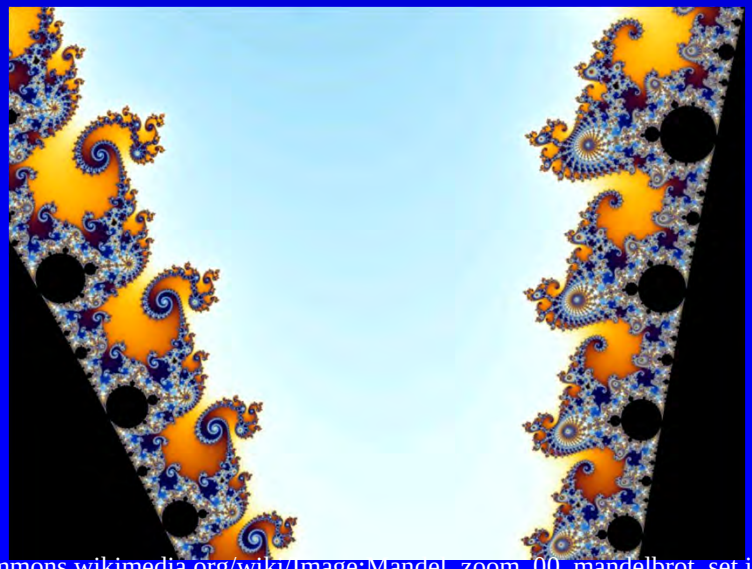
A deterministic fractal – the Koch Snowflake

