

MLR	4.76	0.53	11.3%
MAL	2.48	0.27	10.9%
ME	3.84	0.21	5.5%
MV	2.98	-0.21	-7.0%
CTVV	9.13	-0.05	-0.5%
HYOS	11.61	-0.05	-0.4%
PLUG	21.14	-0.11	-0.5%
ESLR	26.37	-0.04	-0.2%
LMT	62.20	0.53	0.8%
CD	21.77	0.13	0.6%
IOC	26.6	-0.35	-1.3%
TT	19.59	0.09	0.4%
	49.86	-0.16	-0.3%
	39.16	0.22	0.6%

ECONOPHYSICS

Data Science in Fundamental Physics
and the bridge to industry & society

SANTIAGO DE COMPOSTELA, GALICIA, SPAIN 3 – 7 JUNE 2024

Luis Miguel Varela

Grupo de Nanomateriales y Materia Blanda

Dpto. Física de Partículas

Universidad de Santiago de Compostela

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Econophysics

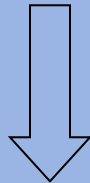
TOC

Econophysics

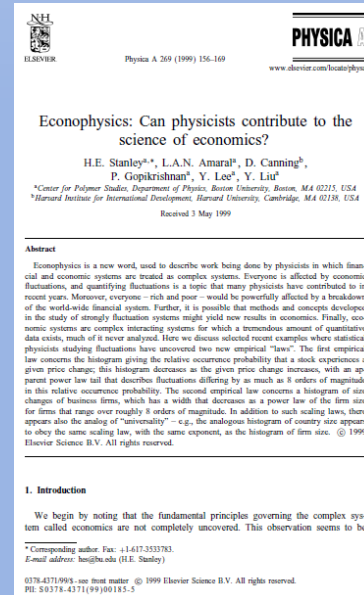
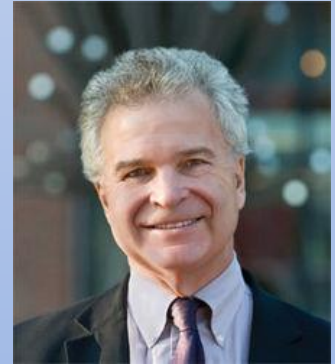
- Physics and Economics: the story of a “love affair”
- Standard financial model.
- Complex systems
- Critical phenomena
- Turbulent flows in fluids
- Economic complexity: the economy as a complex evolutionary system
- Complex networks

ECONOPHYSICS

- **ECONOMICS + PHYSICS** (H. E. Stanley, Calcutta, 1995) and appears for the first time in the proceedings published in *Physica A* 1996.
- **Organization and complex dynamics of financial markets** (scale invariance, systems with self-organized criticality)



PHYSICS OF COMPLEX SYSTEMS



FÍSICA Y ECONOMÍA

LA HISTORIA DE UN “ROMANCE”

Síntesis neoclásica (Hicks: marginalismo y+ keynesianismo)

Principios

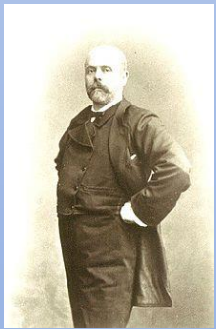
- 1) los individuos tienen preferencias racionales
- 2) los individuos maximizan utilidad y las empresas ganancia.
- 3) los individuos actúan independientemente sobre las bases de información completa y relevante.

Equilibrio general
Monetarismo

PHYSICS AND ECONOMY

History of a “love affair”

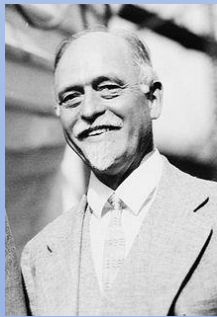
S. XIX Economy becomes a quantitative science (marginalism)



Leon Walras



W. S. Jevons



I. Fisher

Economic dynamics in an irrotational
Price field

$$\vec{\nabla} \times \vec{P} = 0$$

$$\frac{\partial P_i}{\partial x_j} = \frac{\partial P_j}{\partial x_i} \quad i, j = 1 \dots n \quad \text{Slutsky}$$

$$\vec{P} = \vec{\nabla} U(x_1, \dots, x_n)$$

$$U = U(x_1, \dots, x_n) \quad \text{Utility - quant.}$$

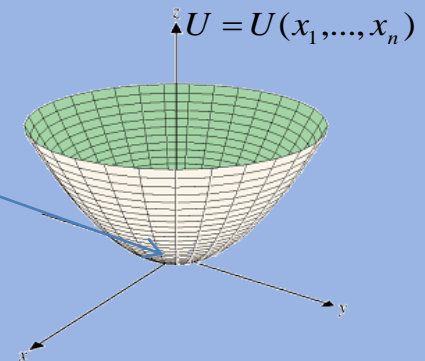
General Equilibrium

$$L = U(x_1, \dots, x_n) + \lambda \sum_i P_i x_i$$

W. Jevons

Irving Fisher

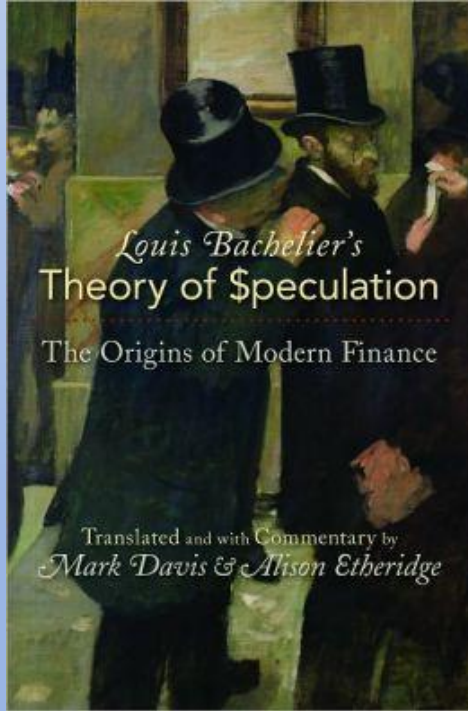
$$\sum_i P_i x_i = \text{cte.} \quad \text{Budget restriction}$$



STANDARD MODEL OF FINANCE

(L. Bachelier, 1900)

THEORIE DE LA SPÉCULATION



Report on Bachelier's thesis (March 29, 1900)⁵⁷

Le sujet choisi par M. Bachelier s'éloigne un peu de ceux qui sont habituellement traités par nos candidats; sa thèse est intitulée *Théorie de la Spéculation* et a pour objet l'application du Calcul des Probabilités aux Opérations de Bourse. On pourrait craindre d'abord que l'auteur ne se soit fait illusion sur la portée du Calcul des Probabilités, comme on l'a fait trop souvent. Il n'en est rien heureusement; dans son introduction et plus loin dans le paragraphe intitulé "La probabilité dans les Opérations de Bourse", il s'efforce de fixer les limites dans lesquelles on peut avoir légitimement recours à ce genre de Calcul; il n'exagère donc pas la portée de ses résultats et je ne crois pas qu'il soit dupe de ses formules.

Qu'a-t-on donc légitimement le droit d'affirmer en pareille matière? Il est clair d'abord que les cours relatifs aux diverses sortes d'opérations doivent obéir à certaines lois; ainsi on pourrait imaginer des combinaisons de cours telles que l'on puisse jouer à coup sûr; l'auteur en cite des exemples; il est évident que de pareilles combinaisons ne se produisent jamais, ou que si elles se produisaient elles ne sauraient se maintenir. L'acheteur croit la hausse probable, sans quoi il n'achèterait pas, mais s'il achète, c'est que quelqu'un lui vend; et ce vendeur croit évidemment la baisse probable; d'où il résulte que le marché pris dans son ensemble considère comme nulle l'espérance mathématique de toute opération et de toute combinaison d'opérations.

Quelles sont les conséquences mathématiques d'un pareil principe? Si l'on suppose que les écarts ne sont pas très grands, on peut admettre que la probabilité d'un écart donné par rapport au cours coté ne dépend pas de la valeur absolue de ce cours; dans ces conditions le principe de l'espérance mathématique suffit pour déterminer la loi des probabilités; on retombe sur la célèbre loi des erreurs de Gauss.

