CHAOS, COMPLEXITY, AND ENTROPY

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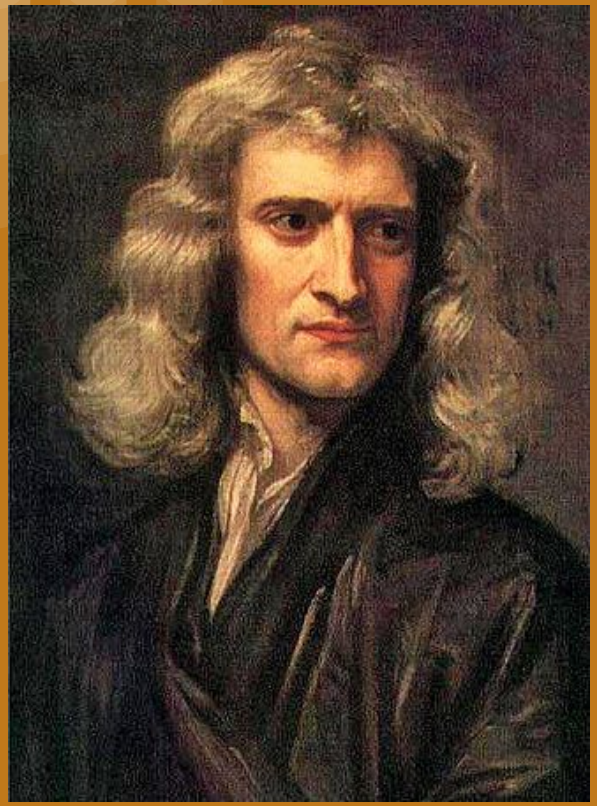
Shahid Beheshti University (SBU), **Nov 14, 2017**

Sitpor.org/Abbas

Chaos

Chaos is the anti-calculus revolution.



Portrait of Newton in 1689 by Godfrey Kneller - *wikipedia*

Calculus is all about:

$y = f(x)$

For smooth and simple f.

