

Complexity and statistical physics of herding behavior

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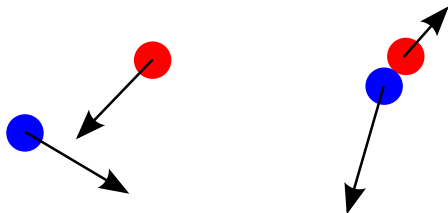
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January 2, 2015

XIX century: Demographics inspires Statistical Mechanics

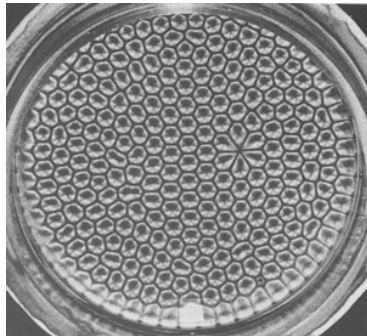
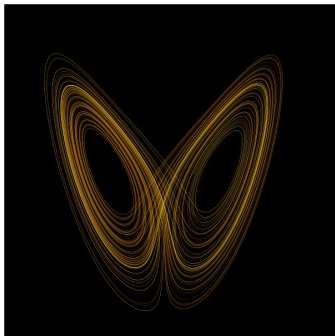
Demographics **neglects the behavior of individuals in favor of macroscopic behavior of populations.**

“**The molecules are like so many individuals**, having the most various states of motion, ...” (L. Boltzmann)



~1950: Open and non-equilibrium systems

Macroscopic dynamics of certain systems sometimes is **not sum nor average of the trajectories of its constituent parts**. Those systems tend to exhibit **emergent behavior**.



Images: Wikimol, idea.tion.to

Nature is self-similar (scale-free)

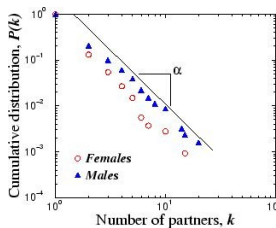
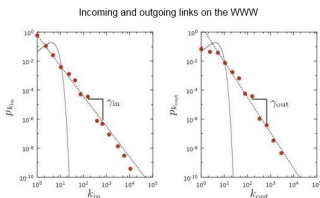
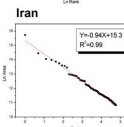
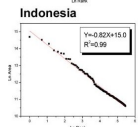
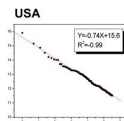
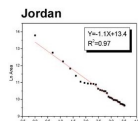
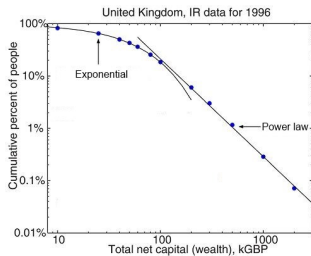


“Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line...” (B. Mandelbrot)

Image: Jacopo Wertherl

Scale-free features of socio-economic systems

Power law functions, $f(x) = x^{-\lambda}$, lack scale: $f(ax) = a^{-\lambda}f(x)$



Images: M. Patriarca and A. Chakraborti, CGU4U, A. Barabasi et al., F. Liljeros et al.

1995: H. E. Stanley coins term “Econophysics”

“The word tries, as anyone would guess, to coin something that reflects the fact that Econophysics is a little like Biophysics or Geophysics or Astrophysics which tells you that people involved in these fields are interested in Biology or Geology or Astronomy, which they connect from a Physics point of view.” (H. E. Stanley)



Image: APS

Meanwhile mainstream Economics achieves...