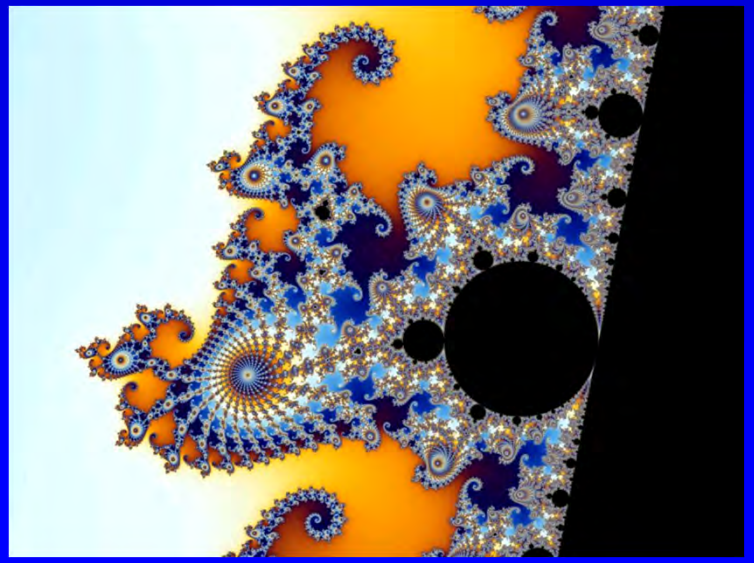


Fractals

A deterministic fractal – the Mandelbrot Set







http://commons.wikimedia.org/wiki/Image:Mandel_zoom_00_mandelbrot_set.jpg

Random Fractals: order in randomness

A random fractal – coastline

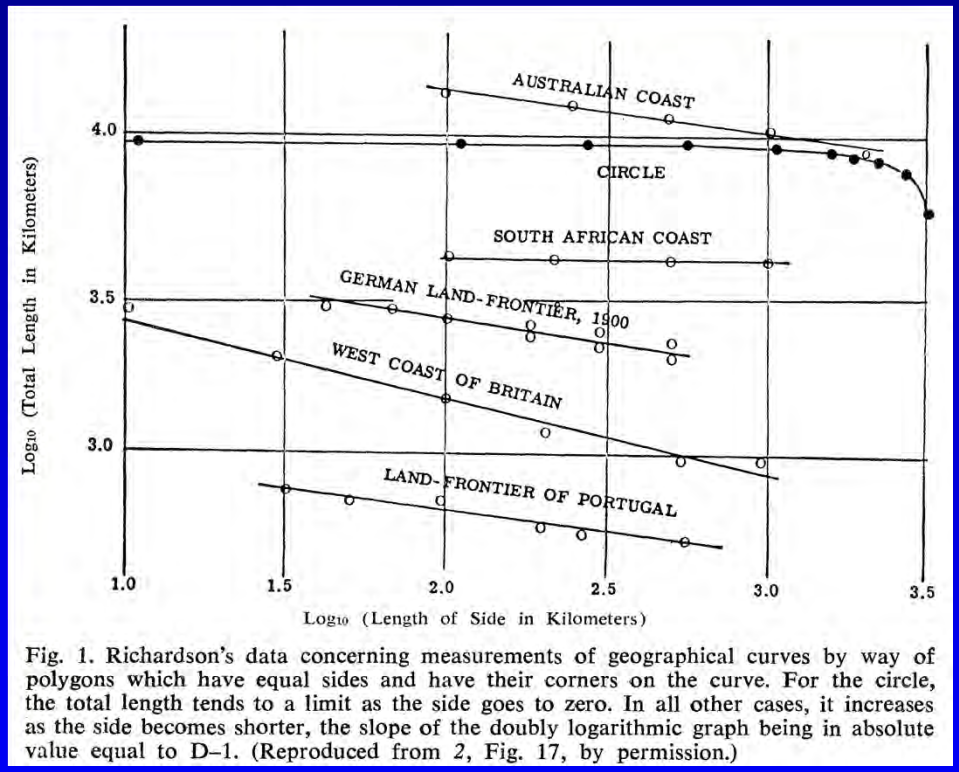


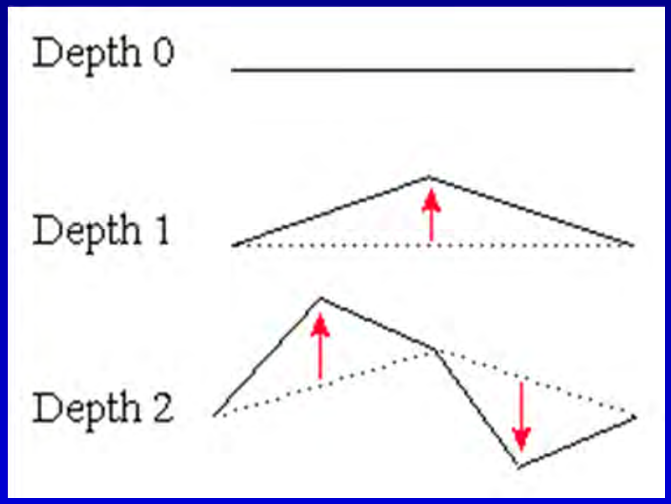
Fig. 1. Richardson's data concerning measurements of geographical curves by way of polygons which have equal sides and have their corners on the curve. For the circle, the total length tends to a limit as the side goes to zero. In all other cases, it increases as the side becomes shorter, the slope of the doubly logarithmic graph being in absolute value equal to D–1. (Reproduced from *2*, Fig. 17, by permission.)

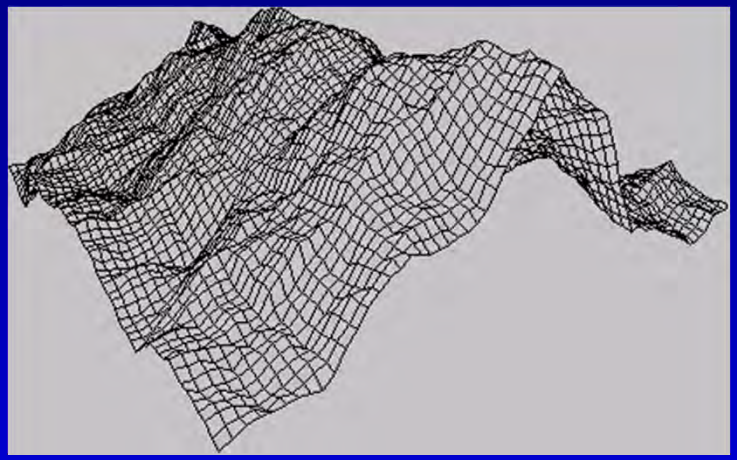
B Mandelbrot (1967) How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension. *Science* 156:636-638.

