Black Swans, Dragons-Kings and PREDICTION

Didier SORNETTE

www.er.ethz.ch
SYNCHRONISATION AND COLLECTIVE EFFECTS IN EXTENDED STOCHASTIC SYSTEMS

Fireflies

Earthquake-fault model

FIG. 1. Evolution of the cumulative earthquake slip, represented along the vertical axis in the white to black color code shown above the picture, at two different times: (a) early time and (b) long time, in a system of size $L=90$ by $L'=90$, where $\Delta\sigma=1.9$ and $\beta=0.1$.

Miltenberger et al. (1993)
Generic diagram for coupled agents with threshold dynamics

Interaction (coupling) strength

Heterogeneity - diversity

SYNCHRONIZATION
EXTREME RISKS

Coexistence of SOC and Synchronized behavior

SELF-ORGANIZED CRITICALITY

INCOHERENT
“fat–tail events” ?
Self-organized criticality

Earthquakes Cannot Be Predicted
Robert J. Geller, David D. Jackson, Yan Y. Kagan, Francesco Mulargia
Science 275, 1616-1617 (1997)

(Bak, Tang, Wiesenfeld, 1987)

Turcotte (1999)
Grid = 50 x 50

Earthquakes Cannot Be Predicted
Robert J. Geller, David D. Jackson, Yan Y. Kagan, Francesco Mulargia
Science 275, 1616-1617 (1997)
Black Swan story

- Unknown unknowable event
  - ★ cannot be diagnosed in advance, cannot be quantified, no predictability

- No responsability (“wrath of God”)

- One unique strategy: long put and insurance
The Paradox of the 2007-20XX Crisis

(trillions of US$)

Source: IMF Global Financial Stability Report; World Economic Outlook November update and estimates; World Federation of Exchanges.
2008 FINANCIAL CRISIS

Non-Borrowed Reserves of Depository Institutions (BOGNONBR) continue to plummet. This makes sense as under capitalized banks continue to hemorrhage money via outright losses and write downs of over valued assets. The result is that these banks now have to borrow money from the Fed to maintain their reserves so that when you go to the ATM money actually comes out...

This also explains why all interbank lending rates from LIBOR and EURIBOR to HIBOR all did moonshots. You see, there were few banks capable of lending in any size, and even fewer willing.
2008 FINANCIAL CRISIS

Total Borrowings of Depository Institutions from the Federal Reserve (BORROW)
Source: Board of Governors of the Federal Reserve System

Shaded areas indicate US recessions.
2009 research.stlouisfed.org

March 2009
Crises are not
but
“Dragon-kings”
Most crises are “endogenous”

★ can be diagnosed in advance, can be quantified, (some) predictability

Moral hazard, conflict of interest, role of regulations

Responsibility, accountability

Strategic vs tactical time-dependent strategy

Weak versus global signals

http://www.businessweek.com/the_thread/economicsunbound/archives/2009/03/a_bad_decade_fo.html

Michael Mandel
Black Swan (Cygnus atratus)
Dragon-king story (for finance)

Dragon-king-outlier drawdowns

Require new different mechanism

Follow excesses ("bubbles")

Bubbles are collective endogenous excesses fueled by positive feedbacks

Most crises are "endogenous"

Possible diagnostic and predictions via "coarse-grained" metrics (forest versus trees)
Beyond power laws: 7 examples of “Dragons”

**Financial economics**: Outliers and dragons in the distribution of financial drawdowns.

**Population geography**: Paris as the dragon-king in the Zipf distribution of French city sizes.

**Material science**: failure and rupture processes.

**Hydrodynamics**: Extreme dragon events in the pdf of turbulent velocity fluctuations.

**Metastable states in random media**: Self-organized critical random directed polymers

**Brain medicine**: Epileptic seizures

**Geophysics**: Gutenberg-Richter law and characteristic earthquakes.
Crashes as “Black swans”?

Traditional emphasis on Daily returns do not reveal any anomalous events


“Black swans”
Better risk measure: drawdowns
“Dragons” of financial risks

A. Johansen and D. Sornette, Stock market crashes are outliers, European Physical Journal B 1, 141-143 (1998)


\[ N(DD) = A \exp \left( - \left( \frac{|DD|/\chi}{\gamma} \right)^\gamma \right) \].
“Dragons” of financial risks
(require special mechanism and may be more predictable)
10% daily drop on Nasdaq: 1/1000 probability

1 in 1000 days  =>  1 day in 4 years

30% drop in three consecutive days?