Comme cette loi a été l'objet de démonstrations nombreuses qui pour la plupart sont de simples paralogismes, il convient d'être circonspect et d'examiner cette démonstration de près; ou du moins il est nécessaire d'énoncer d'une manière précise les hypothèses que l'on fait. Ici l'hypothèse que l'on a à faire c'est, comme je viens de le dire, que la probabilité d'un écart donné à partir du cours actuel est indépendante de la valeur absolue de ce cours. L'hypothèse peut être admise, pourvu que les écarts ne soient pas trop grands. L'auteur l'énonce nettement, sans y insister peut-être autant qu'il conviendrait. Il suffit pourtant qu'il l'ait énoncée explicitement pour que ses raisonnements soient corrects.

La manière dont M. Bachelier tire la loi de Gauss est fort originale et d'autant plus intéressante que son raisonnement pourrait s'étendre avec quelques changements à la théorie même des erreurs. Il le développe dans un chapitre dont le titre peut d'abord sembler étrange, car il l'intitule "Raisonnement de

⁵⁷ Registre des thèses de la Faculté des Sciences de Paris, at the Archives nationales, 11 rue des Quatre-Fils, 75003 Paris, classification AJ/16/5537.

la Probabilité." C'est en effet à une comparaison avec la théorie analytique de la propagation de la chaleur que l'auteur a eu recours. Un peu de réflexion montre que l'analogie est réelle et la comparaison légitime. Les raisonnements de Fourier sont applicables presque sans changement à ce problème si différent de celui pour lequel ils ont été créés.

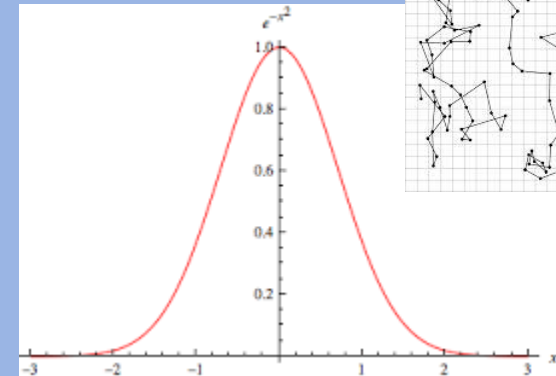
On peut regretter que M. Bachelier n'ait pas développé davantage cette partie de sa thèse. Il aurait pu entrer dans le détail de l'Analyse de Fourier. Il en a dit assez cependant pour justifier la loi de Gauss et faire entrevoir les cas où elle cesserait d'être légitime.

La loi de Gauss étant établie, on peut en déduire assez aisément certaines conséquences susceptibles d'une vérification expérimentale. Telle est par exemple la relation entre la valeur d'une prime et l'écart avec le ferme. On ne doit pas s'attendre à une vérification très exacte. Le principe de l'espérance mathématique s'impose en ce sens que, s'il était violé, il y aurait toujours des gens qui auraient intérêt à jouer de façon à le rétablir et qu'ils finiraient par s'en apercevoir. Mais ils ne s'en apercevront que si l'écart est considérable. La vérification ne peut donc être que grossière. L'auteur de la thèse donne des statistiques où elle se fait d'une façon très satisfaisante.

M. Bachelier examine ensuite un problème qui au premier abord semble devoir donner lieu à des calculs très compliqués. Quelle est la probabilité pour que tel cours soit atteint avant telle date? En écrivant l'équation du problème, on est conduit à une intégrale multiple où on voit autant de signes \int superposés qu'il y a de jours avant la date fixée. Cette équation semble d'abord insurmontable; mais elle se résout par un raisonnement court, simple et élégant; il faut d'ailleurs remarquer l'analogie avec le raisonnement connu de M. André au sujet du problème du dépassement d'un scrutin. Mais cette analogie n'est pas assez étroite pour diminuer ce qui est de son originalité et ingénieux artifice. Pour d'autres problèmes analogues, l'auteur s'en sert également.

En résumé, il y a lieu d'honorer M. Bachelier à titre de mathématicien et de physicien. Il a fait faire un pas à la théorie de la spéculation.

Signed: Poincaré, Bousinesq

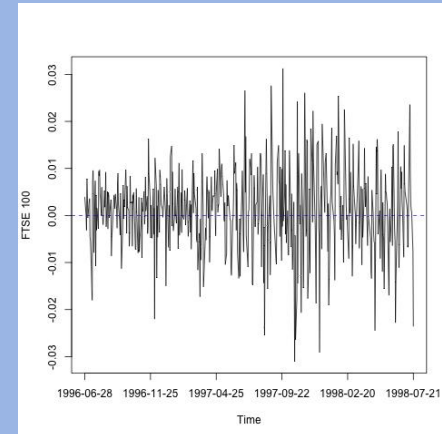


STANDARD FINANCIAL MODEL

(Black-Merton-Scholes)

Black-Merton-Scholes model for valuing derivatives

- Efficient and complete market (**Fama hypothesis**: all information in the price; informationally efficient markets)
- Formulation of the **efficient market hypothesis** in terms of martingales.
- Risk-free (**hedging strategy**).
- There are no transaction costs.
- All market participants use all options arbitration (**arbitrage-free**).
- The stochastic process followed by the underlying assets (stocks) It is **geometric Brownian motion** (price dynamics).



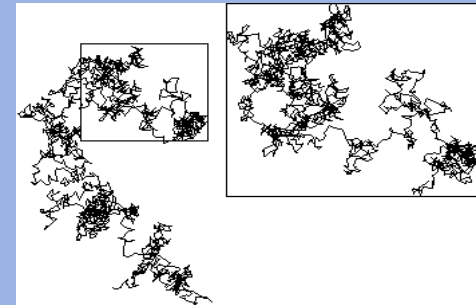
FTSE 100

STANDARD FINANCIAL MODEL

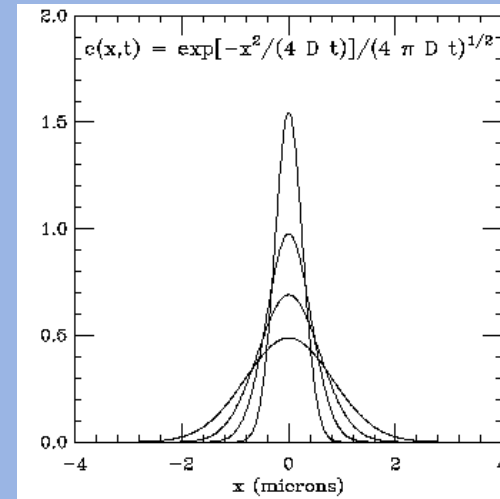
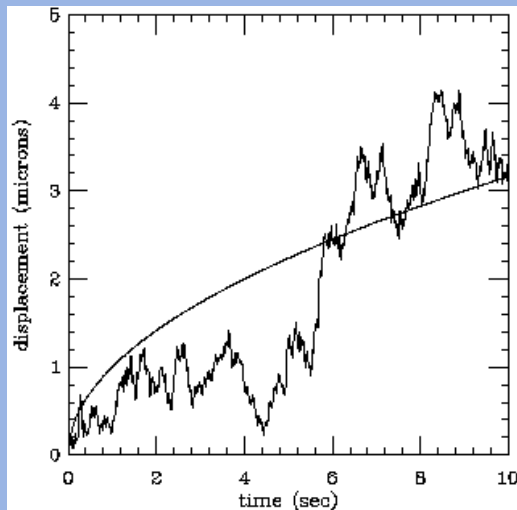
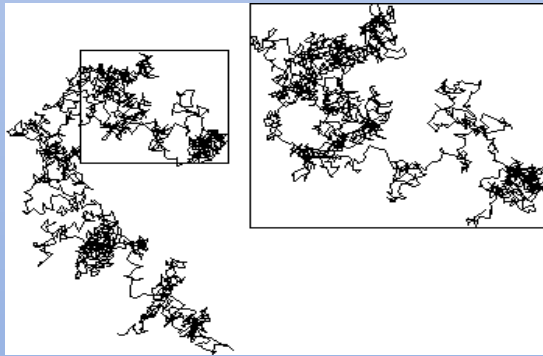
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STANDARD FINANCIAL MODEL (Black-Merton-Scholes)



STANDARD FINANCIAL MODEL (Black-Merton-Scholes)

UNDERLYING STOCK DYNAMICS

$$dY(t) = \mu Y(t)dt + \sigma Y(t)dz$$

Itô process (v.a. iid)

$$\frac{dY(t)}{Y(t)} = \mu dt + \sigma dz = \mu dt + \sigma^2 dt$$

Brownian motion



$$p(Y, t) = \frac{1}{\sqrt{2\pi\sigma^2\tau}Y} \exp \left\{ -\frac{[\ln(Y/Y_0) - (\mu - \sigma^2/2)\tau]^2}{2\sigma^2\tau} \right\}; \quad \tau = t - t_0$$