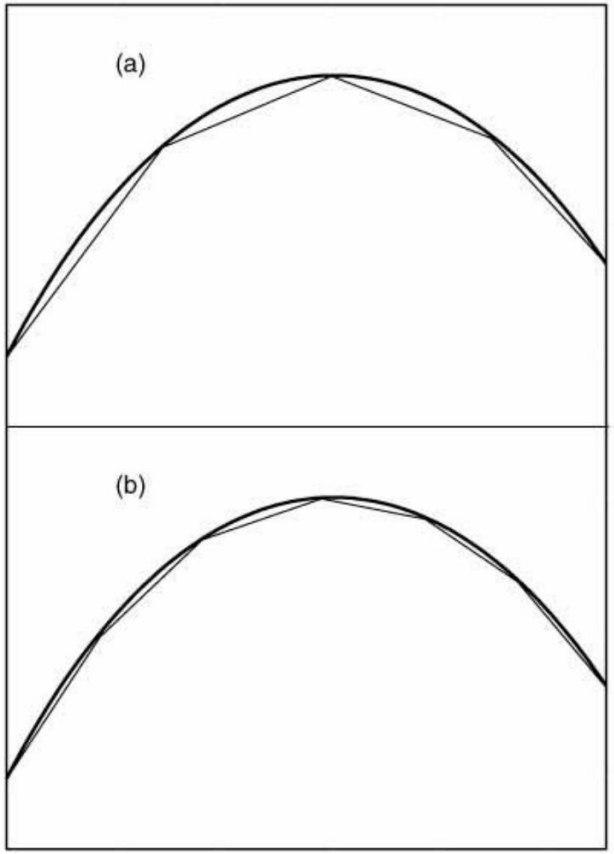
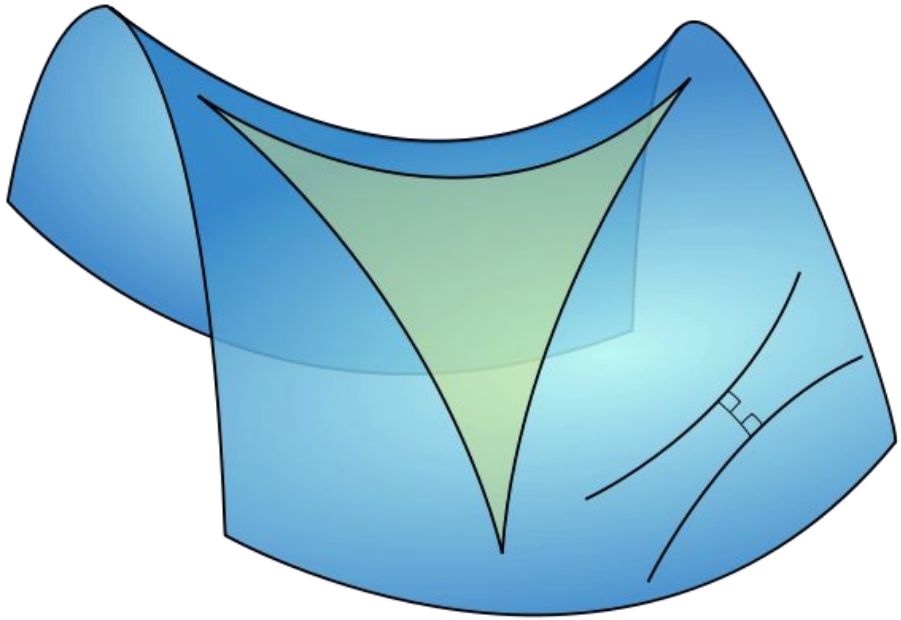
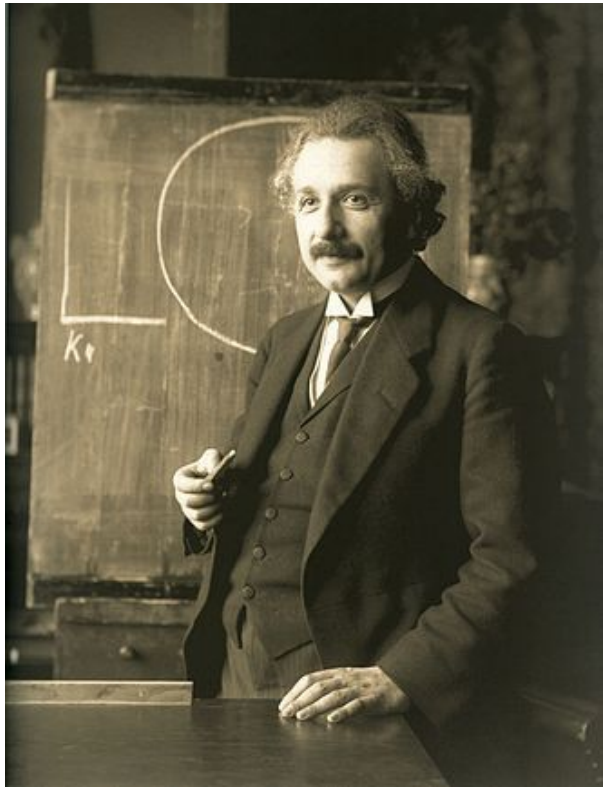


Figure 1: *The first and last calculus lesson.*

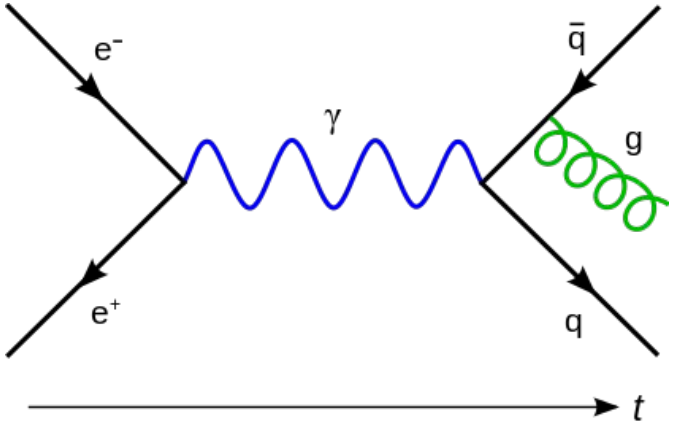


A triangle immersed in a saddle-shape plane (a hyperbolic paraboloid), as well as two diverging ultraparallel lines. *Wikipedia*