\[(1/1000)*(1/1000)*(1/1000) = (1/10000000)\]

=> one event in 4 millions years!
Positive feedbacks

- bubble phase
- crash phase

\[ \frac{dp}{dt} = cp^d \]

\[ p(t) = \left( \frac{c}{m} \right)^{-m} (t_c - t)^{-m} \]

\[ m = \frac{1}{d - 1} > 0 \text{ and } t_c = t_0 + \frac{1}{d - 1} \frac{\ln p_0}{c}. \]

Bubble preparing a crisis:
Faster than exponential transient transient unsustainable growth of price
Mechanisms for positive feedbacks in the stock market

• Technical and rational mechanisms
  1. Option hedging
  2. Insurance portfolio strategies
  3. Trend following investment strategies
  4. Asymmetric information on hedging strategies

• Behavioral mechanisms:
  1. Breakdown of “psychological Galilean invariance”
  2. Imitation (many persons)
     a) It is rational to imitate
     b) It is the highest cognitive task to imitate
     c) We mostly learn by imitation
     d) The concept of “CONVENTION” (Orléan)
Finite-time Singularity

as a result of positive feedbacks

- Planet formation in solar system by run-away accretion of planetesimals
- PDE’s: Euler equations of inviscid fluids and relationship with turbulence
- PDE’s of General Relativity coupled to a mass field leading to the formation of black holes
- Zakharov-equation of beam-driven Langmuir turbulence in plasma
- Rupture and material failure
- Earthquakes (ex: slip-velocity Ruina-Dieterich friction law and accelerating creep)
- Models of micro-organisms chemotaxis, aggregating to form fruiting bodies
- Surface instability spikes (Mullins-Sekerka), jets from a singular surface, fluid drop snap-off
- Euler’s disk (rotating coin)
- Stock market crashes...
Beyond power laws: 7 examples of “Dragons”


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**Fig. 7.** French agglomerations: stretched exponential and "King effect".

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Fig. 4. Frequency of elastic shocks under increasing stresses in materials with different heterogeneity. From Mogi [1962]
Energy distribution for the [+62] specimen #4 at different times, for 5 time windows with 3400 events each. The average time (in seconds) of events in each window is given in the caption.

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Mathematical Geophysics Conference  Extreme Earth Events
Villefranche-sur-Mer, 18-23 June 2000
Fig. 3.2. Apparent probability distribution function of the square of the fluid velocity, normalized to its time average, in the eleventh shell of the toy model of hydrodynamic turbulence discussed in the text. The vertical axis is in logarithmic scale such that the straight line, which helps the eye, qualifies as an apparent exponential distribution. Note the appearance of extremely sparse and large bursts of velocities at the extreme right above the extrapolation of the straight line. Reproduced from [252].
Pdf of the square of the Velocity as in the previous figure but for a much longer time series, so that the tail of the distributions for large Fluctuations is much better constrained. The hypothesis that there are no outliers is tested here by collapsing the distributions for the three shown layers. While this is a success for small fluctuations, the tails of the distributions for large events are very different, indicating that extreme fluctuations belong to a different class of their own and hence are outliers.

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FIG. 1. Typical set of optimal configurations for a RDP of length $W = 4096$ and for $0 \leq y \leq 1200$: (a) global system [gray framed boxes outline regions of succeeding plots such that the horizontal and vertical extensions of these boxes follow Eqs. (10) and (8) with $\alpha \approx 0.9$], (b) magnification of the largest box in (a), (c) magnification of the largest box in (b) and (d) magnification of the box in (c). Note, that at each grid point of the lattice we assign an independent random number drawn from an exponential distribution with unit mean and variance.
**Definition of “avalanches”**

**FIG. 2.** Schematic representation of optimal RDPs fixed at their two end points. An avalanche is defined by the area $S$ spanned by the transition from the optimal configuration at $y$ to $y + 1$, i.e., $S$ is the area interior to the perimeter formed by the union of the two optimal RDP configurations at $y$ and $y + 1$ and the two vertical segments $((0,y);(0,y+1))$ and $((W,y);(W,y+1))$. The successive avalanches are represented in different gray scales.
\[ P(S) dS \propto \frac{W^{2/3}}{S^{1+\mu}} dS, \]

\[ \mu = 2/5. \]

**FIG. 3.** Distribution \( P(S) \) of RDP avalanche sizes obtained numerically for system widths from \( W=8 \) to 512 on a log-log plot. Here the system lengths \( L \) are \( 2 \times 10^7 \) (for \( W=8 \)), \( 3 \times 10^6 (W=16) \), \( 2 \times 10^7 (W=32) \), \( 10^8 (W=64) \), \( 2 \times 10^8 (W=128) \), \( 5 \times 10^7 (W=256) \), and \( 9 \times 10^6 (W=512) \).

