The Physics of Finance?
Econophysics and Financial Market Reflexivity

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Chair of Entrepreneurial Risks

(partially based on collaborative work with Prof. Didier Sornette)

The Physics of Society
Philosophy of Econophysics and Complex Social Systems

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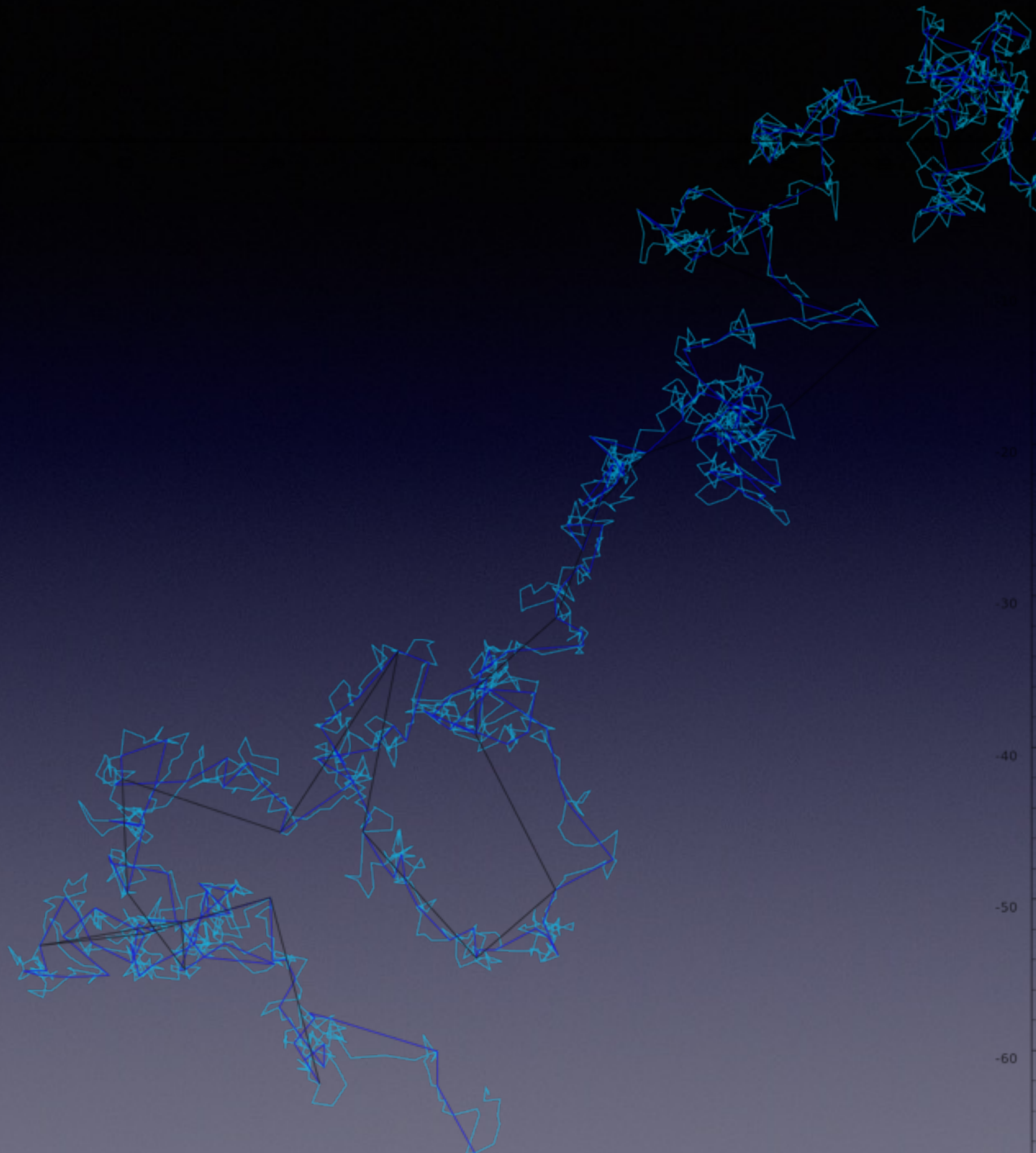
Entrepreneurial Risks

Can there be a physics of markets?