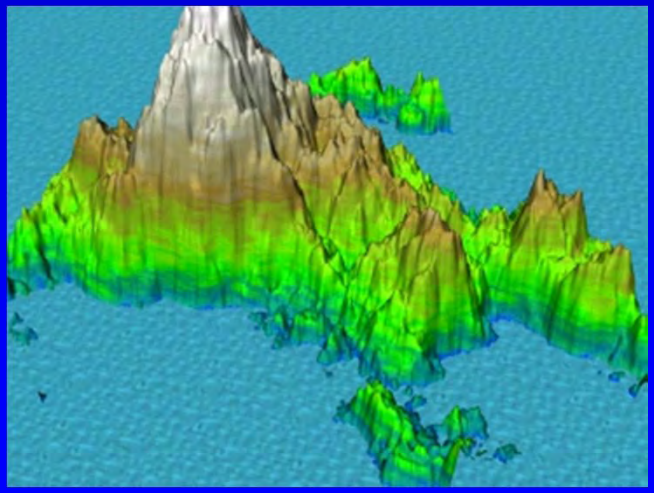
http://commons.wikimedia.org/wiki/Image:Britain-fractal-coastline-combined.jpg

Random Fractals: order in randomness

A random fractal – mountains







http://www.javaworld.com/javaworld/jw-06-2007/images/jfgfigure8.gif

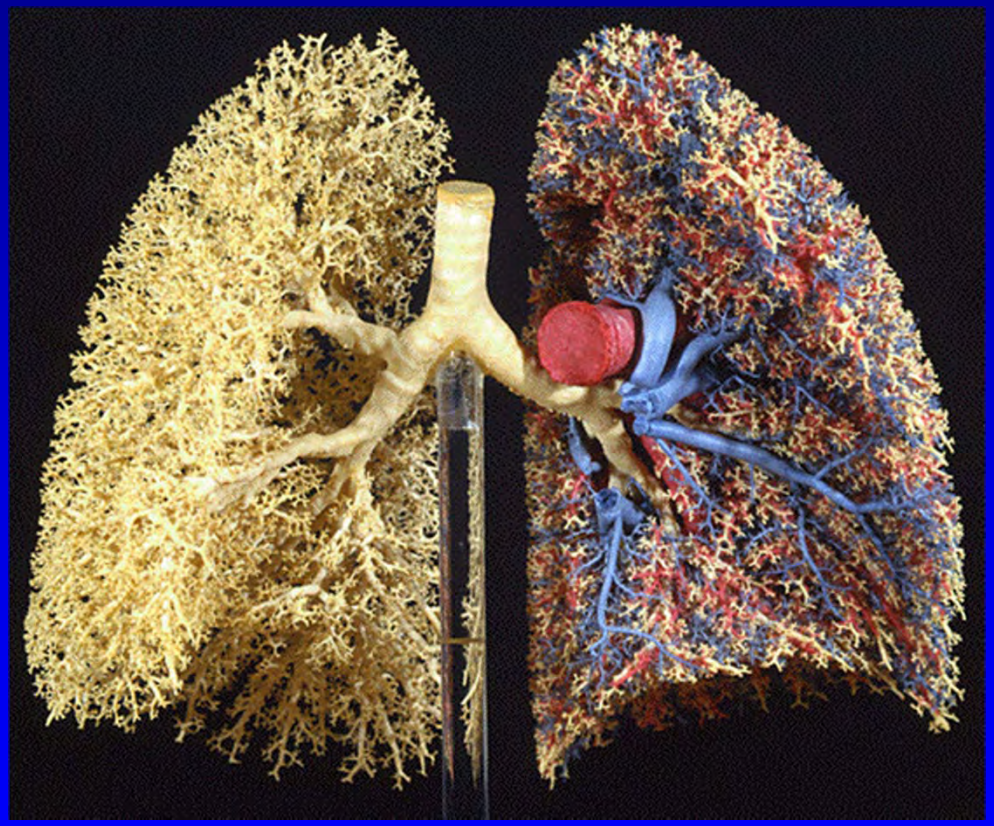
http://www.effectware.com/download/images/efx_mountain2.jpg