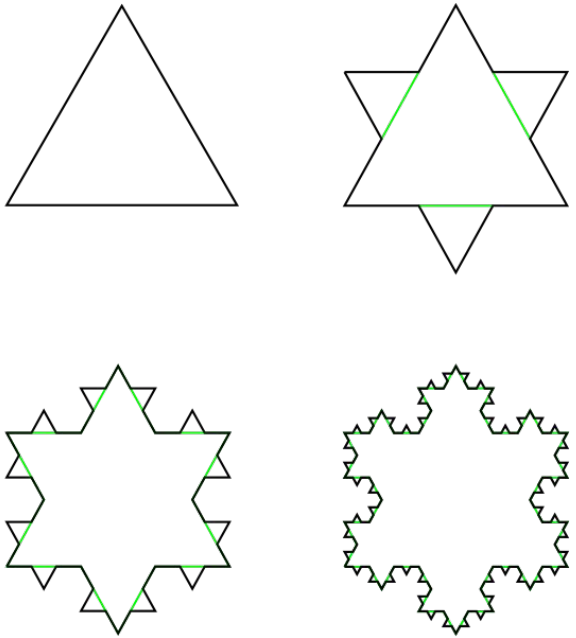
Albert Einstein in 1921 – *Wikipedia*

QM & QFT, both based on Calculus!



$$\hat{H}|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$

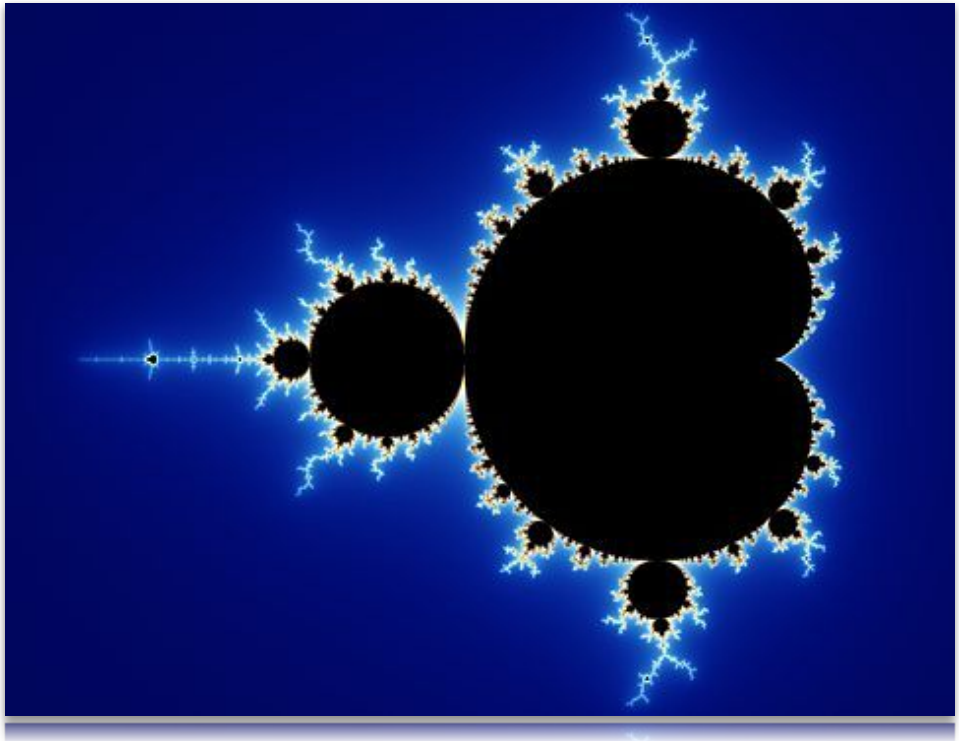
- ***Fractals are chaos in space!***



Koch snowflake– *Wikipedia*

- ***Fractals are chaos in space!***

Sierpinski triangle – *Wikipedia*



Initial image of a Mandelbrot set zoom sequence with a continuously colored environment - *Wikipedia*

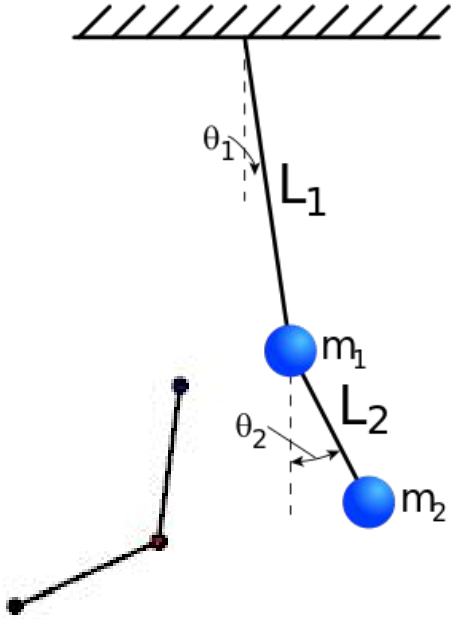
Fractals are chaos in space!