STANDARD FINANCIAL MODEL

(Black-Merton-Scholes)

OPTIONS

$$df(Y, t) = \left(\frac{\partial f}{\partial t} + \mu Y \frac{\partial f}{\partial Y} + \frac{1}{2} \sigma^2 Y^2 \frac{\partial^2 f}{\partial Y^2} \right) dt + \frac{\partial f}{\partial Y} \sigma Y dz$$

$$dV(t) = - \left(\mu Y \frac{\partial f}{\partial Y} + \frac{\partial f}{\partial t} + \frac{1}{2} \sigma^2 Y^2 \frac{\partial^2 f}{\partial Y^2} - \mu N Y \right) dt - \left(\frac{\partial f}{\partial Y} - N \right) \sigma Y dz$$

$$\frac{\partial f}{\partial t} + rY \frac{\partial f}{\partial Y} + \frac{1}{2} \sigma^2 Y^2 \frac{\partial^2 f}{\partial Y^2} = r f$$

$$N = \partial f / \partial Y$$

- Parabolic differential equation in linear partial derivatives of 2nd order
- Operator structure similar to the Fokker-Planck equation (Physics) or Kolmogorov (Mathematics).
- Equation similar to that of diffusion with negative diffusion constant.



$$f(Y, T) = \max(Y - K, 0) \quad \text{opción de compra (call)}$$

$$f(Y, T) = \max(K - Y, 0) \quad \text{opción de venta (put)}$$

Nobel Prize (Bank of Sweden), 1997
-Merton/Scholes

STANDARD FINANCIAL MODEL

(Black-Merton-Scholes)

$$u(x, t') = \frac{1}{\sqrt{4\pi t'}} \int_0^{+\infty} \left(e^{bx'} - e^{ax'} \right) e^{-(x-x')^2/4t'} dx'$$

$$f(Y, t) = YN(d_1) - Ke^{-r(T-t)}N(d_2)$$

$$N(d) = \frac{1}{\sqrt{2\pi}} \int_{-d}^{\infty} e^{-x'^2} dx'$$

$$d_1 = \frac{\ln \frac{Y}{K} + \left(r + \frac{\sigma^2}{2} \right) (T - t)}{\sigma \sqrt{T - t}}$$

$$d_2 = \frac{\ln \frac{Y}{K} + \left(r - \frac{\sigma^2}{2} \right) (T - t)}{\sigma \sqrt{T - t}}$$

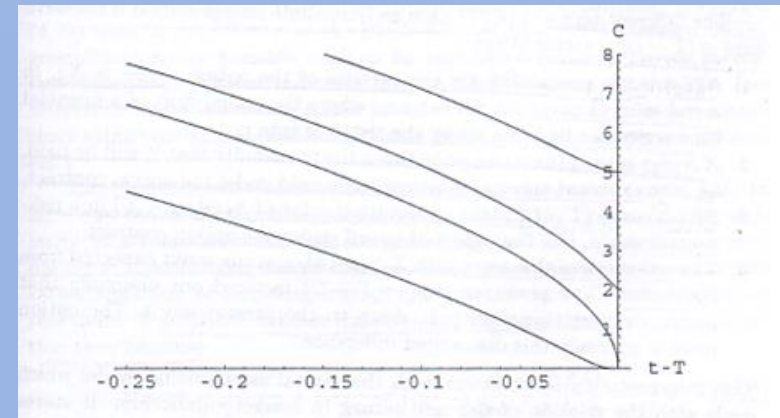
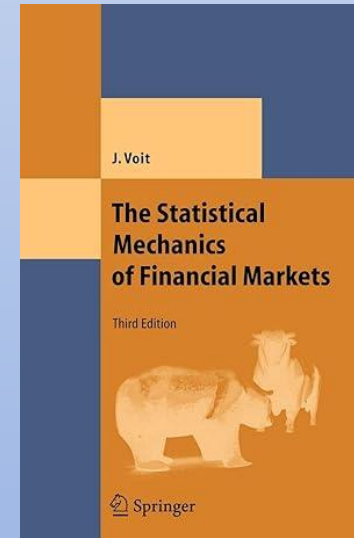


Fig. 4.7. Time evolution of the price of a European call option as a function of time before maturity in years. Fixed stock price $S = 100$, interest rate $r = 6\%/y$, and volatility $\sigma = 30\%/ \sqrt{y}$ have been assumed. The curves represent different strike prices $X = 95, 98, 100, 105$ from top to bottom, i.e., the options are in the money (top two lines), at the money, and out of the money, respectively

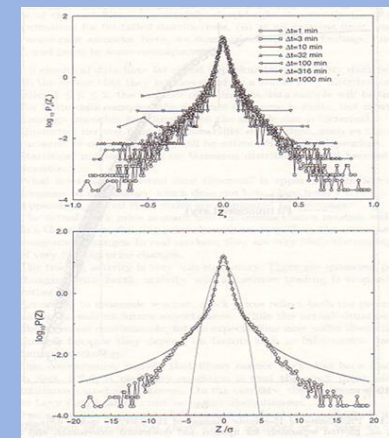
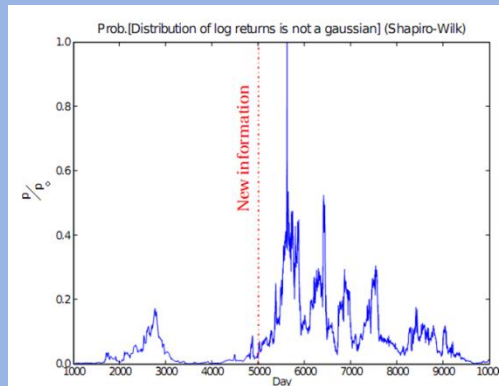
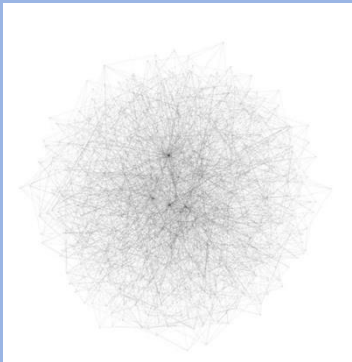
STANDARD FINANCIAL MODEL (Black-Merton-Scholes)

Deficiencies of the Black_Merton-Scholes model

- Information asymmetries during information inputs to the market.
- Investor networks.
- Commissions.

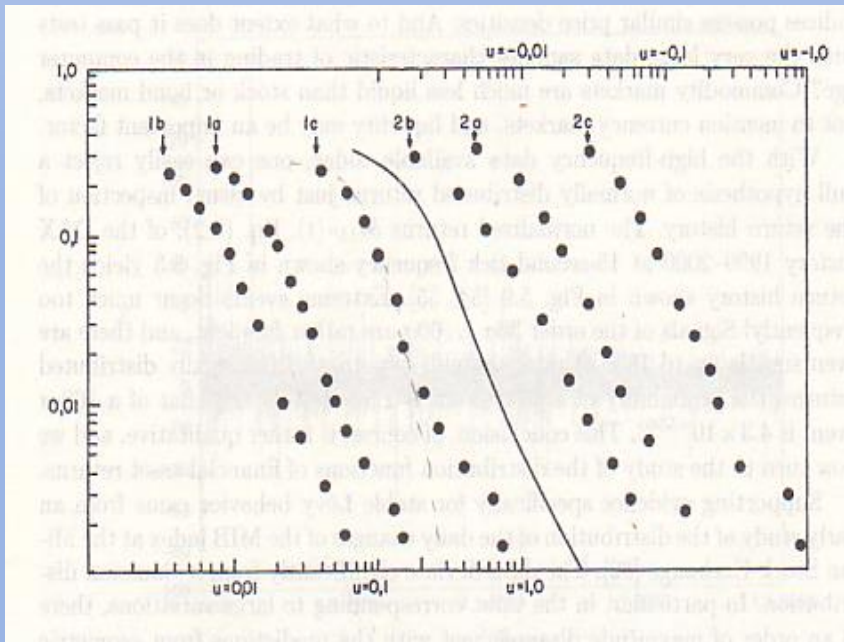


- Non-Gaussian stock price returns
- Existence of long-range memory in time series of prices

