Dynamical Diagnosis and Solutions for Resilient Natural and Social Systems

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www.er.ethz.ch
Big problems are piling up...
The “problem” of the post-financial crisis

Implosion of major banks
(bank market value)

Q2 2007 to 20 Oct. 2008
The “problem” of the post-financial crisis
The “problem” of the post-financial crisis

Derivatives, notional amounts outstanding, $trn

- Exchange-traded options
- Exchange-traded futures
- Foreign exchange
- Interest rate
- CDS*
- Other OTC

Source: Bank for International Settlements

*Credit-default swap
†Over the counter
The “problem” of sovereign debts

Gross debt to GDP, 1980-2016

(Niall Ferguson, 2012)
The faces of malnutrition
The “problem” of the “epidemics” of obesity and chronic diseases

The natural history of childhood overweight/obesity using IOTF cut-offs in Australia over the last century and regional global increases

Norton K et al, Int J Ped Ob 2006


(Philip James, 2010)
The “problem” of aging

UN forecasts: percentage people over 60 years
The energy problem

• Econometric analysis of growth in the USA, Japan, and Germany between 1960 and 1996 shows that energy drives about 50% of economic growth.

• Mainstream economics, on the other hand, gives energy only a weight of 5% according to energy's share in the total cost of the production factors capital, labor and energy.

The water problem

Current contribution per water resource to water used for irrigated crops (gross crop water demand in irrigated areas) for major groundwater users. Background shows a map of nonrenewable groundwater abstraction for irrigation. Labels indicate percentages of nonrenewable groundwater abstraction contributing to gross irrigation water demand (%). Sizes of pie charts are relative to amounts of gross crop water demand in irrigated areas among the countries shown.

The “problem” of soil erosion

*Figure 1.* About 50 mm of soil blown from cropland in Kansas during the winter of 1995–1996 (E.L Skidmore, USDA, Manhattan, KS., photo spring of 1996).

David Pimentel
Environment, Development and Sustainability (2006) 8: 119–137

*Figure 2.* Cloud of soil from Africa being blown across the Atlantic Ocean (Imagery by SeaWIFS Project, NASA/Goddard Space Flight Center and ORBIMAGE, 2000).
Humanity in the Anthropocene


Steffen, W., et al. 2004

Humanity in the Anthropocene

Johan Rockström (Stockholm Resilience Centre)

Steffen, W., et al. 2004
Species are becoming extinct at a rate of:
~ 4,000 – 30,000 species/year
~ 100/day
~ 1 species every 15 minutes

Extinction magnitudes of IUCN-assessed taxa in comparison to the 75% mass-extinction benchmark (International Union for Conservation of Nature)

Barnosky et al., Nature 471, 51-57 (2011)
The “problem” of Earth boundaries

Nitrogen flow
Agricultural land use
Phosphorus flow
Biodiversity loss
Climate Change
Chemical pollution
Atmospheric aerosol load
Freshwater consumption
Ocean acidity
Ozone depletion

Latest data
90-00
70-80
50-60
Pre-Ind.

Prof. Johan Rockström
Stockholm Resilience Centre
The “problem” of consuming 1.5 Earth’s Global Ecological Footprint:

Biodiversity, biocapacity and development

Living Planet Report 2010

Global Ecological Footprint: Human demand on the biosphere more than doubled between 1961 and 2007 (Global Footprint Network, 2010)
The “problem” of extreme industrial disasters

Deepwater Horizon oil spill (April 2010)

Fukushima-Daiichi (11 March 2011)
The “problem” of geo-political risks
The “problem” of ensuring social stability for responsible steering of sensitive industries and wastes (nuclear wastes, heavy metals, ...
Approaching a state shift in Earth’s biosphere and human systems