- ***But not always self-similar***

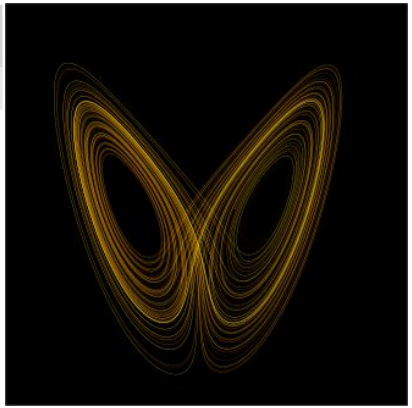
Edward lorenz - *Wikipedia*

- ***The signature of time-chaos is something called:***

  “sensitivity to initial conditions”.

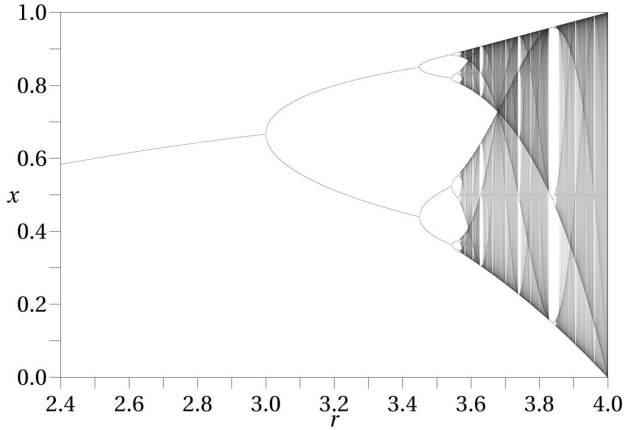

θ1
L1
m1
L2
θ2
m2

Sensitivity to initial conditions is the death of ***reductionism****!*



Lorenz System- *Wikipedia*

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sigma(y - x),$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = x(\rho - z) - y,$$
$$\frac{\mathrm{d}z}{\mathrm{d}t} = xy - \beta z.$$



- ***Every chaotic dynamical system is a fractal-manufacturing machine.***
- ***Conversely, every fractal can be seen as the possible result of the prolonged action of time-chaos.***