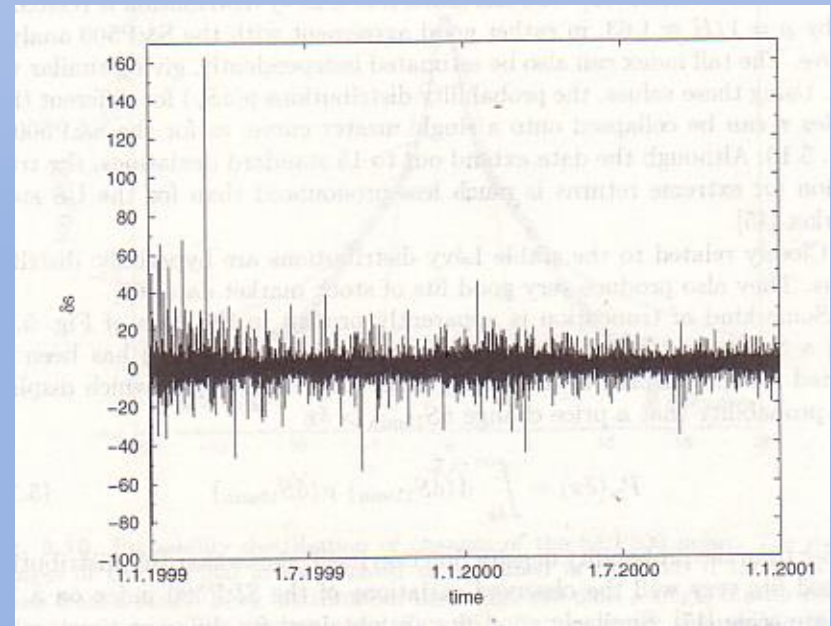


STANDARD FINANCIAL MODEL (Black-Merton-Scholes)

Deficiencies of the Black_Merton-Scholes model



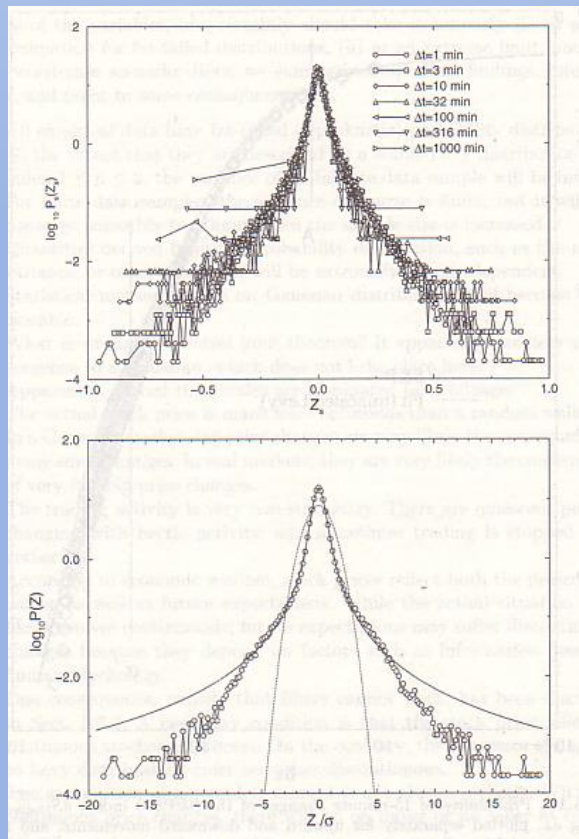
Frequencies of positive (1) and negative (2) changes in logarithms of cotton prices in various US markets. The solid line represents a cumulative Lévy distribution of index 1.7. (B. Mandelbrot, J. Business 40, 394 (1963)).



History of returns normalized with the standard deviation of the German DAX index during 1999 and 2000, with data taken with a time scale of 15 s. Note the occurrence of one event at 160s and several at (30s, 60s) (J. Voit, The Statistical Mechanics of Financial Markets. Springer, Berlin, 2003).

STANDARD FINANCIAL MODEL (Black-Merton-Scholes)

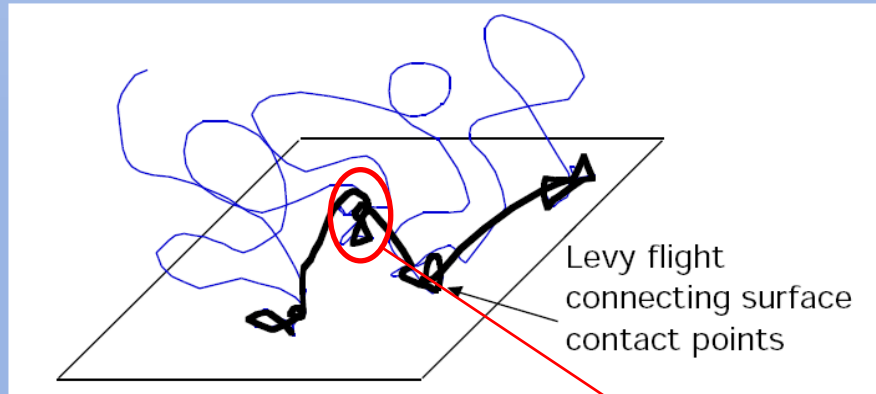
Deficiencies of the Black_Merton-Scholes model



Probability distribution of changes in the S&P500 index. Comparison with Gaussian and stable Lévy distributions.

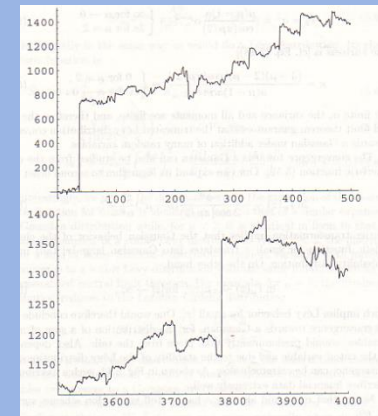
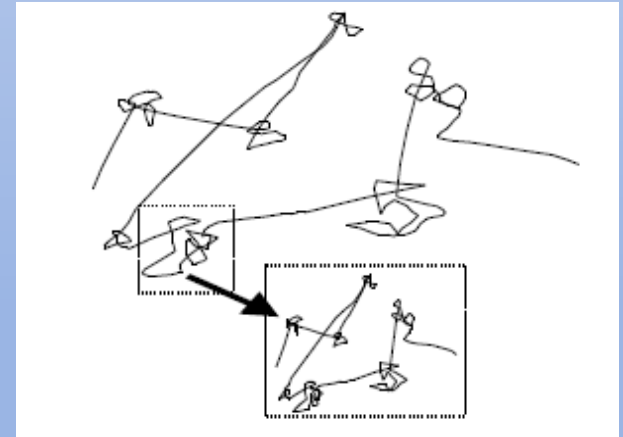
MODELO FINANCIERO STANDARD (Black-Merton-Scholes)

Deficiencies of the Black_Merton-Scholes model



LÉVY FLIGHT

NEW INFORMATION
ENTERS THE MARKET

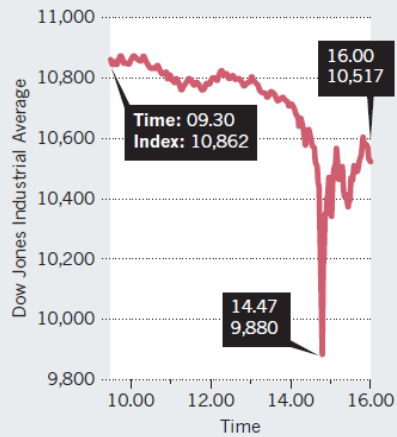




Laser units on rooftops connect New Jersey's Nasdaq data centre with the New York Stock Exchange.

FLASH CRASH

On 6 May 2010, the market value of the Dow Jones Industrial Average fell by 9%, but recovered in minutes. High-speed trading algorithms were in part to blame.



Trading at the speed of light

To minimize risks, we must learn more about how financial markets operate at ever faster rates, urges **Mark Buchanan**.

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FAST TRADING HOTSPOTS

The speed of light is the ultimate limit to how rapidly trades can be made between financial centres (●) — it would take signals travelling at this speed 67 milliseconds to travel halfway around the Earth. The midpoints between exchanges (◐) are the best places to site high-frequency trading computers because they access information from both simultaneously and with the minimum delay.