- **Outline**

1. “Physics Envy”
2. Booms, Bubbles and Busts: Reflexivity in Financial Markets
3. Quantifying Reflexivity? From Earthquakes to Markets
4. Conclusions

1. “Physics Envy”



- **Physics → Economics (18th-19th century):**
  - Isaac Newton's *Philosophiae Naturalis Principia Mathematica* (1687) → Adam Smith's *Inquiry into the Nature and Causes of the Wealth of Nations* (1776)
  - Pierre-Simon Laplace's *Essai philosophique sur la probabilities* (1812) and Adolphe Quetelet's "social physics" (1835): law-like regularities and predictability of social phenomena

- Michael Faraday’s field theory (1832) → William Stanley Jevons’ formulation of (marginal) utility theory (1871)
- James Clerk Maxwell and Ludwig Boltzmann’s (1871-1875) gas equilibrium → Leon Walras (1874/1877), Alfred Marshall and Francis Edgeworth’s development of economic equilibrium (1890) (cf. Sornette 2014)

- **Economics → Physics (20th Century):**
  - Vilfredo Pareto's (1897) power law distribution of incomes → distributions of events sizes in different scientific fields (cf. Bouchaud 2001)
  - Louis Bachelier's (1900) random walk model of Paris stock market → Einstein's theory of Brownian Motion (1905) (cf. Daniel and Sornette 2010)

- **Classical Thermodynamics and "Neoclassical" Economics**
  - 19th century classical thermodynamics → neoclassical economics (cf. Mirowski 1991; Beinhocker 2006)
  - Formal mathematical isomorphism between classical thermodynamics and economic systems (cf. Samuelson 1947)
  - Economic methodology modeled on classical thermodynamics → economics as deductive science (cf. Lo and Mueller 2010)

- **Some Organizing Principles of Neoclassical Economics**
  - i) optimizing behavior
  - ii) rational expectations
  - iii) stable market equilibria (market clearing, perfect competition, etc.)

- **“Neoclassical” Modeling-Assumptions**
  - Postulation of utility functions of economic agents
  - Assumptions about agents’ optimization strategies
  - Computation of equilibria (cf. Farmer 2013)

- **Rise of the Representative Agent**
    - Reduction of agent/strategy heterogeneity to one representative agent (similar to mean-field representations in thermodynamics) (cf. Gallegati and Kirman 1999; Sornette 2014)

- **A Static View of Economics**
  - Mathematization / axiomatization of economics / finance → divergence from 20th century physics (cf. Derman 2004)
  - Equilibria → static view of economic systems (closed systems, consisting of mathematically conserved quantities, heterogeneous agents and strategies) (cf. Farmer and Geanakoplos 2009)
  - Economics defined as science of allocation (cf. Beinhocker 2006)

- **A Dynamic View of Economics**
  - Economic theory updated by evolutionary biology, statistical physics, complex systems science → dynamic view of economic/financial systems (cf. Yakovenko 2009)
  - Economies/markets characterized in terms of out-of-equilibrium behavior, non-liner dynamics, heterogeneity, etc.
  - Economics redefined as science of formation (cf. Kirman 2011; Arthur 2013)

- **A New Scientific Understanding of Economic Systems**
  - the four “C’s” (cybernetics, chaos, catastrophe, complexity)
  - Complexity Economics
  - Behavioral/Evolutionary Economics
  - Econophysics

- **Econophysics (1996-2016)**
  - Similarity between social (economic) and natural (physical) systems
  - Application of methods, tools and concepts from statistical and condensed matter physics to economic / financial systems
  - Economies and markets conceptualized as multi-scale complex adaptive systems (evolution, non-linear dynamics, disequilibrium, universality, criticality, phase transitions, heterogeneity, emergent properties, etc.) (cf. Stanley and Mantegna 2004)