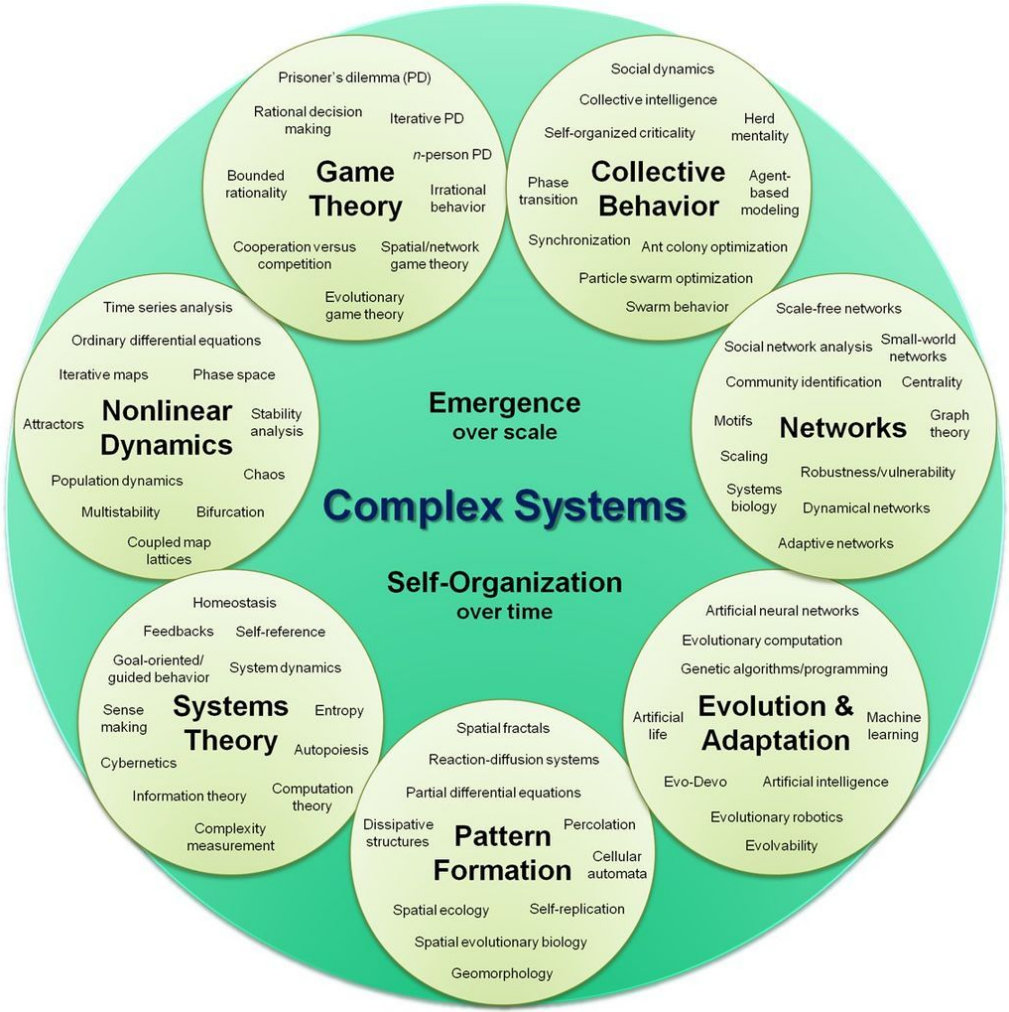
Non-linearity: #stretching and #folding

Cantor set

(the mathematical equivalent of a croissant).

Complexity!

Oh, yeah!, see: sitpor.org

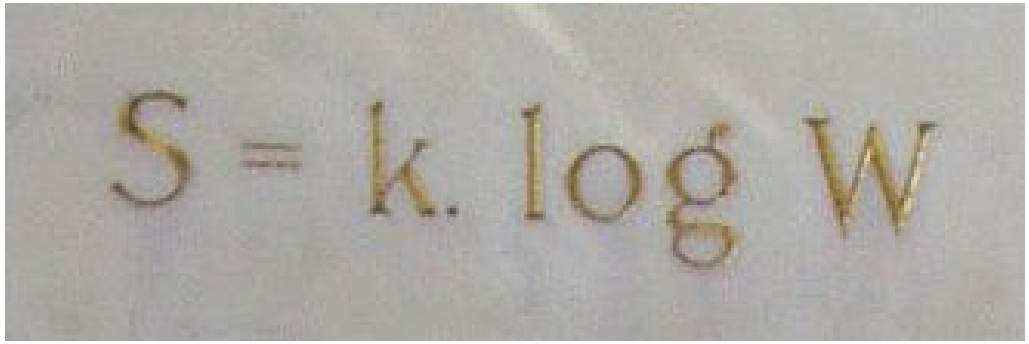

Complex Systems
Emergence
over scale
Self-Organization
over time
Game Theory
Prisoner's dilemma (PD)
Rational decision making
Iterative PD
n-person PD
Bounded rationality
Irrational behavior
Cooperation versus competition
Spatial/network game theory
Evolutionary game theory
Collective Behavior
Social dynamics
Collective intelligence
Herd mentality
Self-organized criticality
Phase transition
Agent-based modeling
Synchronization
Ant colony optimization
Particle swarm optimization
Swarm behavior
Networks
Scale-free networks
Social network analysis
Small-world networks
Community identification
Centrality
Motifs
Graph theory
Scaling
Robustness/vulnerability
Systems biology
Dynamical networks
Adaptive networks
Nonlinear Dynamics
Time series analysis
Ordinary differential equations
Iterative maps
Phase space
Attractors
Stability analysis
Population dynamics
Chaos
Multistability
Bifurcation
Coupled map lattices
Systems Theory
Homeostasis
Feedbacks
Self-reference
Goal-oriented/ guided behavior
System dynamics
Sense making
Entropy
Autopoiesis
Cybernetics
Information theory
Computation theory
Complexity measurement
Evolution & Adaptation
Artificial neural networks
Evolutionary computation
Genetic algorithms/programming
Artificial life
Machine learning
Evo-Devo
Artificial intelligence
Evolutionary robotics
Evolvability
Pattern Formation
Spatial fractals
Reaction-diffusion systems
Partial differential equations
Dissipative structures
Percolation
Cellular automata
Spatial ecology
Self-replication
Spatial evolutionary biology
Geomorphology

Where Does Complexity Come From?

http://www.aparat.com/v/84ncH

Entropy

*Did anyone say Hail **Boltzmann?!***



Boltzmann's grave in the Zentralfriedhof, Vienna, with bust and entropy formula. – *Wikipedia*

“The paradox of the Arrow of Time”

Unsolved problem in physics:

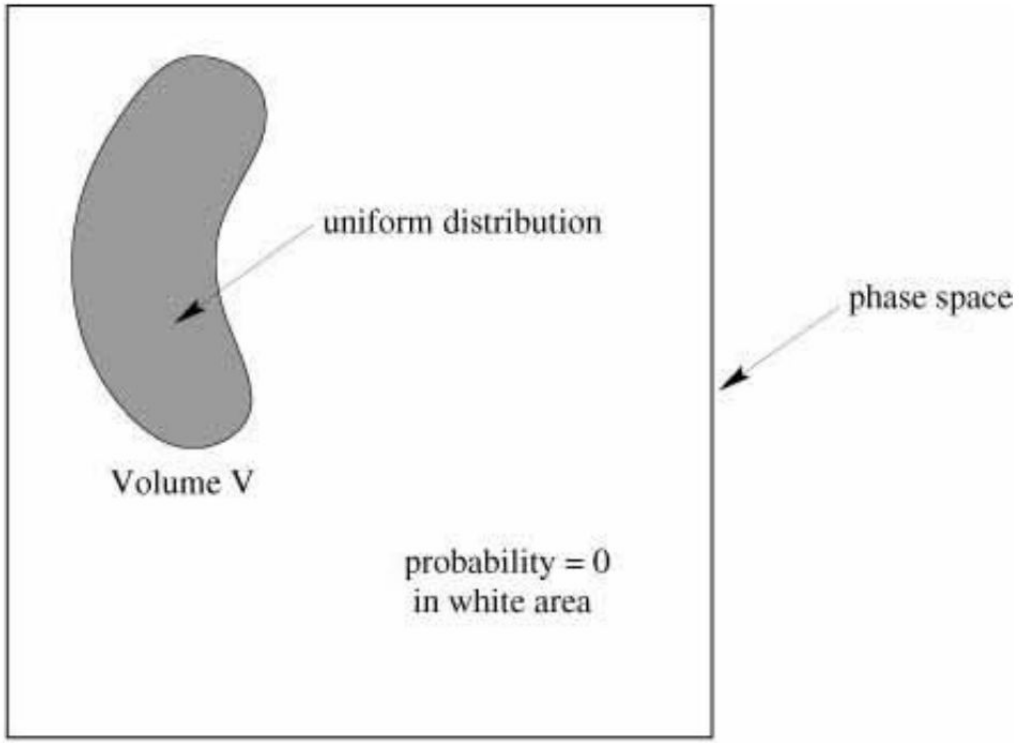
? *What links the quantum arrow of time to the thermodynamic arrow?*

(more unsolved problems in physics)

Chaos ⇔ Thermodynamics

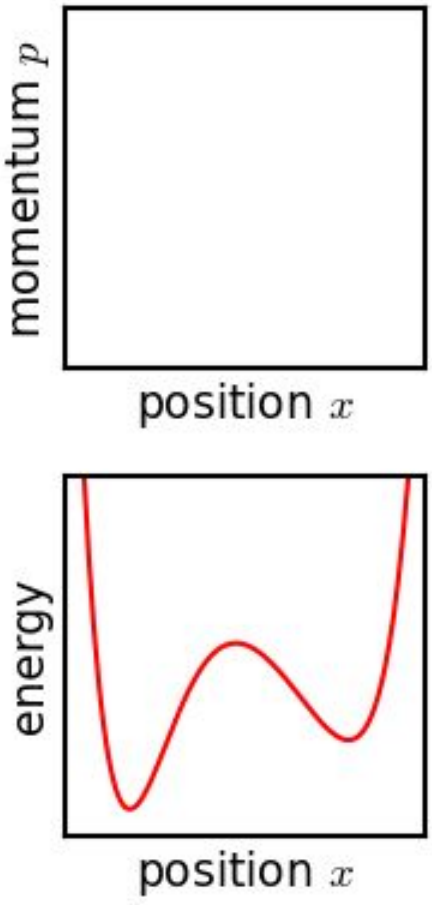
Nicolai Krylov

- **dissipative chaos:** engineer's chaos:
  - "strange attractors
- **conservative chaos:** the physicist's chaos
  - Hamiltonian mechanics, with its special symplectic geometry and its many interesting conservation law


uniform distribution
phase space
Volume V
probability = 0
in white area

Liouville's Theorem

Evolution of an ensemble of classical systems in phase space (top). Each system consists of one massive particle in a one-dimensional potential well (red curve, lower figure). Whereas the motion of an individual member of the ensemble is given by Hamilton's equations, ***Liouville's equations describe the flow of the whole distribution.*** *The motion is analogous to a dye in an incompressible fluid.*