http://www.vb-helper.com/vbgp/fractal_surface.gif

http://www.wizardnet.com/musgrave/cool2.jpg

Random Fractals: order in randomness

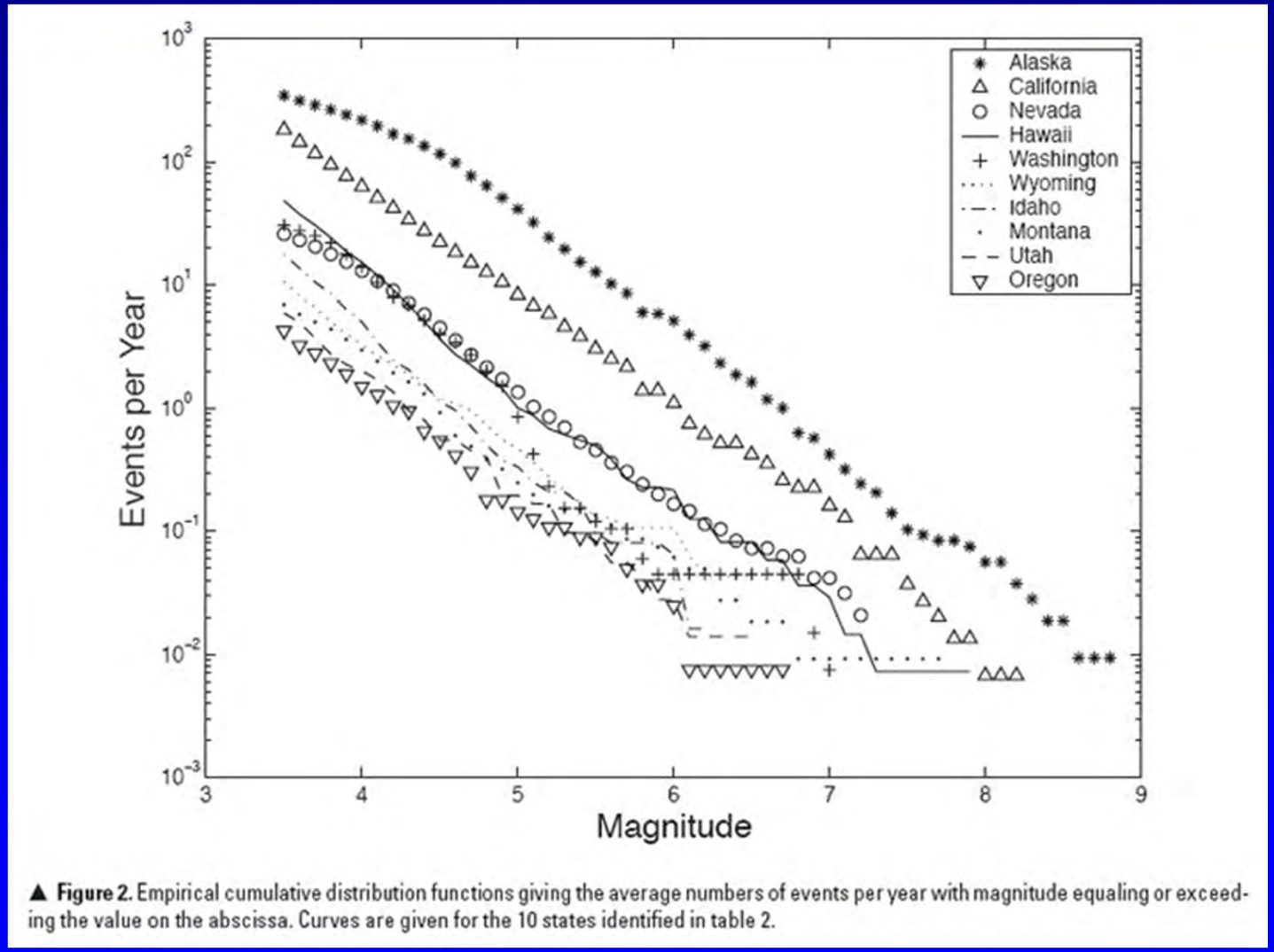
A random fractal – lungs



http://classes.yale.edu/fractals/WorldOfFractals/Us/Lungs/Lungs.html

Rare Events are not necessarily Abnormal

Richter scale and earthquake distribution
– what is a “rare” event?



