Complex Systems

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Content:

1. **Fractals:** Fractals in Nature, mathematical fractals, self-similarity, scaling laws, relation to chaos, multifractals.
2. **Percolation:** phase transition, critical exponents, geometrical properties, substructures, universality, critical dimension, applications (oil recovery, nanomagnets, etc.)
3. **Networks:** classical networks, Erdos Renyi graphs, small world, scale free, Internet and www, biological networks, social networks, models for epidemic spreading.
4. **Models and methods:** self-organized criticality (avelanches and earthquakes), random walk (Brownian motion, diffusion, Levy flight, DLA), long-term correlations (DNA, heartbeat, climate temperature fluctuations), synchronization (neurons and Parkinson, heartbeat and breathing), optimization (strong and weak disorder, polymers, optimal paths).

Books

1. B.B. Mandelbrot: The Fractal Geometry of Nature (Freeman, San Francisco 1982).
2. A. Bunde and S. Havlin (eds): Fractals and Disordered Systems (2nd Ed, Springer, Berlin 1996); Fractals in Science (Springer, Berlin 1994).
3. T. Vicsek: Fractal Growth Phenomena (World Scientific, Singapore 1992).
4. J. Feder: Fractals (Plenum, NY 1988).
5. S. Havlin and D. Ben Avraham, Diffusion in Random Media, Adv. in Phys. 36, 659 (1987).
6. D. Stauffer and A. Aharony: Introduction to Percolation (1992).
7. H.O. Peitgen, H. Jurgens and D. Saupe: Chaos and Fractals (Springer, NY 1992).
8. P. Bak, How Nature Works (Copernicus, NY 1996).
9. James Gleick, Chaos (Penguin books, NY 1997).
10. P. Meakin, Fractals, Scaling and Growth far from Equilibrium (Cambridge University press, 1998).
11. D. ben Avraham and S. Havlin, Diffusion and Reactions in Fractals and Disordered Systems (Cambridge University Press, 2000).
12. A. L. Barabasi, Linked (Plume books, 2003).
13. R. Pastor-Satorras, A. Vespignani, Evolution and Structure of the Internet: A Statistical Physics Approach (Cambridge University Press, 2004).
14. S. N. Dorogovtsev, J. F. F. Mendes, Evolution of Networks: From Biological Nets to the Internet and www (Physics) (Oxford University Press, 2003).
15. A. Pikovsky, M. Rosenblum, J. Kurths, B. Chirikov, P. Cvitanovic, F. Moss, H. Swinney, Synchronization : A Universal Concept in Nonlinear Sciences (Cambridge University Press, 2003).

TOPICS

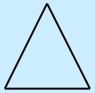
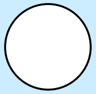
1. Climate systems (scaling and multifractality)
2. Economic systems (Mantegna and Stanley)
3. Earthquakes (scaling and models)
4. Networks (Biology, graph theory, self-similar networks, energy landscape and protein folding)
5. Chaos and nonlinearity
6. Cellural automata
7. Self-organized criticality (Per Bak)
8. Synchronization and applications (Kurths)
9. Multifractality and applications
10. Optimization and applications

Introduction

Since about 1980, extensive research was held in complex systems in many areas:

- Earthquakes
- Galaxies-density and structure
- Neurons structure
- Heartbeat dynamics, etc…

Euclidian geometry cannot describe such complex structures, it deals with

straight lines: triangles:  and circles: 

However, Nature does not have such structures:

trees are not triangles

mountains are not cones

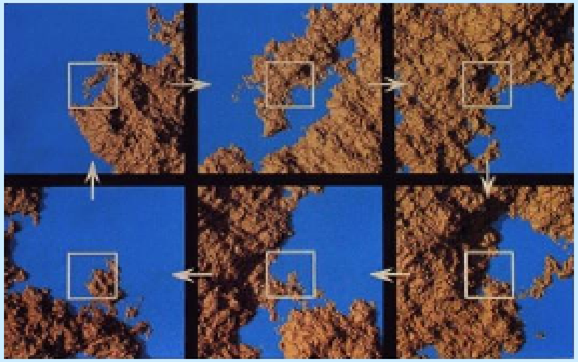
clouds do not look like balls

Also many physics laws are not valid in complex disordered systems: diffusion, conductivity, elasticity.

In recent years it became clear:

(a) New geometry is needed – called "fractal geometry", developed by Benoit Mandelbrot.
(b) Many laws in physics are based on "translational symmetry". This is true in ordered systems such as solids where atoms are ordered in a lattice, but not valid in many complex systems. Instead, in many cases a new symmetry exists "scale invariance" called, also "self-similarity". This is a basic property of fractals.

Self-similarity



Self-similarity ≡ Revolution in science

In every scientific discipline (biology, chemistry, physics) the assumption of "characteristic length scale" is a basic concept. For example, in atomic lattices it is the distance between atoms. Or the mean free path in gas state. In fractals there is no characteristic length as happens in many natural systems. Trees for example do not have branches of a specific length. Instead one has many length scales starting with the smallest leaves until branches of almost the size of the tree.

Why Nature chose fractals – trees of many length scales are more stable against storms.