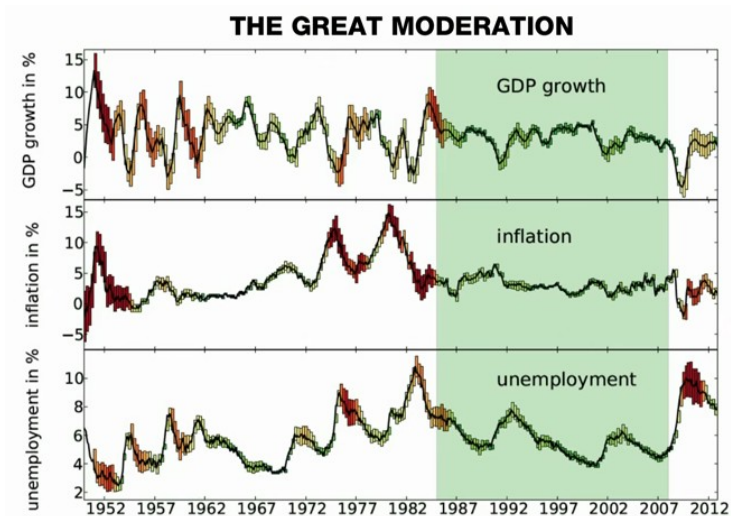
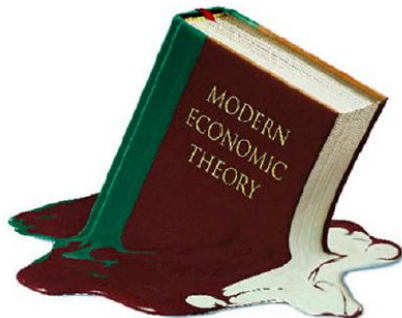


Image: D. Sornette

... everything breaks down with the 2007-08 crisis



**Where it went wrong—and how
the crisis is changing it**

Image: The Economist (July 2009)

Econophysicists feel somewhat happy about it (as well as nonmainstream economists)

nature International weekly journal of science

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Essay

Article 455, 1185 (20 October 2009) | doi:10.1038/4551185a Published online 29 October 2009

Economics needs a scientific revolution

See associated Correspondence: [Economics_Nature_532_147_2009_2009](#)

Jean-Philippe Bouchaud

Jean-Philippe Bouchaud is head of research of Capital Fund Management and a physics professor at cole Polytechnique in France. Email: jpbouchaud@polytechnique.fr

Economics engineers have put too much faith in untested axioms and faulty models, says Jean-Philippe Bouchaud. To prevent economic havoc, that needs to change.

Compared with physics, it seems fair to say that the quantitative success of the economic sciences has been disappointing. Rockets fly to the Moon; energy is extracted from minute changes of atomic mass. What is the flagship achievement of economics? Only its recurrent inability to predict and avert crises, including the current worldwide credit crunch.

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Vol 460 | 6 August 2009 nature

OPINION

The economy needs agent-based modelling

The leaders of the world are flying the economy by the seat of their pants, say **J. Doyne Farmer** and **Duncan Foley**. There is, however, a better way to help guide financial policies.

In today's high-tech age, one naturally assumes that US President Barack Obama's economic team and its international counterparts are using sophisticated quantitative computer models to guide us out of the current economic



pull society out of a recession; that, as rising prices had historically stimulated supply, producers would respond to the rising prices seen under inflation by increasing production and hiring more workers. But when US policy-

Proceedings of the National Academy of Sciences of the United States of America

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49 > Current issue < Vol. 115 no. 10 > Robert Frederick, 3753-3755

Agents of influence

Robert Frederick, Science Writer

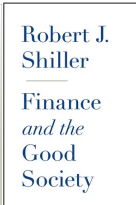
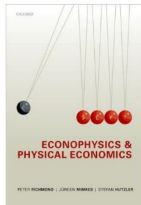
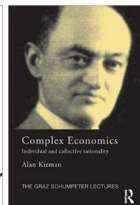
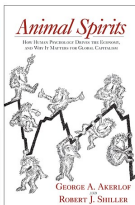
Models of complex systems have become a staple of business strategy, and now they are showing early promise for improving economic forecasts.

The European Physical Journal Special Topics
November 2010, Volume 214, 3699-1, pp 295-324

See: 01 Dec 2012

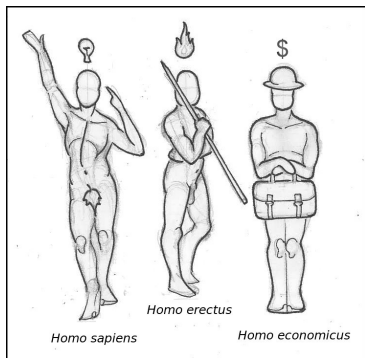
A complex systems approach to constructing better models for managing financial markets and the economy

J. Doyne Farmer, M. Galgani, C. Henkes, A. Kirman, P. Ormerod, S. Cincotti, A. Sanchez, D. Helmen



Images: (%_%)

So where it (most probably) went wrong?