- **A Core Strategy in Econophysics**
    - identification and decomposition of system’s key components and networks
    - reproduction of low-level interactions and operations that generate higher-level collective self-organizing dynamics and non-trivial emergent patterns
    - simulation of system’s evolution and adaption (cf. Chakraborti et al. 2011; Schinckus 2012)

- **Achievements of Econophysics**
  - scaling laws in financial data
  - “criticality” and phase transitions (theories of market bubbles and crashes) (cf. Sornette 2003)
  - development of new models (minority games, agent-based modeling, evolutionary models, etc.) (cf. Challet et al. 2005; Chakraborti et al. 2011)
  - simulation / explanation of stylized facts (e.g., volatility clustering, leptokurtic returns distributions, absence of linear return correlations, etc.) (cf. Teyssière and Kirman 2005)

- **Some Features of Econophysics**
  - methodological diversification
  - data-driven model construction and validation
  - simulation and experimentation
  - lower levels of abstraction
  - higher degrees of freedom
  - realism (cf. Farmer 2013)

- **A Methodological and Epistemological (R)evolution**
  - Deviation from foundational assumptions of neo-classical economics / finance (equilibrium, market clearing, rational expectations, representative agents, exogenous volatility, etc.)
  - Integration of out-of-equilibrium phenomena, non-linearity, bounded rationality, heuristics and biases, collective social behavior (i.e., imitation and herding)
  - Application of non-Gaussian statistics and physics of critical phenomena (e.g., "long memory", heavy tails, Ising model of phase transitions , fluctuation-dissipation theorem) → extreme events (Sornette 2006)

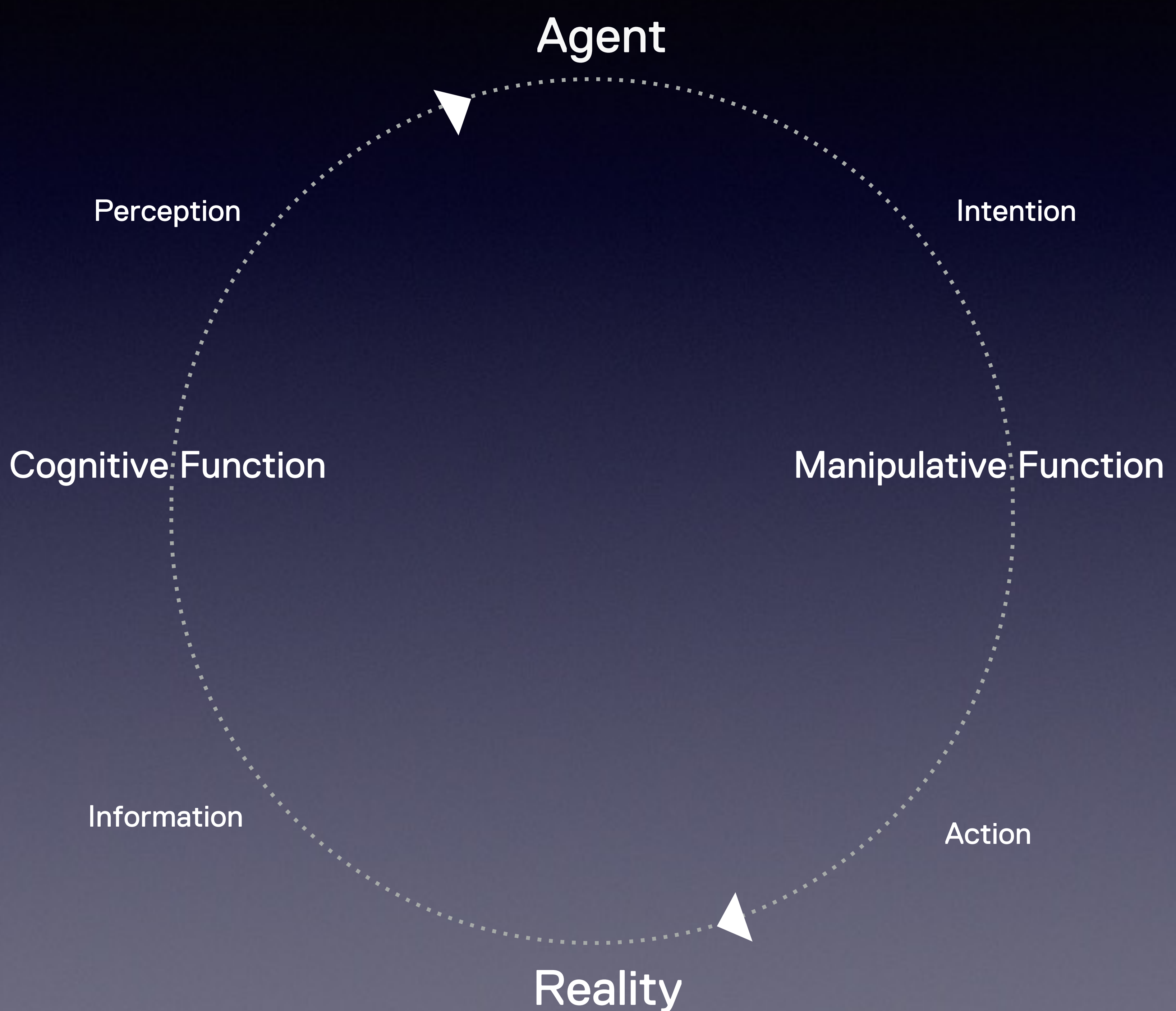
Agents $\equiv$ Particles ?