▲ **Figure 2.** Empirical cumulative distribution functions giving the average numbers of events per year with magnitude equaling or exceeding the value on the abscissa. Curves are given for the 10 states identified in table 2.

http://www.seismo.unr.edu/feature/NVrank.html

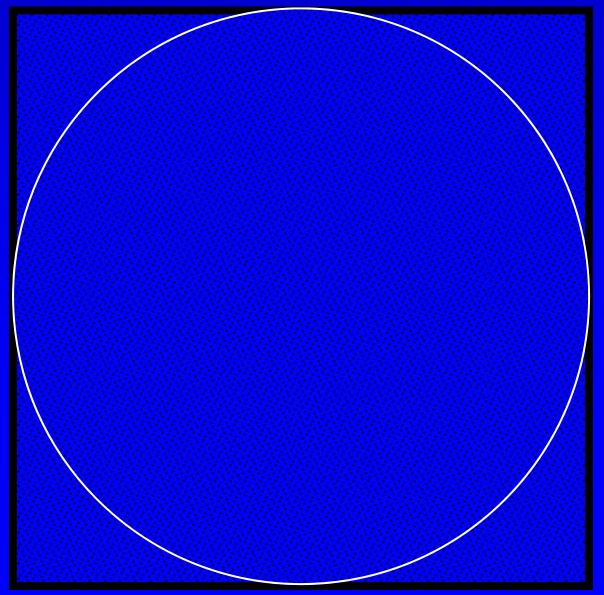
Good Things Brought About by Randomness

- Jansky – galactic noise source
- Penzias & Wilson – cosmic background
- Brownian motion and the atom (Einstein)