World human population
World GDP

`=> regime shift in 2030-2060
Has already started.`

A. Johansen and D. Sornette
Finite-time singularity in the dynamics of the world population and economic indices, Physica A 294 (3-4), 465-502 (2001)
Quantifying land use as one method of anticipating a planetary state shift. The trajectory of the green line represents a fold bifurcation with hysteresis. At each timepoint, light green represents the fraction of Earth’s land that probably has dynamics within the limits characteristic of the past 11,000 yr. Dark green indicates the fraction of terrestrial ecosystems that have unarguably undergone drastic state changes; these are minimum values because they count only agricultural and urban lands. The percentages of such transformed lands in 2011 come from refs 1, 34, 35, and when divided by 7,000,000,000 (the present global human population) yield a value of approximately 2.27 acres (0.92 ha) of transformed land for each person. That value was used to estimate the amount of transformed land that probably existed in the years 1800, 1900 and 1950, and which would exist in 2025 and 2045 assuming conservative population growth and that resource use does not become any more efficient. Population estimates are from refs 31–33. An estimate of 0.68 transformed acres (0.28 ha) per capita (approximately that for India today) was used for the year 1700, assuming a lesser effect on the global landscape before the industrial revolution. Question marks emphasize that at present we still do not know how much land would have to be directly transformed by humans before a planetary state shift was imminent, but landscape-scale studies and theory suggest that the critical threshold may lie between 50 and 90% (although it could be even lower owing to synergies between emergent global forcings). See the main text for further explanation.
Big problems are piling up...

Need for understanding their fundamental mechanisms...

to design robust strategies and solutions
Crises result from maturation towards an instability

Instead of Water Level:
-economic index (Dow-Jones etc...)

Crash = result of collective behavior of individual traders

(S. Solomon)
Critical Transitions

Peer pressure, leadership, complexity and homogeneity can influence critical transitions / shifts in group attitudes

A critical transition occurs if external conditions transform the stability landscape.

In this figure, the system moves from an underexploited to an overexploited state. The initial global minimum is transformed in a local basin of attraction up to a point where a small perturbation shifts it into the newly global minimum state.

(M. Scheffer, 2009)
Generically, close to a regime transition, a system bifurcates through the variation of a SINGLE (or a few) effective “control” parameter

**Bifurcation**: Qualitative change in behavior as parameter is (slowly) varied

**Bifurcation surface**: B

**Strategy 1**: understand from proximity to a reference point as a function of a small parameter

**Strategy 2**: a few universal “normal forms”

Space of all dynamical systems: $\mathcal{M}$

a particular dynamical system: $M \in \mathcal{M}$
<table>
<thead>
<tr>
<th>Precursors of codimension-one bifurcations (● local decay rate of transients → 0)</th>
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<tbody>
<tr>
<td><strong>Supercritical Hopf</strong></td>
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<tr>
<td><strong>Supercritical Neimark</strong></td>
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<td><strong>Supercritical flip</strong></td>
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<td><strong>Band merging</strong></td>
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<td><strong>Flow explosion</strong></td>
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<td><strong>Map explosion</strong></td>
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<td><strong>Intermittency expl: flow</strong></td>
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<td><strong>Regular interior crisis</strong></td>
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<td><strong>Static fold</strong></td>
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<td><strong>Saddle connection</strong></td>
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- **Linearly with control**
- **Linearly along folding path**
- **Linearly with control**
- **As for trigger (fold, flip, Neimark)**
  - Lingers near impinging saddle
- **Period of cycle tends to infinity**
  - Lingers near impinging saddle
  - Lingers near impinging saddle

_J Michael T Thompson (DAMTP, Cambridge)_
By classifying a system in a given regime, we can assert its degree of predictability.
Bifurcations, catastrophes, phase transitions, tipping points...

are associated with...

“dragon-king” extreme events!
Crisis are not black swans 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

POSITIVE FEEDBACKS

http://www.businessweek.com/the_thread/economicsunbound/archives/2009/03/a_bad_decade_for.html
Positive feedbacks

Bubble preparing a crisis:
Faster than exponential
transient unsustainable
growth of price
Paris as a dragon-king

Fig. 7. French agglomerations: stretched exponential and “King effect”.

Extreme risks: Dragon-kings vs Black Swans

1. Geosciences of the solid envelop
   1.1. Earthquake magnitude.
   1.2. Volcanic eruptions.
   1.3. Landslides.
   1.4. Floods.