2. Booms, Bubbles and Busts: Reflexivity in Financial Markets

- **A Primer on Market Reflexivity**
  - Feedback mechanisms between expectations and prices
  - Self-reinforcing loops between trading, prices and volume
  - Price divergence from fundamental information

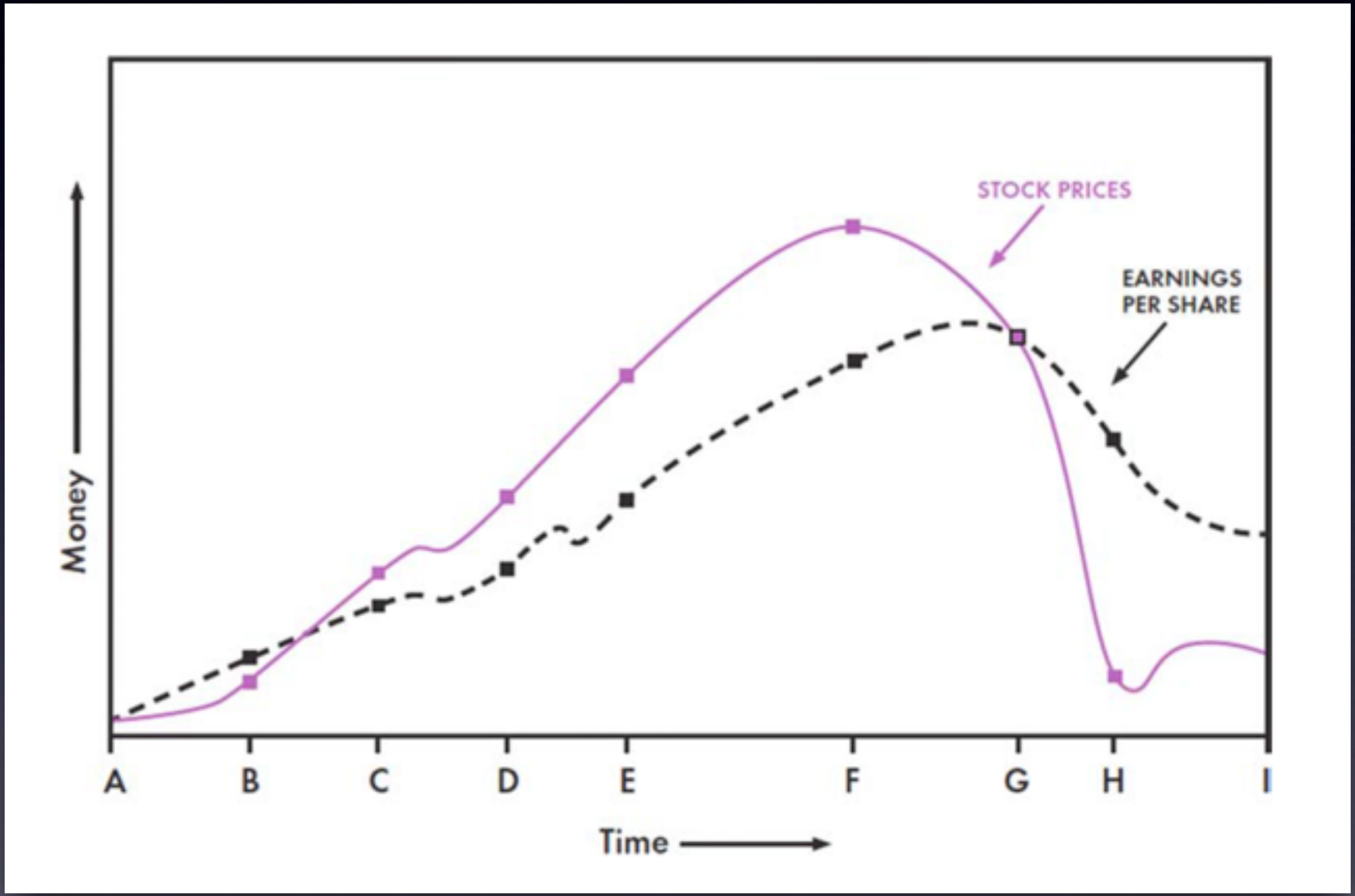
- **Soros on Reflexivity**