Fractal geometry was developed mainly due to development of computers – graphics and powerful computers were necessary.

Fractal geometry is much more suitable for computers than Euclidian geometry due to the recursive language of both fractals and computers.

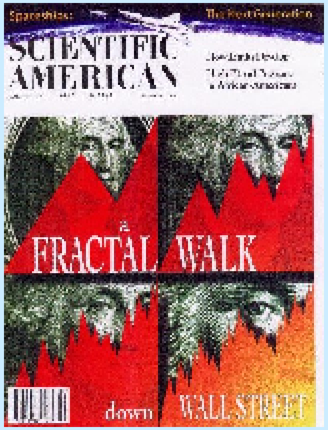
To plot a fractal in a computer is usually much easier than to plot a circle.

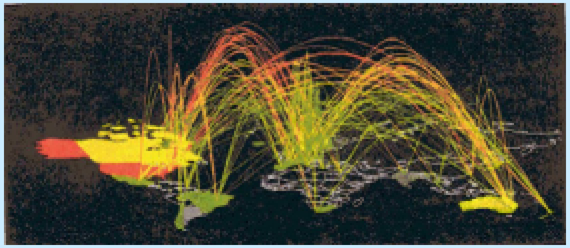
Applicatons in many fields

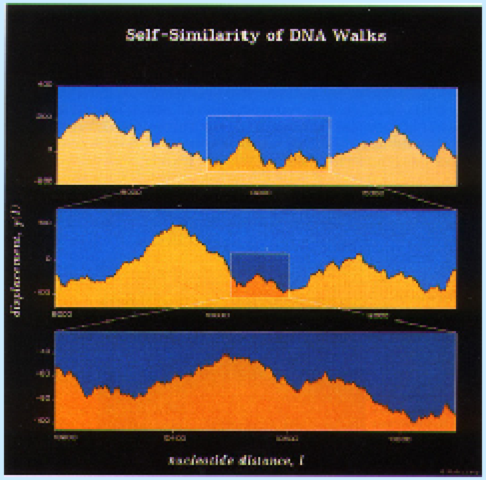
Astrophysics – distribution of stars and galaxies
Geology – earthquakes, oil recovery, rivers
Medicine – heartbeat dynamics, cancer diagnostics, Alzheimer disease
Economics – stock market changes, currency dynamics, companies
Biology – DNA molecules, proteins, neural cells
Mesoscopics – localization wave function
Technology – compressing pictures, background for movies, Internet.

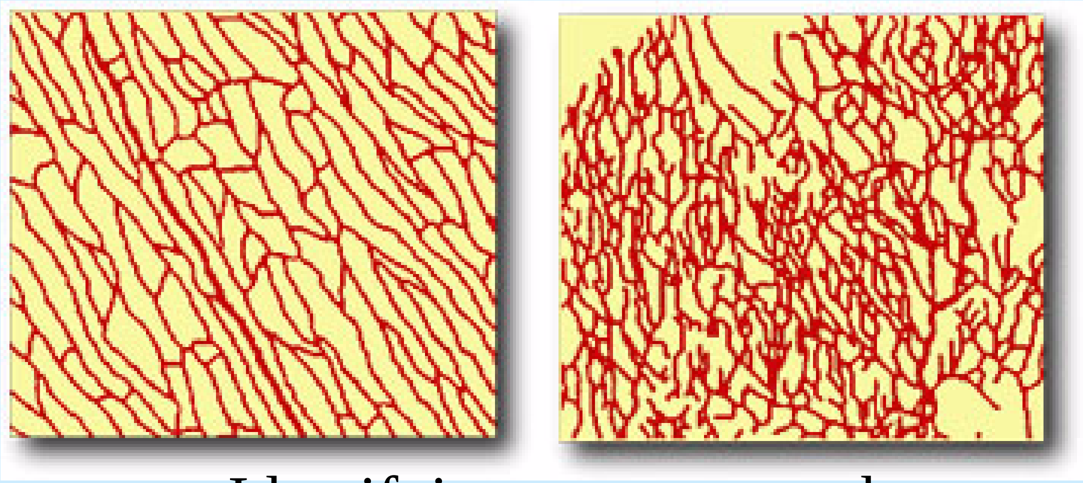
DNA fractal

Internet fractal

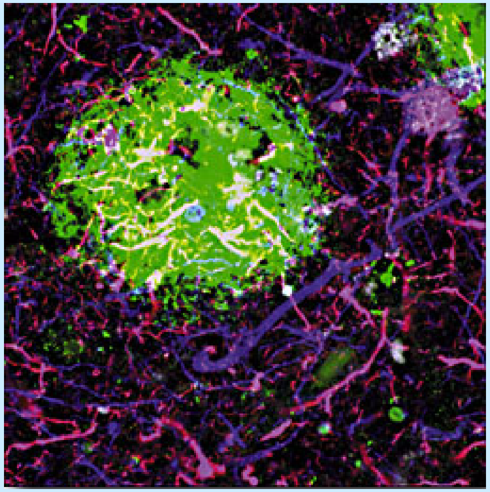








Identifying cancer growth



Plaques in Alzheimer disease

Artificial landscape for movies