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.
Signs of Upcoming Transition

Early warning signals as predicted from theory

- Slower recovery from perturbations
- Increasing (or decreasing) autocorrelation
- Increasing (or decreasing) cross-correlation with external driving
- Increasing variance
- Flickering and stochastic resonance
- Increased spatial coherence
- Degree of endogeneity/reflexivity
- Finite-time singularities
Financial Crisis Observatory

The Financial Crisis Observatory (FCO) is a scientific platform aimed at testing and quantifying rigorously, in a systematic way and on a large scale the hypothesis that financial markets exhibit a degree of inefficiency and a potential for predictability, especially during regimes when bubbles develop.

Current analysis and forecasts

**CDS** (19 February 2009)
Our analysis has been performed on data kindly provided by Amjed Younis of Fortis on 19 February 2009. It consists of 3 data sets: credit default swaps (CDS); German bond futures prices; and spread evolution of several key euro zone sovereigns. The date range of the data is between 4 January 2006 and 18 February 2009. Our log-periodic power law (LPPL) analysis shows that credit default swaps appear bubbly, with a projected crash window of March-May, depending on the index used. German bond futures and European sovereign spreads do not appear bubbly. (See report for more information.)

**OIL** (27 May 2008)
Oil prices exhibited a record rise followed by a spectacular crash in 2008. The peak of $145.29 per barrel was set on 3 July 2008 and a recent low of $40.81 was reached on 5 December, a level...
• **Hypothesis H1**: financial (and other) bubbles can be diagnosed in real-time before they end.

• **Hypothesis H2**: The termination of financial (and other) bubbles can be bracketed using probabilistic forecasts, with a reliability better than chance (which remains to be quantified).
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
Predictability of the 2007-XXXX crisis: 15y History of bubbles and Dragon-kings

- Real-estate bubbles (2003-2006)
- MBS, CDOs bubble (2004-2007)
- Stock market bubble (2004-2007)
- Commodities and Oil bubbles (2006-2008)

Didier Sornette and Ryan Woodard
Ex-ante diagnostic of bubbles and timing of crashes

- NASDAQ ICT 2000
- Real-estate UK mid-2004
- Real-estate USA mid-2006
- Oil July 2008
- S&P500 USA Oct. 2007
Ex-ante diagnostic of bubbles and timing of crashes

R. Woodard and D. Sornette (2008)
Ex-ante diagnostic of bubbles and timing of crashes

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)
Evolution of the project
The methodology has been developed and tested in the past fifteen years following different phases.

**Phase 1: Ex-post analysis of bubbles and crashes**
Development and testing of the methodology based on ex-post analysis of historical bubbles and crashes. A review can be found in the book “Why Stock Markets Crash”, or in the overview of publications on our website: [http://www.er.ethz.ch/publications/finance](http://www.er.ethz.ch/publications/finance)

**Phase 2: Ex-ante prediction of bubbles and crashes**
Prediction and publication, on an ad-hoc basis, of the risk of bubbles and crashes before the actual occurrence, examples:


**Phase 3: Ex-ante prediction in the FBE experiment**
The digital authentication key of a document with the forecasts is published on the internet. The contents of the document is only published after the event has passed to avoid any possible impact of the publication of the ex-ante prediction on the final outcome.
The results are published on [http://www.er.ethz.ch/fco/index](http://www.er.ethz.ch/fco/index)

**Phase 4: Manual Trading**
Getting out of the ivory tower of platonic modeling, testing, analyzing and publication. This is a real-money trading experiment with the purpose to thoroughly test and try to falsify our hypotheses in the Financial Markets Laboratory. This is the phase we are currently in. We trade equities, indices, ETFs, commodities and currencies. We use different strategies (hedged/unhedged, Long/Short, Spreads, Options, Gamma, Vol). The models are calibrated based on daily data series.

**Phase 5: Algorithmic Trading**
We are currently working on extending our manual trading into an automatic algorithmic trading process. This includes expanding our time resolution from daily data to intraday minute data. We want to apply this in liquid contracts like: equity index futures, EMINI, Bund Futures, Currencies, …
Investment Strategies as “CAT scan” Spectroscopy of Financial Markets to detect bubble regimes
Investment Strategies as “CAT scan” Spectroscopy of Financial Markets to detect bubble regimes
Are solutions requiring increasing complexity?

Innovations?

What about remembering well-known solutions?
Solutions for Financial and biological Health?