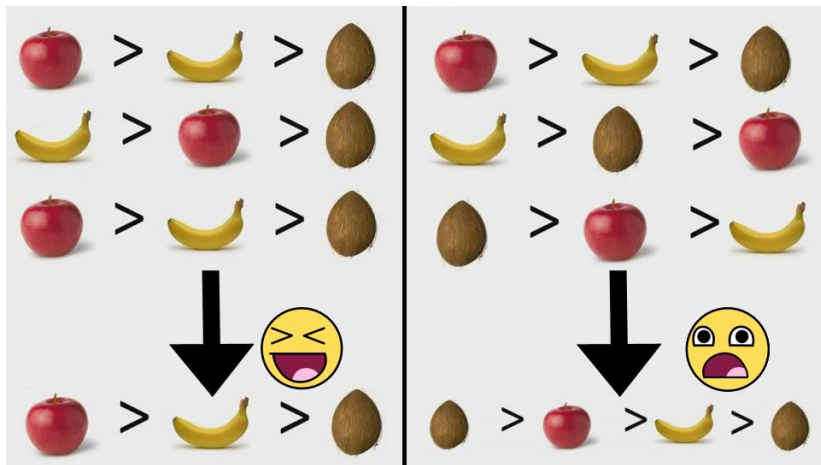


Homo economicus:

- has all relevant information (**is informed**),
- is able to process it (**is rational**),
- uses it towards his own well-being (**is self-interested**).