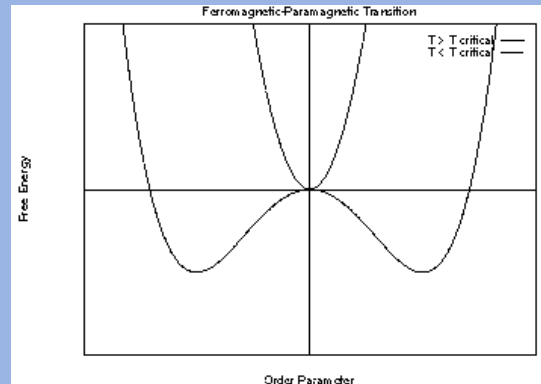
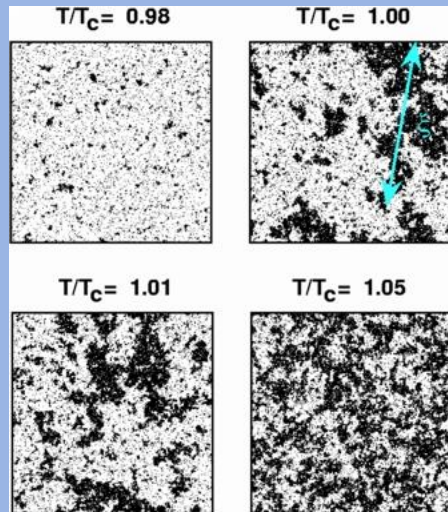
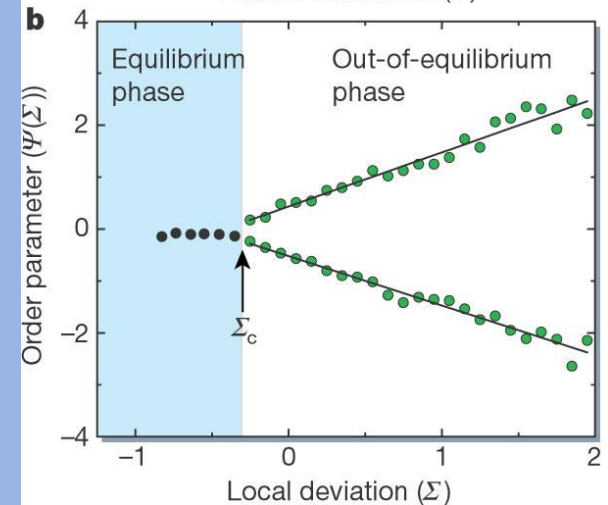
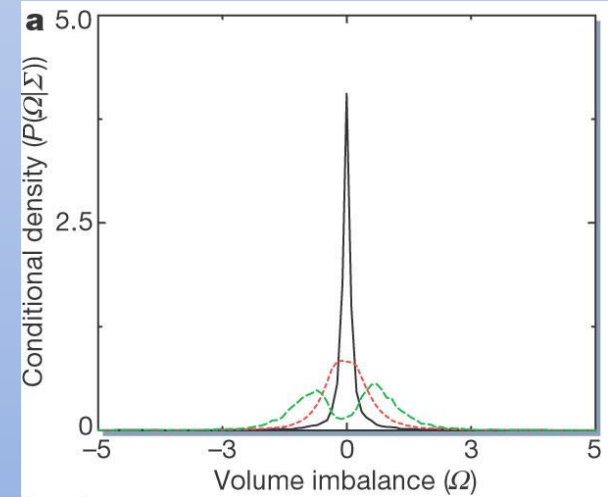
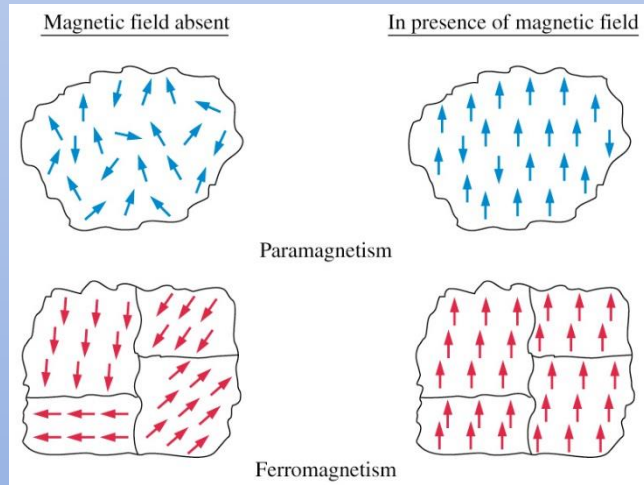
COMPLEX SYSTEMS

Systems with a very high number of constituent parts that interact with each other in a non-linear manner, which causes the existence of complex organization and dynamics.

- Existence of **correlations**: importance of fluctuations (Statistical Mech.)
- **Non-linearity**: there are no simple cause-effect relationships between elements. A small stimulus can cause a big effect or none at all. Extreme events. Non-Gaussian Lévy distributions.
- **Scale invariant phenomena**: lack of a characteristic scale (criticality, self-organization, fractality)
- **Feedback** mechanisms in both amplification and attenuation of effects.
- **Open** systems.

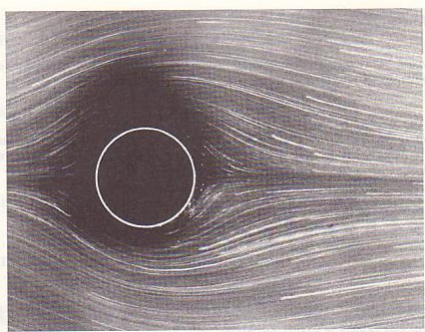
Applications {
- Critical phenomena
- Fluid turbulence
- Economy (Econophysics)

CRITICAL PHENOMENA

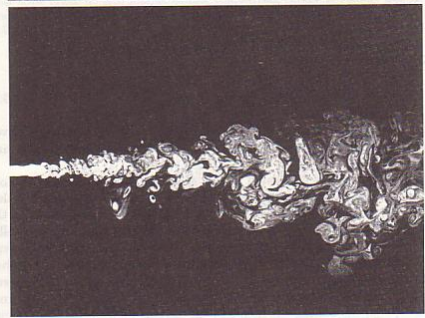


Ferromagnetic phase transition.

TURBULENT FLUXES IN FLUIDS

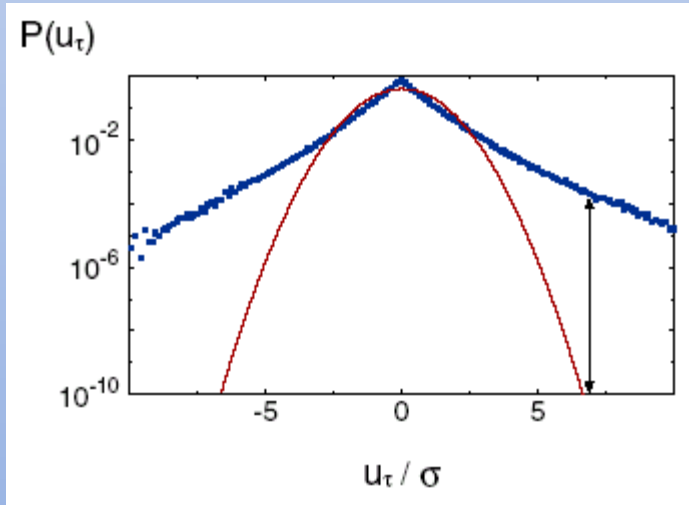


$R=1. > 54$

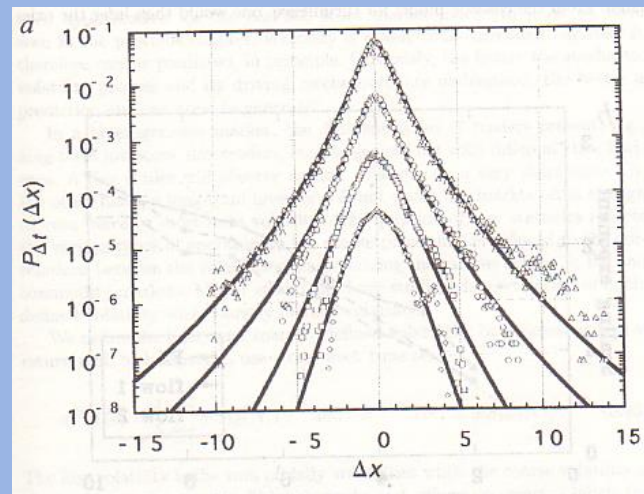


$R=2300$

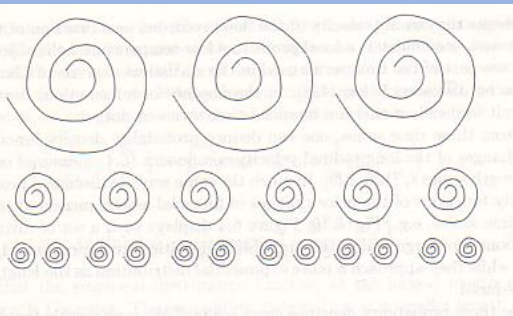
**Reynolds
number
 $R=lv/h$**



Distribution of changes in wind speed during 4 s intervals obtained on the German North Sea coast. The curve represents the Gaussian distribution with the sample standard deviation.