The problem of institutional and academic memory loss

• Glass-Steagall act (1933)

• Credit creation by banks (S. Keen, R. Werner,...)

The key question: is there evidence that the new financial innovations and a much expanded bank system has brought any real gain for innovations, economic development, employment?

Proposition: put back the banks at the service of the economy
Interaction (coupling) strength

By classifying a system in a given regime, we can assert its degree of predictability.

SYNCHRONIZATION
EXTREME RISKS

Coexistence of SOC and Synchronized behavior

SELF-ORGANIZED CRITICALITY

INCOHERENT

Heterogeneity - diversity
Resilience at the individual level

1) **Sleep**: Rest with quality sleep for a minimum of 7-8 hours per night;

2) **Love and sex**: Fall in love. Cultivate the romance and relationship; interrupt your work when needed with one minute of intense focus on the loved one, perhaps using romantic or sexy pictures of him/her to trigger happiness hormones that boosts brain performance and well-being. Make love as often as possible with your special partner.

3) **Deep breathing and daily exercises**: Start each of your day (no exception) with 5-10 minutes of exercises, including deep breathing-stretching followed by abdominal and finishing with a very short intense workout; perform a few 2-3 minutes of intense workouts and deep breathing at different times of your day in your office or wherever you happen to be in order to oxygen your body and refresh your brain;

4) **Water and chewing**: Drink at least 2 liters of water per day (no canned juice, no coke, no beer, no sugar) outside meals and drink minimally or not at all during meals (a small glass of red wine or cup of hot green tea is fine); “drink your food” and “eat your drinks”.

*Optimization of brain and life performance: Striving for playing at the top for the long run* (November 2011)
Resilience at the individual level

5) Fruits, unrefined products, food combination, vitamin D and sun exposure and no meat and no dairy: Eat as much fruits with water as possible on an empty stomach during the day, avoid meat and consume only unrefined products and cereals; avoid bad food combination to avoid conflicts between alkaline versus acid foods.


7) Play, intrinsic motivation, positive psychology and will: rediscover the *homo ludens* in yourself in things small and large so that work and life become a large playground, cultivate motivation as a self-reinforcing positive feedback virtuous circle.
If you want to be full of energy, avoid wounds and outperform in sports, Logic Workout is the 45 minutes per week training you need to face these life challenges.

(Paul-Emmanuel Sornette)

Logic Workout uniqueness and efficiency:
- it uses **unstable and asymmetric exercises**: individual muscles are not overtrained. Moreover all the fibers in the muscles are trained.

- there are no breaks: because exercises train different muscles each time, one group of muscles rests while another is training. And it trains endurance.

- each session is 45 minutes.

- One/two sessions per week is enough for amazing results.
Results and Stories

"How I build muscle for my leg after tendon surgery". Paul-Emmanuel Sornette

"How I can now do one hand pushups to rest, recuperating from a shoulder injury" Didier Sornette
Windsurfing with helicopter wind

Didier Sornette
130 miles from Nice France to Calvi Corsica waterskiing

Didier and Paul-Emmanuel Sornette
Big problems are piling up...

Suggested solutions:

- diagnose endogenous instabilities
- diversify
- decouple
- work on incentives and motivations
- “strengthen” individuals
Further Reading


D. Sornette and G. Ouillon, Dragon-kings: mechanisms, statistical methods and empirical evidence, European Physical Journal Special Topics (2012) (special issue on power laws and dragon-kings)


Endogeneity vs Exogeneity

**Extinctions**
- meteorite at the Cretaceous/Tertiary KT boundary
- volcanic eruptions (Deccan traps)
- self-organized critical events

**Financial crashes**
- external shock
- self-organized instability

**Immune system**
- external viral or bacterial attack
  - “internal” (dis-)organization

**Aviation industry recession**
- September 11, 2001
- structural endogenous problems

**Recovery after wars?**
- internally generated (civil wars)
- externally generated

**Discoveries**
- serendipity
- maturation

**Volatility bursts in financial time series**
- external shock
- cumulative effect of “small” news

**Earthquakes**
- tectonic driving
- triggering

**Parturition**
- mother/foetus triggered?
- mother-foetus complex?

**Commercial success and sales**
- Ads
- epidemic network

**Social unrests**
- triggering factors
- rotting of social tissue