Image: keystriken

Condorcet paradox



Individual rationality does not imply collective rationality

People are not rational

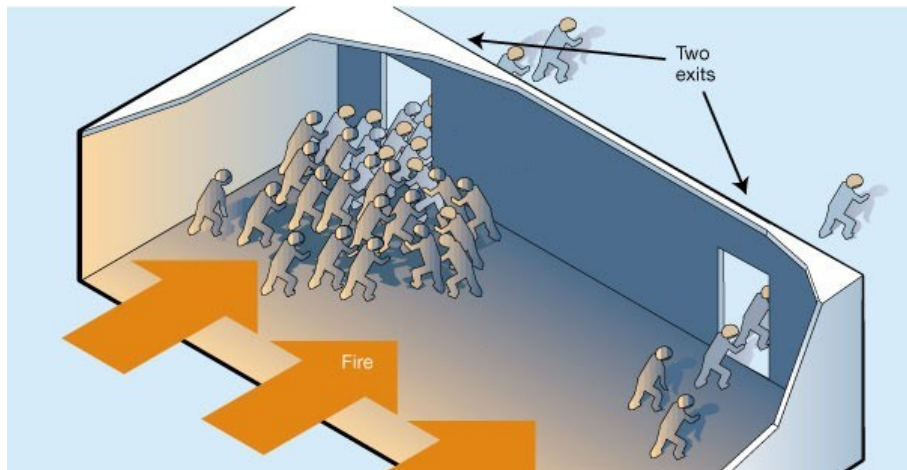


Image: D. J. Low

Nature is also not so rational

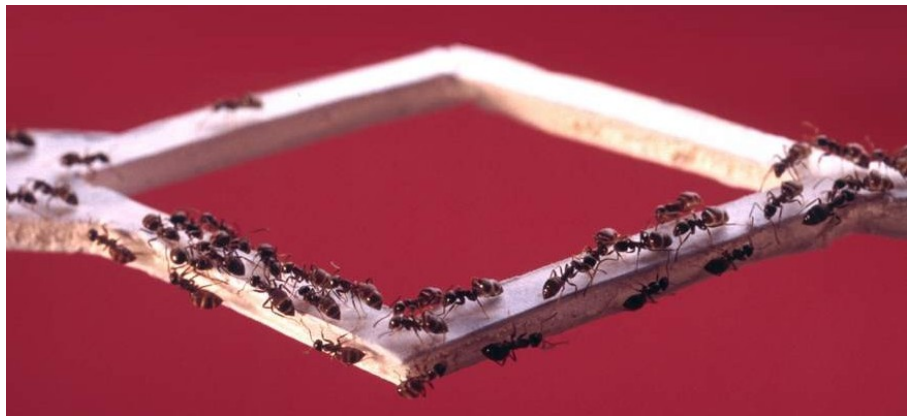
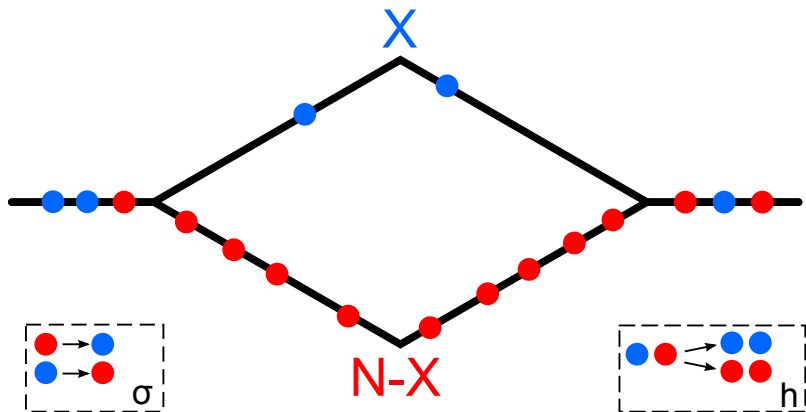


Image: C. Detrain & J. L. Deneubourg

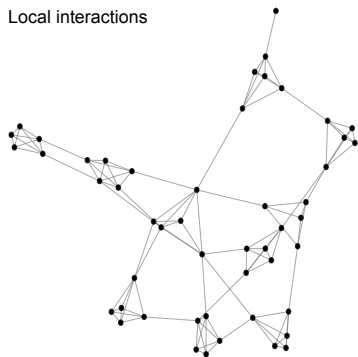
A simple agent-based herding model



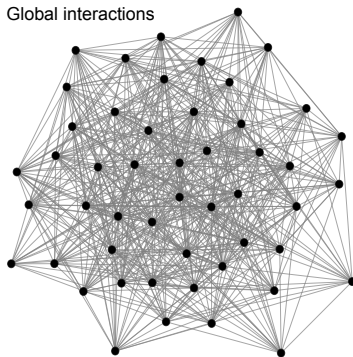
Kirman (Quarterly Journal of Economics, 1993)

The role of the interaction topology

Local interactions



Global interactions



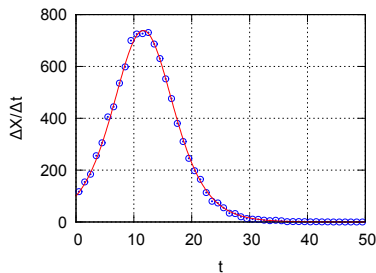
$$p(i \rightarrow j) = \left[\sigma_{ij} + h_{ij} \frac{X_j}{N^{1-\gamma}} \right] \Delta t.$$

Kononovicius & Ruseckas (EPJ B, 2014)

Diffusion of new products

$$p(\text{pot} \rightarrow \text{con}) = \left[\sigma_{\text{pot},\text{con}} + h_{\text{pot},\text{con}} \frac{X_{\text{con}}}{N} \right] \Delta t, \quad p(\text{con} \rightarrow \text{pot}) = 0,$$

here *con* - consumer state, *pot* - potential consumer state. Product is assumed to be durable.



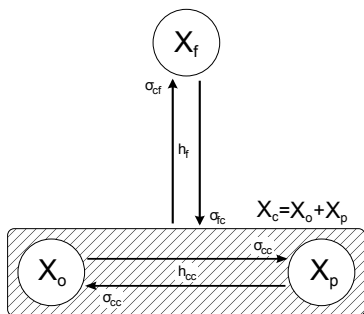
Red curve (macroscopic ODE):

$$\frac{d}{dt}X = [N - X(t)] \left[\sigma + h \frac{X(t)}{N} \right].$$

In marketing science - Bass diffusion.