  - “[…] the participants’ view influence but do not determine the course of events, and the course of events influences but does not determine the participant’s view”
  - “reflexive processes cannot explained and predicted […] by natural science” (Soros 1987)
  - Reflexivity demands a new scientific method that is not physics-based (cf. Soros 2013)

- **A Reflexive System**



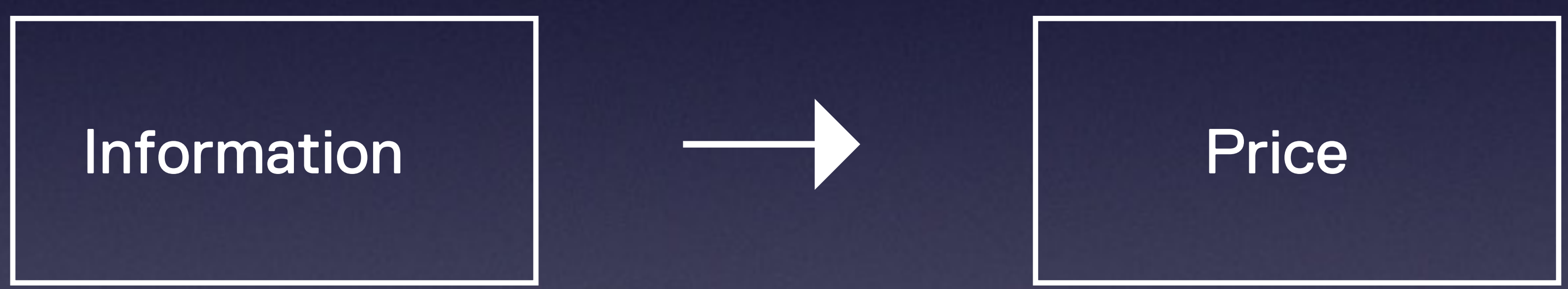
(adapted from Soros 2013)