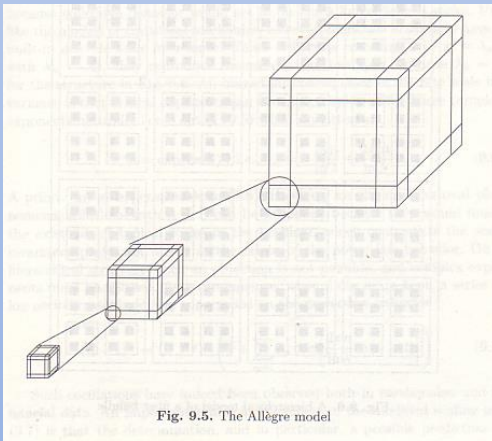


Probability density for variations in the US\$/DEM exchange rate in intervals of 640, 5120, 40960 and 163840 s (from top to bottom). Nature 381, 767 (1996).



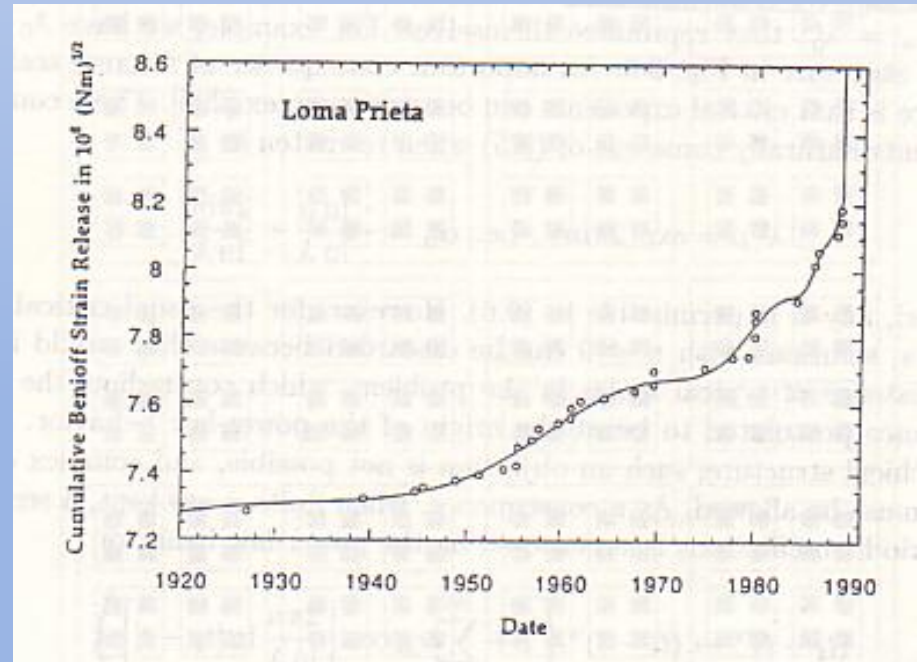
Cascade model: Transfer of energy between scales of the system.

CRISIS CRÍTICAS DEL MERCADO: SISTEMAS JERÁRQUICOS



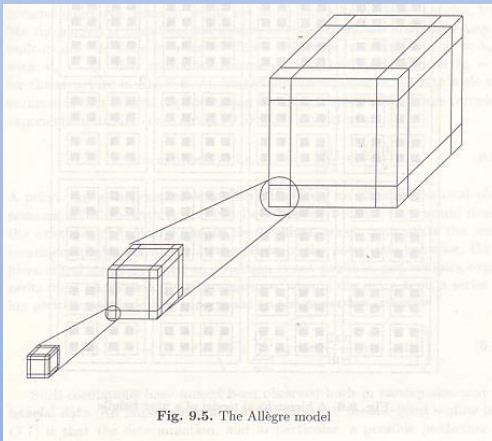
Allègre model of earthquakes

- Multiscale systems
- Interconnexion between objects in different scales.



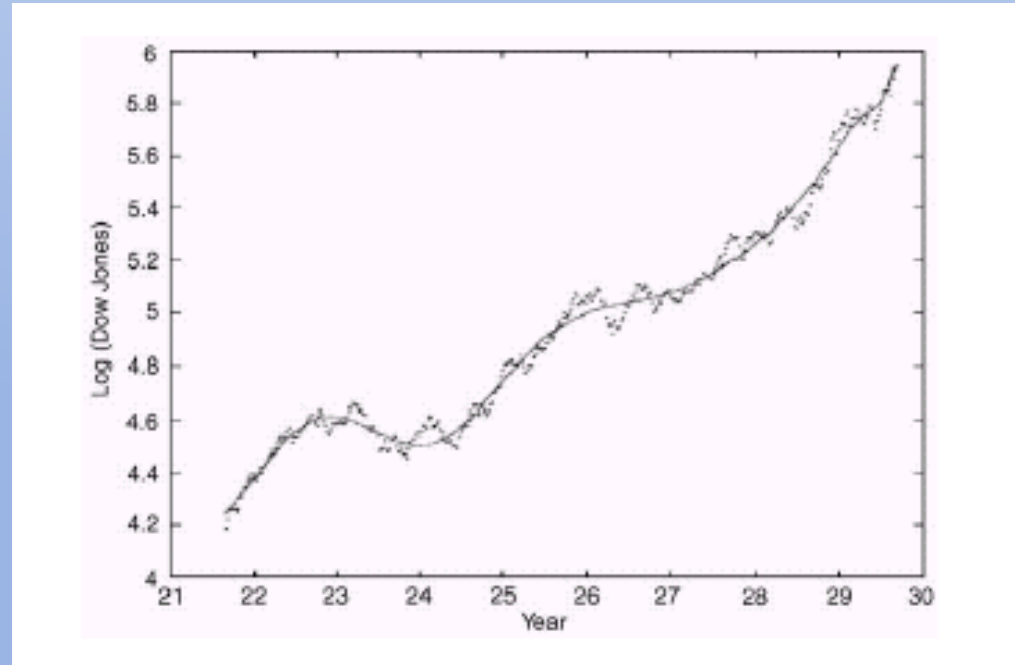
Benioff stress prior to the Loma Prieta earthquake fitted to a power law with log-periodic corrections. D. Sornette, C. G. Sammis, J. Phys. I (France), 5, 607 (1995).

CRISIS CRÍTICAS DEL MERCADO: SISTEMAS JERÁRQUICOS



Allègre model of earthquakes

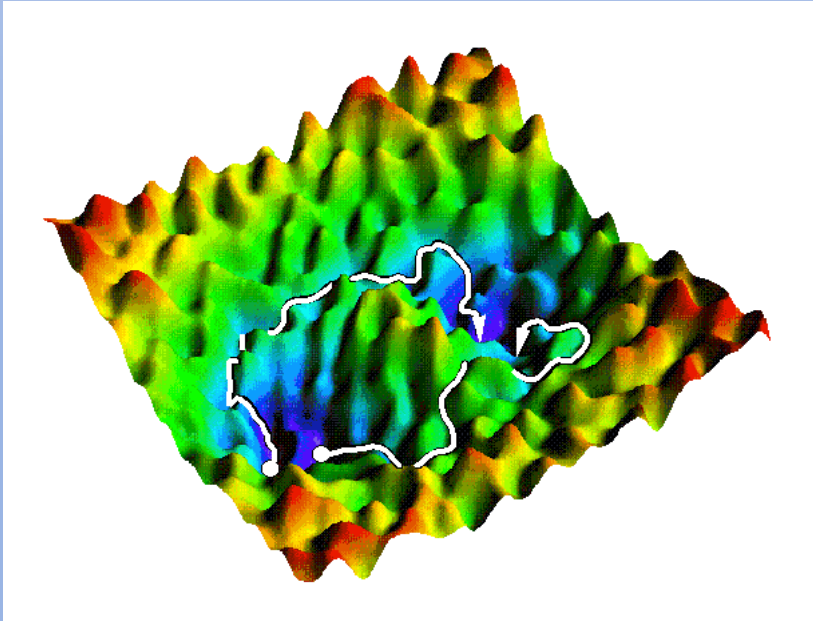
- Multiscale systems
- Interconnenction between objects in diferent scales.