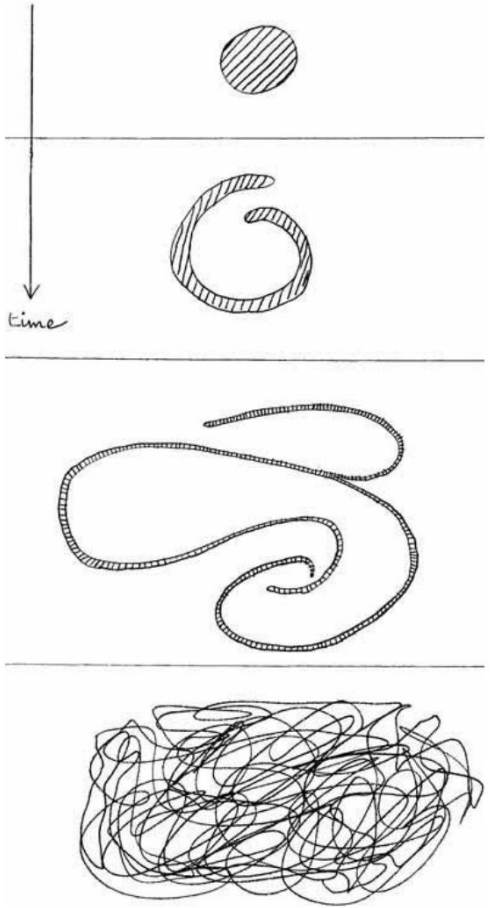
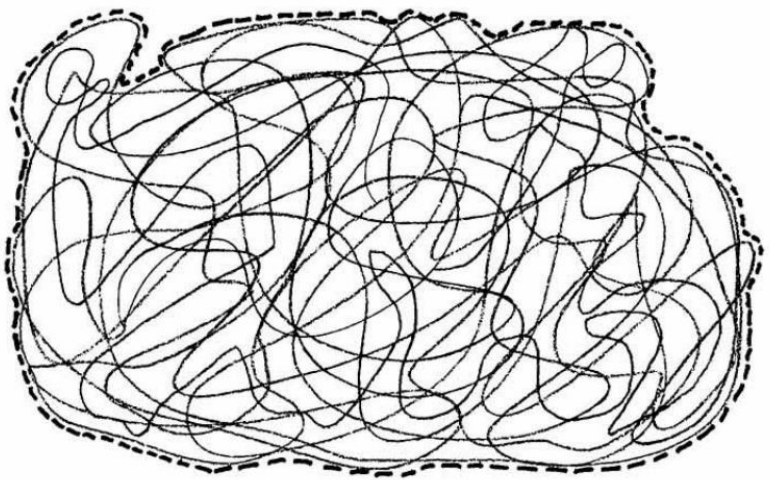


Figure 4: *The time evolution of a simple region of phase space turns it into a fractal.*

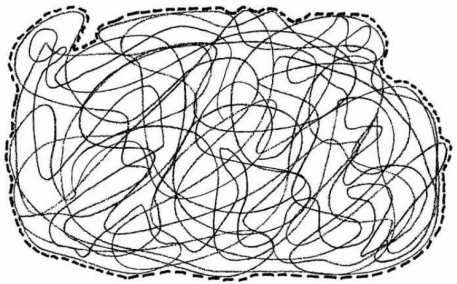
Yes, you are the one who increased the entropy! It is not physics, it is not chaos, it is not Liouville: you drew the smooth volume to make your life easier, you are the one. It was chaos who manufactured the fractal, but you chose to smooth it out.

coarse-graining

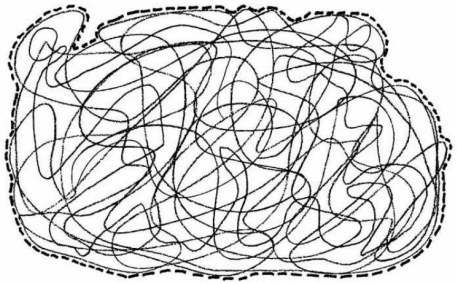


"Now in information theory, we wouldn't say entropy is a property of a system, but a property of an observer who describes a system."

coarse-graining



Before every time at which you want to calculate the entropy, you should smooth out the details of the distribution for all scales finer that some fixed size, which should be the size beyond which you are incapable of keeping track of these details. Every such smoothing is a loss of knowledge and increases the effective volume of the distribution,hence the entropy.