- **Generic Boom-Bust Cycle**

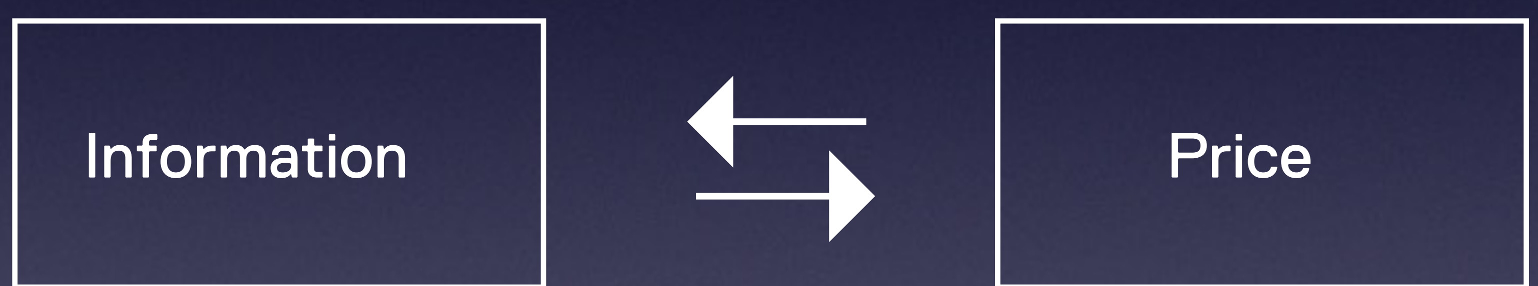


(form Soros 2013)

- Theory of Reflexivity vs. Efficient Market Hypothesis
  - Efficient Market Hypothesis