Randomness Can Serve a Purpose

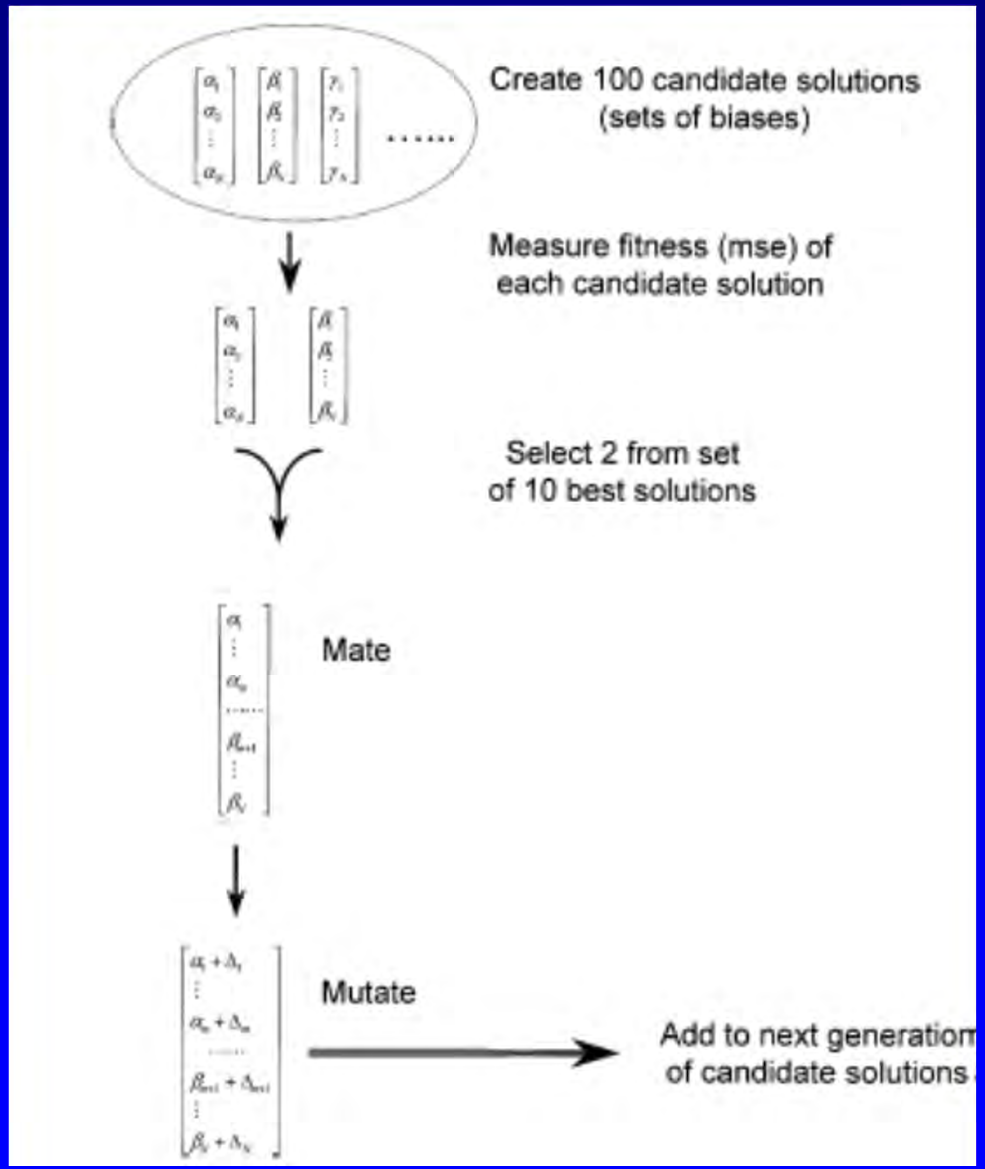
- Monte Carlo simulation
  - Probabilistic simulation of complex systems
  - Generate random stimuli and catalog the responses

- Example: area of a circle
  - Fill 1x1 square with random dots
  - What % fall into the circle?



Randomness Can Serve a Purpose

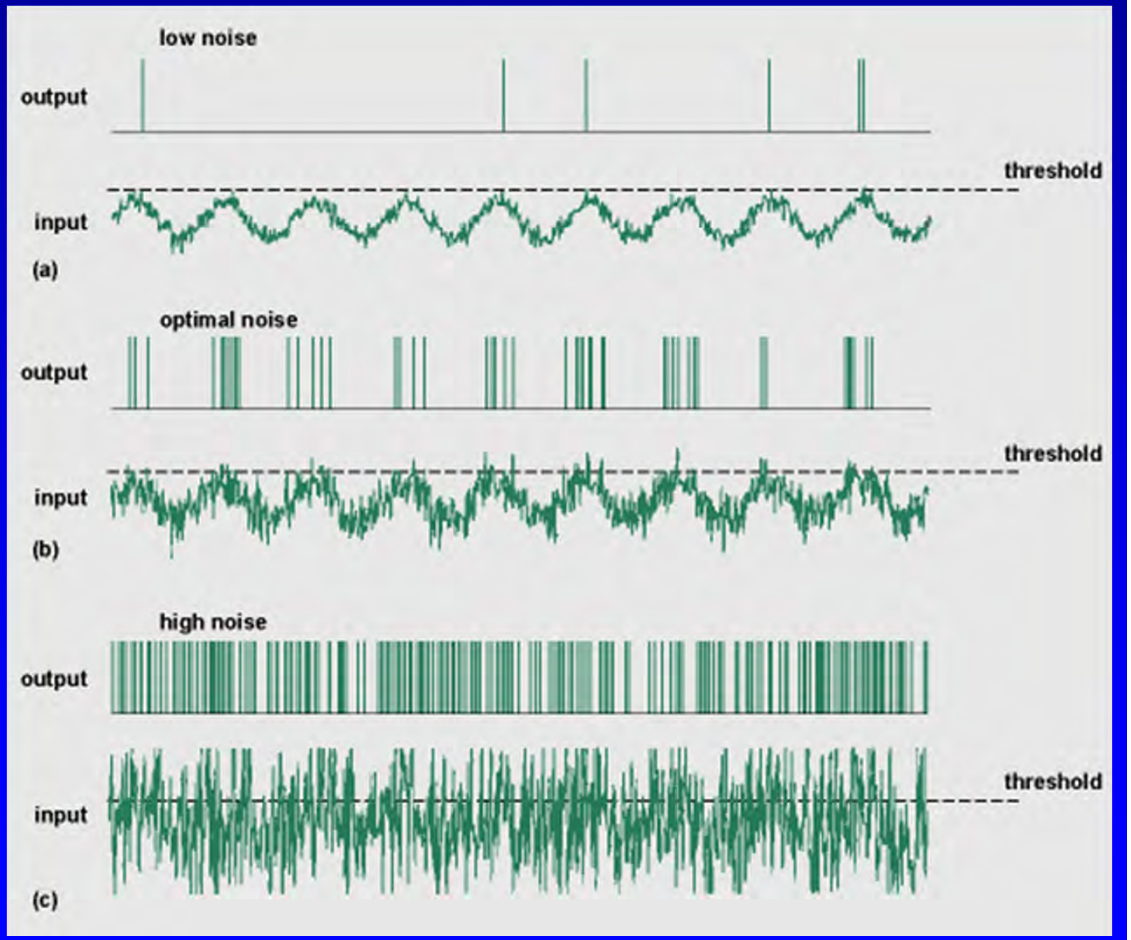
- Genetic algorithm
  - Optimization of multivariate system
  - Random generation of candidate solutions
  - Random selection and mutation
  - Avoid local minima
  - Efficient search of solution space