**FIG. 4.** \( P(S) \) as a function of the rescaled variable \( S/W^{2/3} \) for \( W=8-512 \) on a log-log plot.
Two characteristic scales and their scaling laws

FIG. 7. Estimated $W$ dependence of the three characteristic avalanche sizes, $S_{\text{up}}$, the upper limit for which $P(S)$ seems well approximated by a power law, is judged from Fig. 4 to have high and low values marked by $\nabla$ and $\triangle$, respectively (values taken at the midpoint of the triangle’s horizontal side). $S_{\text{bump}}$ (□) tracks the location of the bump of $P(S)$ and is here chosen as the position of the inflection point of the different distributions displayed in Fig. 3. $S_{\text{tail}}$, (●) represents the lower limit of the linear domain of the curves in Fig. 6. The solid line (proportional to $W^{5/3}$) and the dashed line (proportional to $W^{4/3}$) are included as guides.

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Epileptic Seizures – Quakes of the Brain?

with Ivan Osorio – KUMC & FHS
Mark G. Frei - FHS
John Milton - The Claremont Colleges

(arxiv.org/abs/0712.3929)
Gutenberg-Richter distribution of sizes

pdf of inter-event waiting times

The longer it has been since the last event, the longer it will be since the next one!
19 rats treated intravenously (2) with the convulsant 3-mercaptoproprionic acid (3-MPA)
Interaction (coupling) strength

Heterogeneity; level of compartmentalization

Coexistence of SOC and Synchronized behavior

SYNCHRONIZATION

EXTREME RISKS

SELF-ORGANIZED CRITICALITY

INCOHERENT

Heterogeneity; level of compartmentalization
Landau-Ginzburg Theory of Self-Organized Criticality and of Dragon-kings!

Dynamics of an order parameter (OP) and of the corresponding control parameter (CP): within the sandpile picture, $\frac{\partial h}{\partial x}$ is the slope of the sandpile, $h$ being the local height, and $S$ is the state variable distinguishing between static grains ($S = 0$) and rolling grains ($S \neq 0$).

Normal form of sub-critical bifurcation

$$\frac{\partial S}{\partial t} = \chi \{ \mu S + 2\beta S^3 - S^5 \} \quad (1)$$

where

$$\mu = \left[ \left( \frac{\partial h}{\partial x} \right)^2 - \left( \frac{\partial h}{\partial x} \big|_c \right)^2 \right] \quad (2)$$

and $\beta > 0$ (subcritical condition).

Diffusion equation

$$\frac{\partial h}{\partial t} = -\frac{\partial F(S, \frac{\partial h}{\partial x})}{\partial x} + \Phi \quad (3)$$

L. Gil and D. Sornette
Mechanism:
Negative effective Diffusion coefficient

System sizes range from \( L/a = 64 \) to 2048.

\[ P(M) dM \approx M^{-(1+\mu)} dM. \]
FIG. 3. Distribution $P(J)$ of flux amplitudes at the right border, in the same conditions as for Fig. 1.
Interaction (coupling) strength

Coexistence of SOC and Synchronized behavior

SYNCHRONIZATION
EXTREME RISKS

SELF-ORGANIZED CRITICALITY

INCOHERENT

Heterogeneity; level of compartmentalization
Low dose of convulsant in rats (like most humans)

Distribution of inter-seizure time intervals for rat 5, demonstrating a pure power law, which is characteristic of the SOC state. This scale-free distribution should be contrasted with the pdf’s obtained for the other rats, which are marked by a strong shoulder associated with a characteristic time scale, which reveals the periodic regime.
Interaction (coupling) strength

Heterogeneity; level of compartmentalization

Coexistence of SOC and Synchronized behavior

Synchronization

Extremal Risks

Self-organized criticality

Incoherent

Generic diagram for coupled threshold oscillators of relaxation
Generic diagram for coupled threshold oscillators of relaxation

Interaction (coupling) strength

Coexistence of SOC and Synchronized behavior

Heterogeneity; level of compartmentalization

SYNCHRONIZATION
EXTREME RISKS

SELF-ORGANIZED CRITICALITY

INCOHERENT

SYNCHRONIZATION
EXTREME RISKS

SELF-ORGANIZED CRITICALITY

INCOHERENT
The pdf’s of the seizure energies and of the inter-seizure waiting times for subject 21.