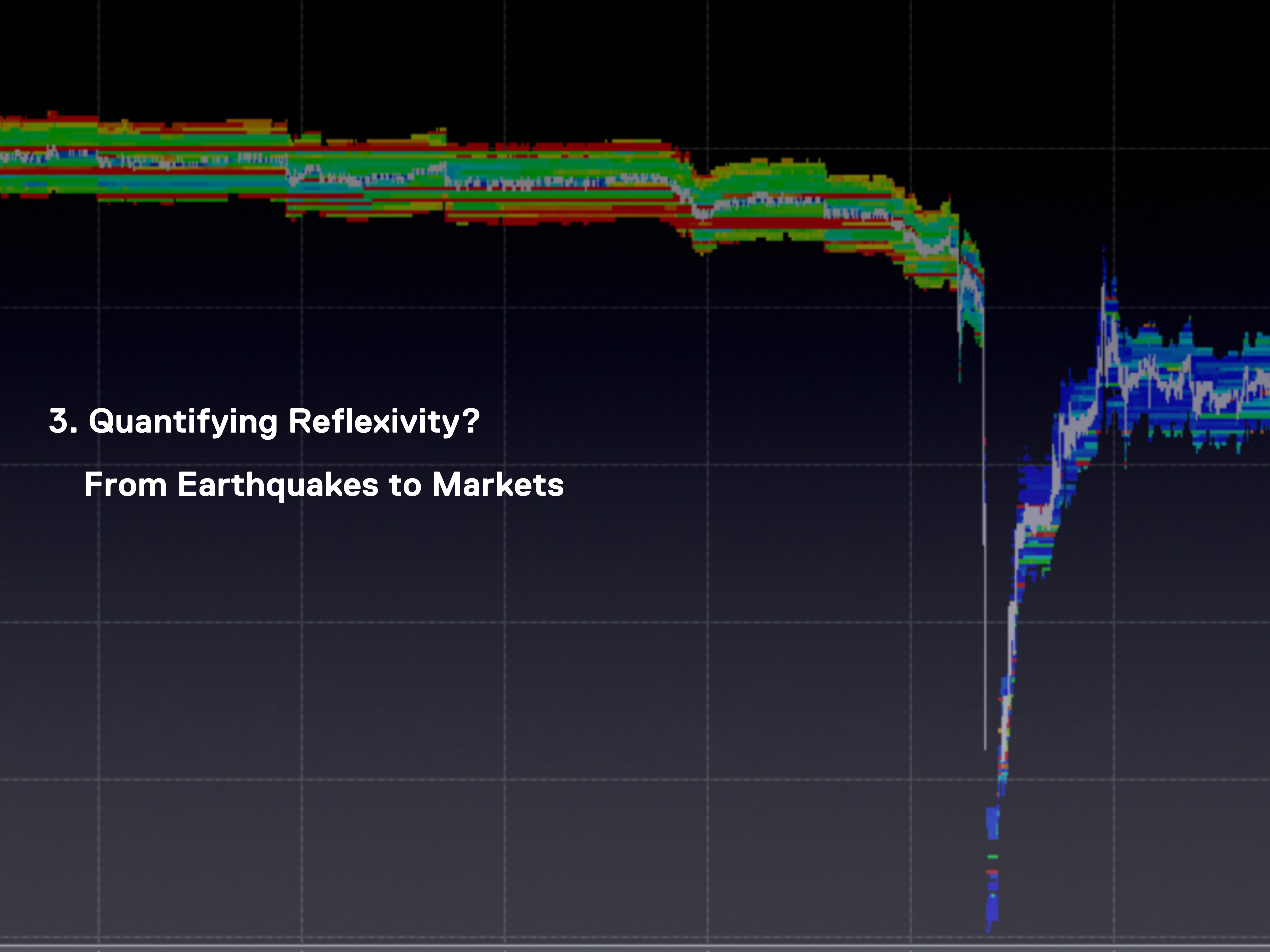
- Theory of Reflexivity



- **Market Anomalies**
  - "Momentum Effect"
  - "Excess Volatility Puzzle"

- **Sources of Reflexivity**
  - Hormonal mechanisms and cognitive biases (risk-aversion and risk-taking)
  - Collective social dynamics (informational cascades → imitation, herding)
  - Leverage, Margin Calls, Stop-loss orders, etc.
  - Synchronization of hedging and trading strategies in human, algorithmic and high-frequency trading (momentum, fundamental, etc.) (cf. Filimonov et al. 2013)
  - Reflexivity induced by human- and algorithmic-trading → "substrate-neutrality"

Can reflexivity be quantified?