M Shelhamer (2001) Use of a genetic algorithm for the analysis of eye movements from the linear vestibulo-ocular reflex. *Ann Biomed Eng* 29:510-522.

Randomness Can Serve a Purpose

- Stochastic resonance
  - Reduction in threshold
  - Additive noise in certain range



http://accessscience.com/loadBinary.aspx?filename=YB980590FG0020.gif

A Note on Information

- What is *information*?
  - Reduction of uncertainty
  - Shannon entropy

$$E = -\sum_i P_i \log_2 (P_i)$$

Conclusions

- Randomness is a law as fundamental to how God runs the universe as any other physical-mathematical law we know.
- Mathematics and physical laws demonstrate a (Divinely Ordained) universal order.
- Despite our subjective sense, randomness has a beauty and order of its own.

  - Therefore randomness should be embraced as one of God's organizing principles.

ON THE OTHER HAND

- Divine Intervention might be completely deterministic and orderly, and our limitations prevent us from seeing this.
  - But would a benevolent God do this?

Evolution and Constrained Variability

- "The potential interactions between chance mutation, environmental pressure and individual survival are so numerous and complex as to constitute a system whose future states are impossible to predict."
  - Doing it over again would lead to a different result, so how can we be God's desired end product?
  - This is *contingent* evolution.

- But there are *convergent* solutions (dolphins and fish)
  - The process is not contingent but constrained.
  - "The selective advantages of advanced intelligence are so vast that its emergence in this particular universe, which itself appears uniquely hospitable to life, may indeed have been inevitable once the evolutionary process was started. In this sense, then, the emergence of intelligent, morally responsive life can reasonably be thought to have been an integral feature of our universe from its inception."

WT Newsome (2001) Life of faith, life of science. Proceedings, Science and the Spiritual Quest.

Randomness is not Intuitive

http://pro.corbis.com/search/Enlargement.aspx?CID=isg&mediauid=EC30F102-0ECD-45E2-A9E2-5B426A44DE8B

Randomness is not Intuitive

"There are no such things as coincidences" –

BUT

If God has ordained the laws of randomness just as much as the deterministic laws of physics, we must expect coincidences.

Example: How large must a group be to have the probability of finding two people with the same birthday at least 50%?