Note the shoulder in each distribution, demonstrating the presence of a characteristic size and time scale, qualifying the periodic regime.

Some humans are like rats with large doses of convulsant.
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Complex magnitude distributions

Characteristic earthquakes?

Singh, et al., 1983, BSSA 73, 1779-1796

Knopoff, 2000, PNAS 97, 11880-11884

Main, 1995, BSSA 85, 1299-1308

Wesnousky, 1996, BSSA 86, 286-291
1. Geosciences of the solid envelop
   1.1. Earthquake magnitude.
   1.2. Volcanic eruptions.
   1.3. Landslides.
   1.4. Floods. No protagonist found yet.

2. Meteorological and Climate sciences
   2.1. Rains, hurricanes, storms.
   2.2. Snow avalanches.

3. Material Sciences and Mechanical Engineering
   3.1. Acoustic emissions.
   3.2. Hydrodynamic turbulence.

4. Economics: financial drawdowns, distribution of wealth

5. Social sciences: distribution of firm sizes, of city sizes, of social groups...

6. Social sciences: wars, strikes, revolutions, city sizes

7. Medicine: epileptic seizures, epidemics

8. Environmental sciences: extinctions of species, forest fires
   8.1. Evolution and extinction of species.
   8.2. Forest fires.
Predictability of catastrophic events: Material rupture, earthquakes, turbulence, financial crashes, and human birth

D. Sornette
Generic Critical Precursors to a Bifurcation

Braxton hicks contractions

(Simple example of Catastrophe theory)

-Amplitude of fluctuations
-Response to external forcing

D. Sornette, F. Ferre and E. Papiernik
Mathematical model of human gestation and parturition: implications for early diagnostic of prematurity and post-maturity

Methodology for predictability of crises

Strategy: look at the forest rather than at the tree

Rocket-science application!

Our prediction system is now used in the industrial phase as the standard testing procedure.

J.-C. Anifrani, C. Le Floch, D. Sornette and B. Souillard
Hong-Kong

Red line is 13.8% per year: but
The market is never following the average
growth; it is either super-exponentially
accelerating or crashing

Patterns of price trajectory during 0.5-1 year before each peak: Log-periodic power law
Predictability of the 2007-XXXX crisis: 15y History of bubbles and Dragon-kings

- Real-estate bubbles (2003-2006)
- Commodities and Oil bubbles (2006-2008)

Didier Sornette and Ryan Woodard
The Internet stock index and non-Internet stock index the Nasdaq composite which are equally weighted.


The two indexes are scaled to be 100 on 1/2/1998.
Fig. 1. (Color online) Plot of the UK Halifax house price indices from 1993 to April 2005 (the latest available quote at the time of writing). The two groups of vertical lines correspond to the two predicted turning points reported in Tables 2 and 3 of [1]: end of 2003 and mid-2004. The former (resp. later) was based on the use of formula (2) (resp. (3)). These predictions were performed in February 2003.

Fig. 5. (Color online) Quarterly average HPI in the 21 states and in the District of Columbia (DC) exhibiting a clear upward faster-than-exponential growth. For better representation, we have normalized the house price indices for the second quarter of 1992 to 100 in all 22 cases. The corresponding states are given in the legend.
bubble peaking in Oct. 2007

Source: DS + R. Woodard (FCO, ETH Zurich)
CORN

GOLD

SOYBEAN

WHEAT

R.Woodard and D.Sornette (2008)
Typical result of the calibration of the simple LPPL model to the oil price in US$ in shrinking windows with starting dates $t_{\text{start}}$ moving up towards the common last date $t_{\text{last}} = \text{May 27, 2008}$.

The Global BUBBLE

PCA first component on a data set containing, emerging markets equity indices, freight indices, soft commodities, base and precious metals, energy, currencies...

(Peter Cauwels  FORTIS BANK - Global Markets)
Chinese Equity Bubble: burst in August 2009
K. Bastiaensen, P. Cauwels, D. Sornette, R. Woodard and W.-X. Zhou

Figure 1: Shanghai Composite Index with LPPL result.
FCO@ETH: Towards operational science of financial instabilities

- Main mission:
  - Identify bubbles

- Theory:
  - Positive feedback

- Deliverables
  - Weekly global bubble scan
  - Research, papers
  - Public forecasts
  - Digital timestamps

Didier Sornette, Maxim Fedorovsky, Stefan Riemann, Hilary Woodard, Ryan Woodard, Wanfeng Yan, Wei-Xing Zhou
The Financial Bubble Experiment
First Results (2 November 2009 - 3 May 2010)