Entropy, which measures our lack of knowledge, is a purely **subjective quantity**. It has **nothing to do with the fundamental laws** of particles and their interactions. It has to do with the fact that chaos messes up things; that situations that were initially simple and easy to know in detail, will become eventually so complicated, **thanks to chaos, that we are forced to give up trying to know them**.

Resources

Chaos, Complexity, and Entropy

A physics talk for non-physicists

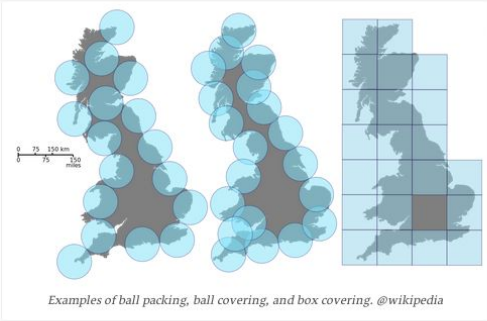
Michel Baranger

Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics
Massachusetts Institute of Technology, Cambridge, MA 02139, USA
and
New England Complex Systems Institute, Cambridge, MA 02138, USA
MIT-CTP-3112

Fractals:

مقدمه‌ای بر هندسه فرکتالی

می 4، 2017 BY عباس کریمی · COMMENTS 0



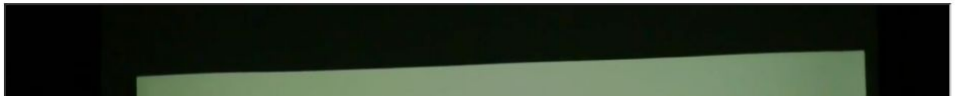
Examples of ball packing, ball covering, and box covering. @wikipedia

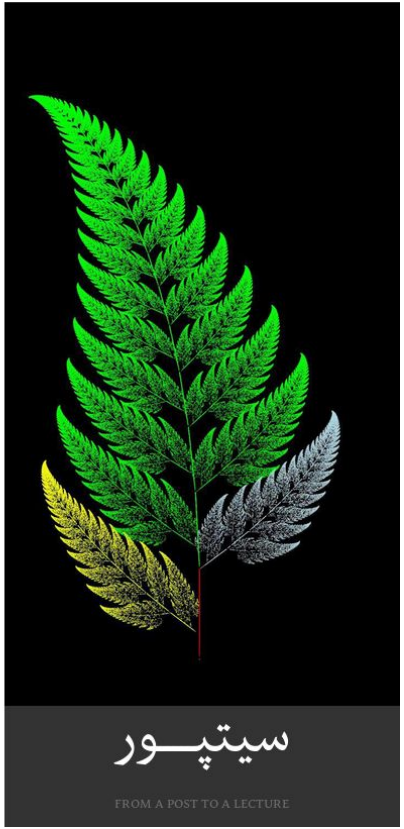
«هندسه‌ی فرکتالی، فقط بخشی از ریاضیات نیست، بلکه موضوعی است که به هرکس کمک می‌کند تا این دنیا را متفاوت ببیند.» بنوا مندلبرو – پدر هندسه‌ی فرکتالی

خیلی وقت پیش در مورد فرکتال‌ها نوشتم که شما می‌تونید اونا رو بخونید:

- قسمت اول) مقدمه و معرفی
- قسمت دوم) ویژگی‌ها و تعاریف
- قسمت سوم) خم‌های فضاپرکن و فرکتال‌های تصادفی
- قسمت چهارم) مجموعه ژولیا
- قسمت پنجم) مجموعه مندلبرو

این هفته، در مورد هندسه فرکتالی یک سخنرانی در دانشگاه شهید بهشتی داشتم با موضوع **«مقدمه‌ای بر هندسه فرکتالی»** می‌تونید ویدیوی این سخنرانی رو ببینید. همین‌طور **اسلایدها** و **فایل صوتی**:





TEXTBOOKS

For the technically inclined, here are a few good books.

Steven H. Strogatz, *Nonlinear Dynamics and Chaos* (Addison-Wesley, Reading, 1994).
Undergraduate level. Mostly about dissipative chaos. Quite entertaining.

L.E. Reichl, *The Transition to Chaos*, (Springer, New York, 1992).
Graduate level. Mostly about conservative chaos. Very complete. Includes quantum chaos.

Yaneer Bar-Yam, *Dynamics of Complex Systems* (Addison-Wesley, Reading, 1997).
Invaluable. Very wide range of topics.

Roger Balian, *From Microphysics to Macrophysics*, 2 volumes (Springer, Berlin, 1991–2).
A thorough introduction to statistical mechanics.

Thanks!

ABBAS KARIMI

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