Kononovicius & Daniunas (Social Technologies, 2013)

Financial market model



- Two “main” states:
 - fundamentalists (f),
 - chartists (c). $c \leftrightarrow f$ switching comparatively slow.
- Chartists may be either:
 - optimists (o),
 - pessimists (p). $o \leftrightarrow p$ switching comparatively fast.

$$p(i \rightarrow j) = \left[\sigma_{ij} + \frac{h_{ij}}{\tau(X_f, X_o, X_p)} X_j \right] \Delta t.$$

$\tau(\dots)$ - macroscopic system state feedback on micro-behavior.

Who is who?

Defining trading strategies



Chartists trade based on their “moods”, ξ :

$$D_c = r_0(X_o - X_p) = r_0 X_c \xi,$$

while fundamentalists based on their “knowledge”, P_f :

$$D_f = X_f [\ln P_f - \ln P(t)].$$

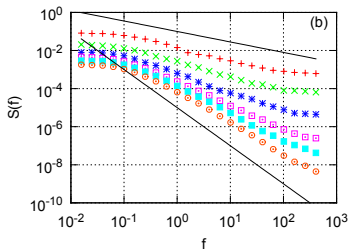
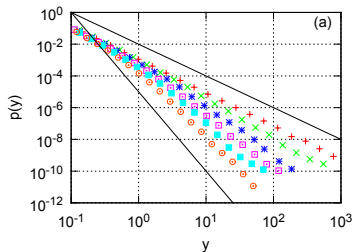
Assuming that their trading behavior balances out, we obtain return:

$$r(t) = \ln P(t) - \ln P(t - T) = r_0 \frac{X_c}{X_f} \Delta \xi.$$

Kononovicius & Gontis (Physica A, 2012); Image: Jeff Parker

Long-term component, $y = X_c/X_f$,

is enough to reproduce two stylized features: heavy tailed distribution ($p(y) \sim y^{-\lambda}$), long-range memory ($S(f) \sim 1/f$).



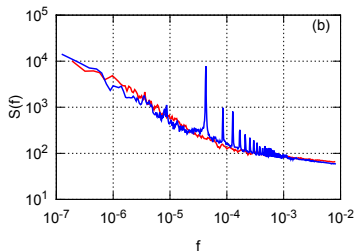
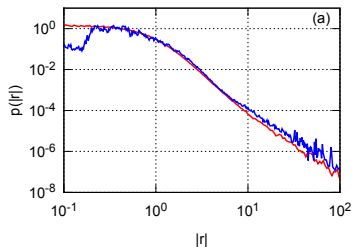
Macroscopic stochastic DE:

$$dy = [\sigma_{fc} + (2 - \sigma_{cf})y^{1+\alpha}](1 + y)dt + \sqrt{2hy^{1+\alpha}(1 + y)}dW.$$

Kononovicius & Gontis (Physica A, 2012)

Reproducing exact empirical statistical features

Considering slow y ($c \leftrightarrow f$) dynamics, fast ξ ($o \leftrightarrow p$) switching as well as additional noise (information flows, smaller scale dynamics) allows to reproduce exact PDF and spectra of the empirical data.

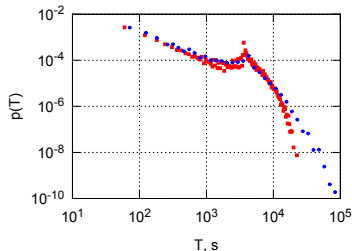


Macroscopic description consists of three SDE.

Gontis & Kononovicius (Plos One, 2014)

What else to say...

- Herding behavior itself seems to be enough to capture essential general features of the dynamics behind the financial markets.
- Importance of herding behavior in the financial markets might be used to prevent endogenous flash-crashes.
- Model parameters are selected to fit empirical PDF and spectra. Yet model is able to reproduce other statistical features, such as burst (above the threshold volatility) duration.



Thank you!



<http://mokslasplius.lt/rizikos-fizika/en/>