D. Sornette, R. Woodard, M. Fedorovsky, S. Reimann, H. Woodard, W.-X. Zhou
(The Financial Crisis Observatory)
Department of Management, Technology and Economics,
ETH Zurich, Kreuzplatz 5, CH-8032 Zurich, Switzerland
Final remarks

1-All proposals will fail if we do not have better science and better metrics to monitor and diagnose (ex: biology, medicine, astronomy, chemistry, physics, evolution, and so on)

2-Leverage as a system variable versus the illusion of control by monetary policy, risk management, and all that

3-Need to make endogenous policy makers and regulators (“creationist” view of government role, illusion of control and law of unintended consequences of regulations)

4-Fundamental interplay between system instability and growth; the positive side of (some) bubbles

5-Time to reassess goals (growth vs sustainability vs happiness). In the end, endogenous co-evolution of culture, society and economy

KEY CHALLENGE: genuine trans-disciplinarity by TRAINING in 2-3 disciplines + CHANGE OF CULTURE
WHAT IS A BUBBLE?

Academic Literature: No consensus on what is a bubble...

For each paper that finds evidence of bubbles, there is another one that fits the data equally well without allowing for a bubble.
We are still unable to distinguish bubbles from time-varying or regime-switching fundamentals, while many small sample econometrics problems of bubble tests remain unresolved.

Professional Literature: we do not know... only after the crash
“We, at the Federal Reserve…recognized that, despite our suspicions, it was very difficult to definitively identify a bubble until after the fact, that is, when its bursting confirmed its existence… Moreover, it was far from obvious that bubbles, even if identified early, could be preempted short of the Central Bank inducing a substantial contraction in economic activity, the very outcome we would be seeking to avoid.”
THE FINANCIAL BUBBLE EXPERIMENT
advanced diagnostics and forecasts of bubble ends

- **Hypothesis H1**: financial (and other) bubbles can be diagnosed in real-time before they end.

- **Hypothesis H2**: The termination (regime change) of financial (and other) bubbles can be bracketed using probabilistic forecasts, with a reliability better than chance.
Methodology for diagnosing bubbles

- Positive feedbacks of higher return anticipation
  - Super exponential price
  - Power law “Finite-time singularity”

- Negative feedback spirals of crash expectation
  - Accelerating large-scale financial volatility
  - Log-periodic discrete scale-invariant patterns
The Financial Bubble Experiment: 
advanced diagnostics and forecasts of bubble terminations

D. Sornette, R. Woodard, M. Fedorovsky, S. Reimann, H. Woodard, W.-X. Zhou
(The Financial Crisis Observatory)*

Department of Management, Technology and Economics,
ETH Zurich, Kreuzplatz 5, CH-8032 Zurich, Switzerland

<table>
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TABLE I: Checksums of Financial Bubble Experiment forecast documents.

## Checksums of forecast documents

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Brazil IBOVESPA

Gold spot price - USD

Merrill Lynch European Bond Index

Cotton future - USD
Brazil IBOVESPA

Forecast

Realized
Gold spot price - USD

Forecast

Realized
The Financial Bubble Experiment:
Advanced Diagnostics and Forecasts of Bubble Terminations
Volume II—Master Document

D. Sornette, R. Woodard, M. Fedorovsky, S. Reimann, H. Woodard, W.-X. Zhou
(The Financial Crisis Observatory)*
Department of Management, Technology and Economics,
ETH Zurich, Kreuzplatz 5, CH-8032 Zurich, Switzerland
(Dated: May 12, 2010)

This is the second installment of the Financial Bubble Experiment. Here we provide the digital
fingerprint of an electronic document [1] in which we identify 7 bubbles in 7 different global assets;
for 4 of these assets, we present windows of dates of the most likely ending time of each bubble. We
will provide that document of the original analysis on 1 November 2010.

7 new forecasts published 12 May 2010

The checksums of the analysis document [1] that contains the names of the 7 assets are:

<table>
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<tr>
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TABLE I: Checksums of Financial Bubble Experiment forecast document.
• A defense of trans-disciplinarity

• Out-of-equilibrium view of the world (social systems, economics, geosciences, biology...)

• Dragon-kings as extreme events are the rule rather than the exception. Their study reveal important new mechanisms.

• Crises are predictable
Further Reading


SCALE INVARIANCE AND BEYOND

1997
Theory of Zipf’s Law and Beyond

Yannick Malevergne
Alex Saichev
Didier Sornette

2009

Springer