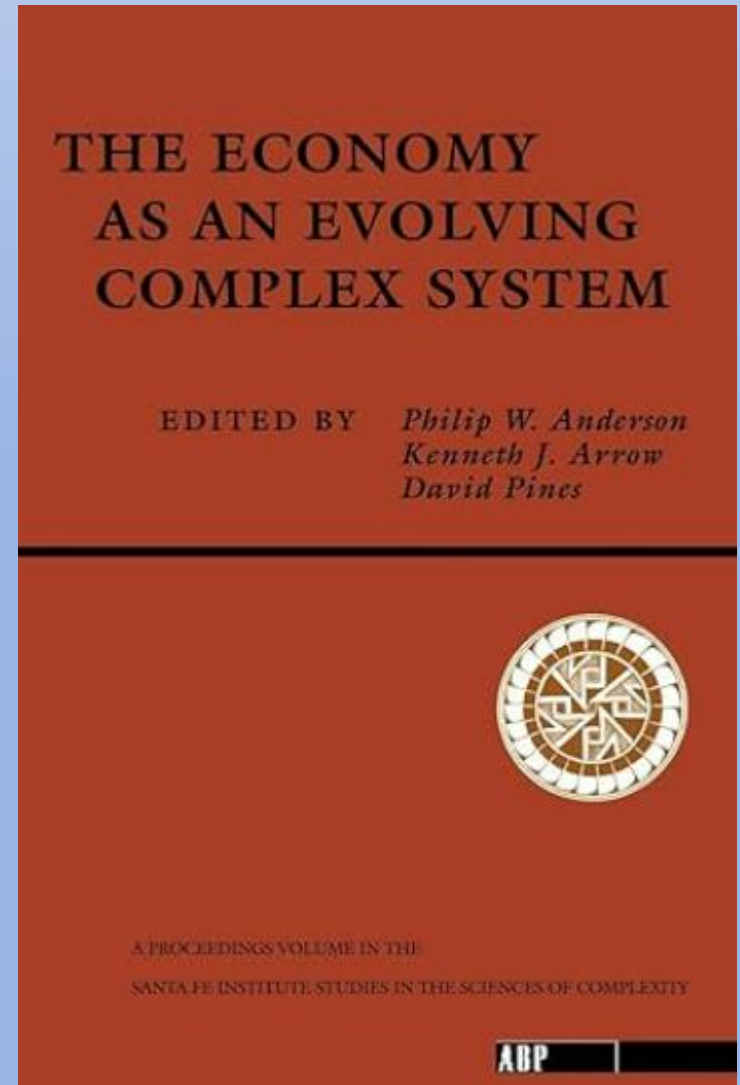
Time dependence of the Dow Jones index from June 1921 to September 1929 and fit with a modified log-periodic equation. Sornette, D., Johansen, A., Large financial crashes. *Physica A* 245, 411 (1997).

ECONOMIC COMPLEXITY: THE ECONOMY AS AN EVOLVING COMPLEX SYSTEM

Is the economy a complex system?



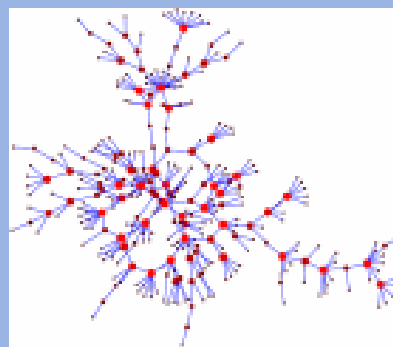
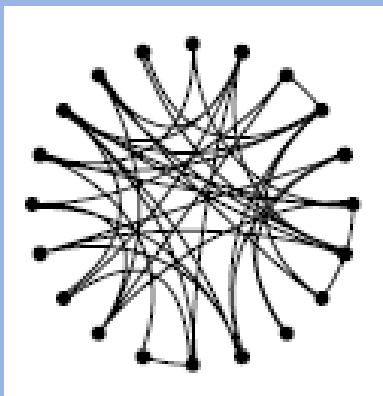
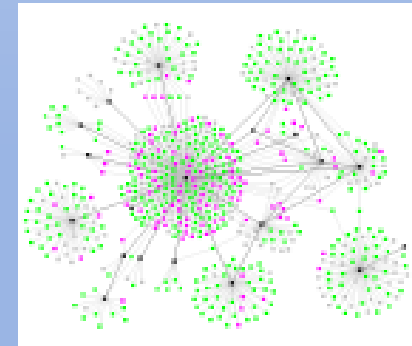
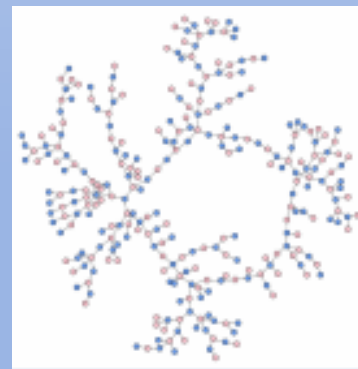
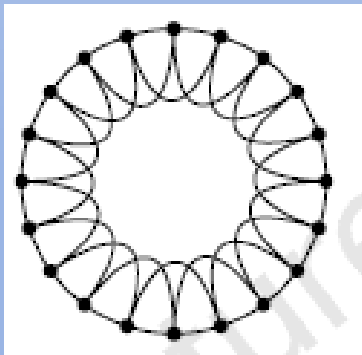
http://gold.cchem.berkeley.edu/Pictures_and_Images/rugged.gif



ECONOMIC COMPLEXITY: THE ECONOMY AS AN EVOLVING COMPLEX SYSTEM

Formal description of the structure and dynamics of a complex system

Structure: network formed by agents (vertices) and interactions between them (connectors).



ECONOMIC COMPLEXITY: THE ECONOMY AS AN EVOLVING COMPLEX SYSTEM

Formal description of the structure and dynamics of a complex system

Mathematical description

- Theory of complex networks.
- Statistical mechanics of stable processes. Fractals.
- Nonlinear dynamic systems. Chaos theory.
- Statistical Mechanics (phase transitions, self-organized criticality...).
- Thermodynamics of irreversible processes (nonlinear regime).
- Computer simulation.



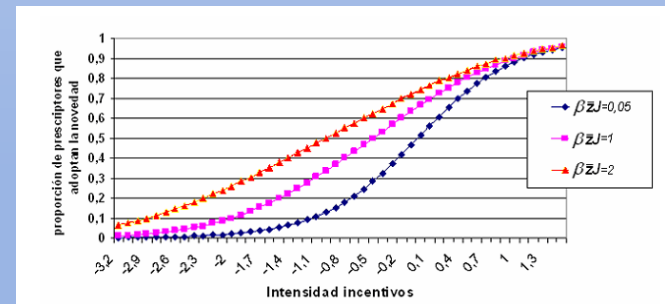
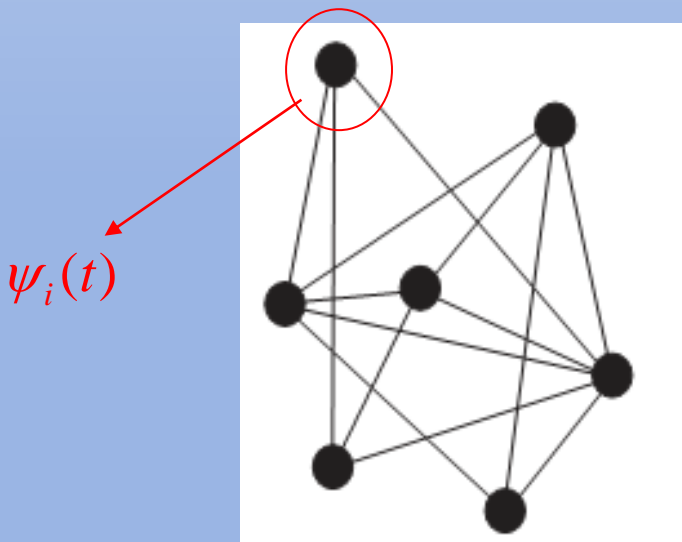
BSC supercomputer

COMPLEX NETWORKS

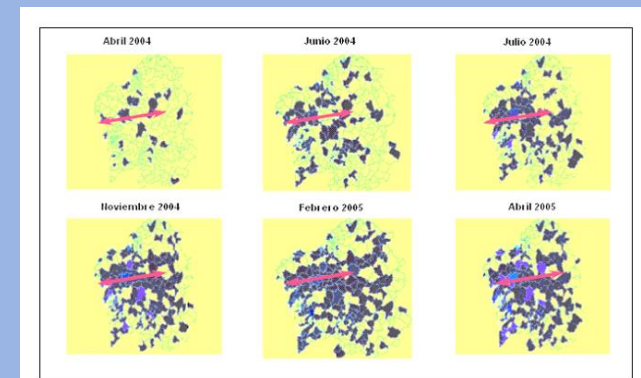
Dynamic processes in complex systems

DYNAMICS: Complex network as a substrate for nonlinear dynamic processes.
Relationship between structure and dynamics of complex networks.

Propagation processes: market penetration



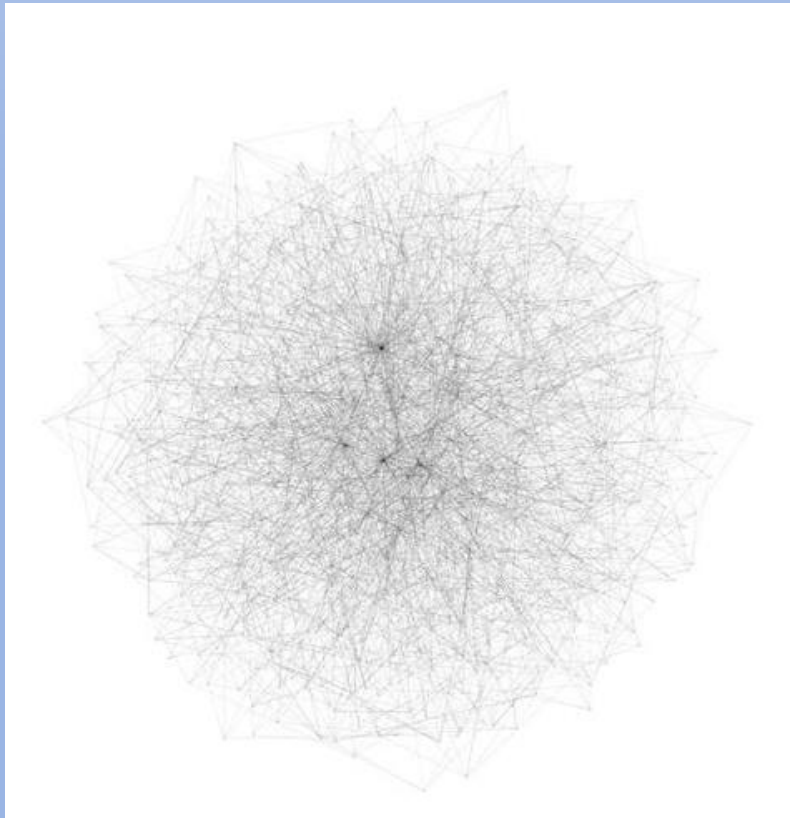
$$\dot{\psi}_i(t) = f(\psi_i, \psi_{j \neq i}; G(N, L); t)$$



COMPLEX NETWORKS

Dynamic processes in complex systems

Diffusion processes in financial markets.



AB scale-free network ($N=500$) employed in the simulations of financial markets.

SIMULATIONS OF FINANCIAL MARKETS

Chaos, Solitons and Fractals 125 (2019) 13–16



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Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos



Simulation of a financial market: The possibility of catastrophic disequilibrium

Amit Sinha^a, Philip A. Horvath^a, Tyler Beason^b, Kelly R. Roos^{c,*}

Fig. 2. A 3D plot of p and D_{ex} as a function of time, including the $D_{ex} - p$ phase space plane, produced using parameter values that were identical to those used to produce the stable solutions of Fig. 1, but with α equal to 1.05.

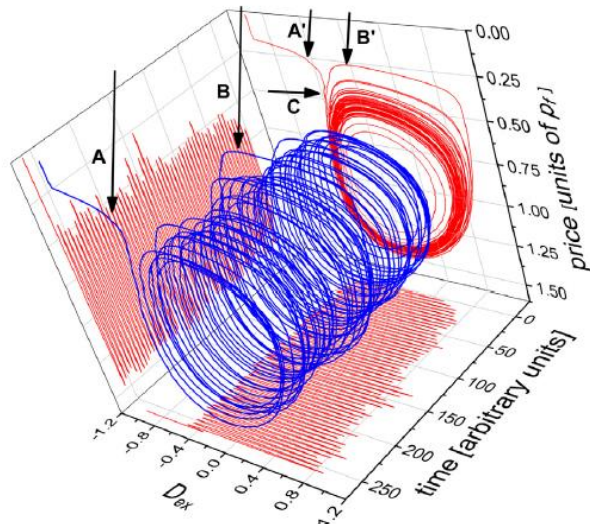


Fig. 3. A 3D plot of p and D_{ex} as a function of time, including the $D_{ex} - p$ phase space plane, from kMC simulations using parameter values that were identical to those used to produce the stable solutions of Fig. 2.

We have revealed a catastrophic market event, that displays the clear harbinger of an imminent crash (a dragon-king), by applying kMC simulations to solve an agent-based model [8–10], thus revealing extreme behavior that had not been observed in other solutions. The stochastic nature of the kMC simulation technique has much potential for broader application in modeling financial markets. The next important step in this research area, especially as applied to financial markets, is identification of tangible observables that can be positively associated with emergent behavior identified as unstable or, as greatly deviating from normal. For instance, by implementing an appropriate time scale, and identifying matches between model variables and actual data, the possibility of catastrophic financial events could be forecast at the daily level, such as the more than thousand point drop in the Dow Jones Industrial Average on February 5, 2018, the long-term disequilibrium in asset price leading to a great depression in 1929, or the great recession in 2008.

POTENTIAL JOBS

QUANTITATIVE ANALYST (STOCK EXCHANGE)

INSURANCE ACTUARY

DATA ANALYST

RISK AND CRISIS MANAGEMENT

QUALITY AND CONTROL

FINANCES IN GENERAL

- UNIV. FRIBURGO

- UNIV. SILESIA

- CNR

<https://wwwold.iac.cnr.it/~filippo/projects/econophysics.html>

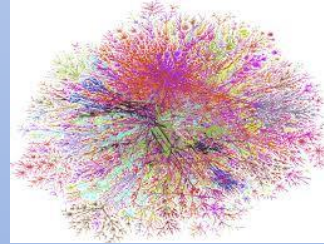
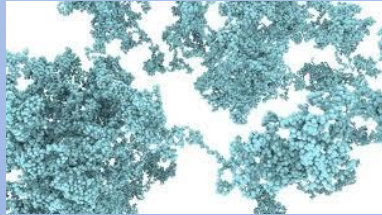
**THANKS A LOT
FOR YOUR
ATTENTION**



“I also have trouble sleeping. I don’t understand why. No one I talk to seems to have any trouble falling asleep.”

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MLR	4.76	0.53	11.2%	1.21	1.21	1.21
MAL	2.82	0.27	9.5%	1.21	1.21	1.21
ME	3.84	0.21	5.5%	1.21	1.21	1.21
MV	2.98	-0.21	-7.0%	1.21	1.21	1.21
CTVV	9.13	-0.05	-0.5%	1.21	1.21	1.21
HYOS	11.61	-0.05	-0.4%	1.21	1.21	1.21
PLUG	21.14	-0.11	-0.5%	1.21	1.21	1.21
ESLR	26.37	-0.04	-0.1%	1.21	1.21	1.21
LFT	62.20	0.53	0.8%	1.21	1.21	1.21
CD	21.77	0.13	0.6%	1.21	1.21	1.21
IOC	26.6	-0.35	-1.3%	1.21	1.21	1.21
TT	19.59	0.09	0.4%	1.21	1.21	1.21
	49.86	-0.16	-0.3%	1.21	1.21	1.21
	39.16	0.22	0.6%	1.21	1.21	1.21



ECONOPHYSICS

Data Science in Fundamental Physics
and the bridge to industry & society

SANTIAGO DE COMPOSTELA, GALICIA, SPAIN 3 – 7 JUNE 2024

Luis Miguel Varela

Condensed Matter Physics

Dpto. Física de Partículas

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