3. Quantifying Reflexivity?

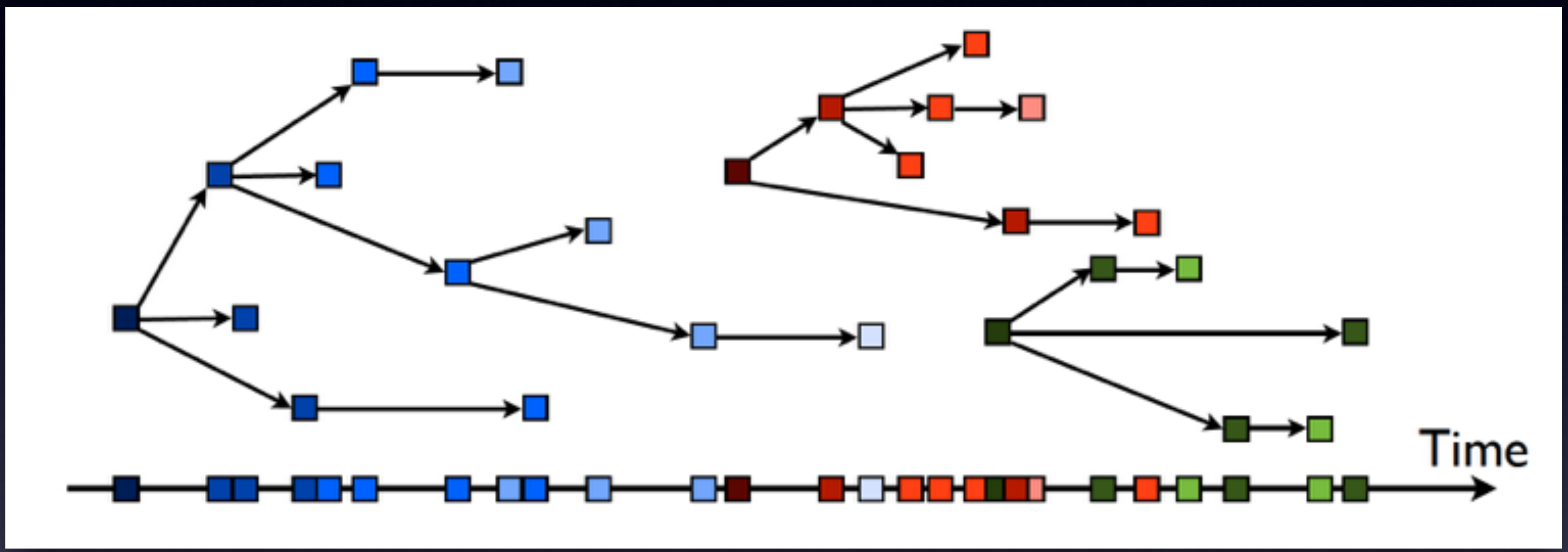
From Earthquakes to Markets

- **A Complex Systems View of Financial Markets**
    - Complex systems features: universality, criticality, emergence, etc.
    - Statistical physics in biology (networks, evolution, neurobiology, etc.), geology (earthquakes, volcanoes, erosions, etc.), climate modeling and social sciences (cognition, learning, etc.)
    - Endogenous vs. exogenous dynamics of complex systems (long-correlations, “memory”, self-excitement, etc.) (cf. Potters et. al. 1998; Sornette 2006; Bouchaud 2010; 2011)
    - Financial markets as geophysical systems (cf. “Omori law”→ volatility)

- **The Quantification of Financial Market Reflexivity**
  - Clustering and long-memory of asset price behavior
  - The self-excited Hawkes process: model used in geophysics to quantify Epidemic-Type Aftershock Sequences (ETAS) (cf. Filimonov and Sornette 2012; 2014; Filimonov et al. 2014)
  - Applications of Hawkes process in finance: high frequency price dynamics, order book arrival, critical events, etc. (cf. Law and Viens 2016)

- **Self-Excited Hawkes Processes**
    - In contrast to Poisson point processes – which model random point processes as having stochastic and memoryless properties – the Hawkes process is designed to quantify self- and cross-excitation (clustering, long-range dependencies, history) → self-excited conditional Poisson model (cf. Law and Viens 2016)

▪ Branching Structure of Earthquakes



- Key parameter for branching process: “branching ratio” (n) → average number of first-order events (“daughters”) per one zero-order event (“mothers”)

(from Filimonov 2012 ; cf. Filimonov and Sornette 2014)

- **Self-Excited Hawkes Processes Formalism**

$$\lambda(t) = \mu + n \sum_{t_i < t} \varphi(t - t_i)$$

Background intensity — Self-excitation part

$\lambda(t)$	Intensity of point process → conditional on its history
t_i	Timestamps of events in process
μ	Background intensity → exogenous events
$\varphi(t)$	Memory kernel function

(from Filimonov 2012)

- **Self-Excited Hawkes Processes: Endogeneity vs. Exogeneity**

$$\lambda(t) = \mu + n \sum_{t_i < t} \varphi(t - t_i)$$

Background intensity

Self-excitation part

- Self-Excited Hawkes process isolates external influences on the system μ from internal feedback mechanisms φ

μ Exogenous component

φ Endogenous / “reflexive” component

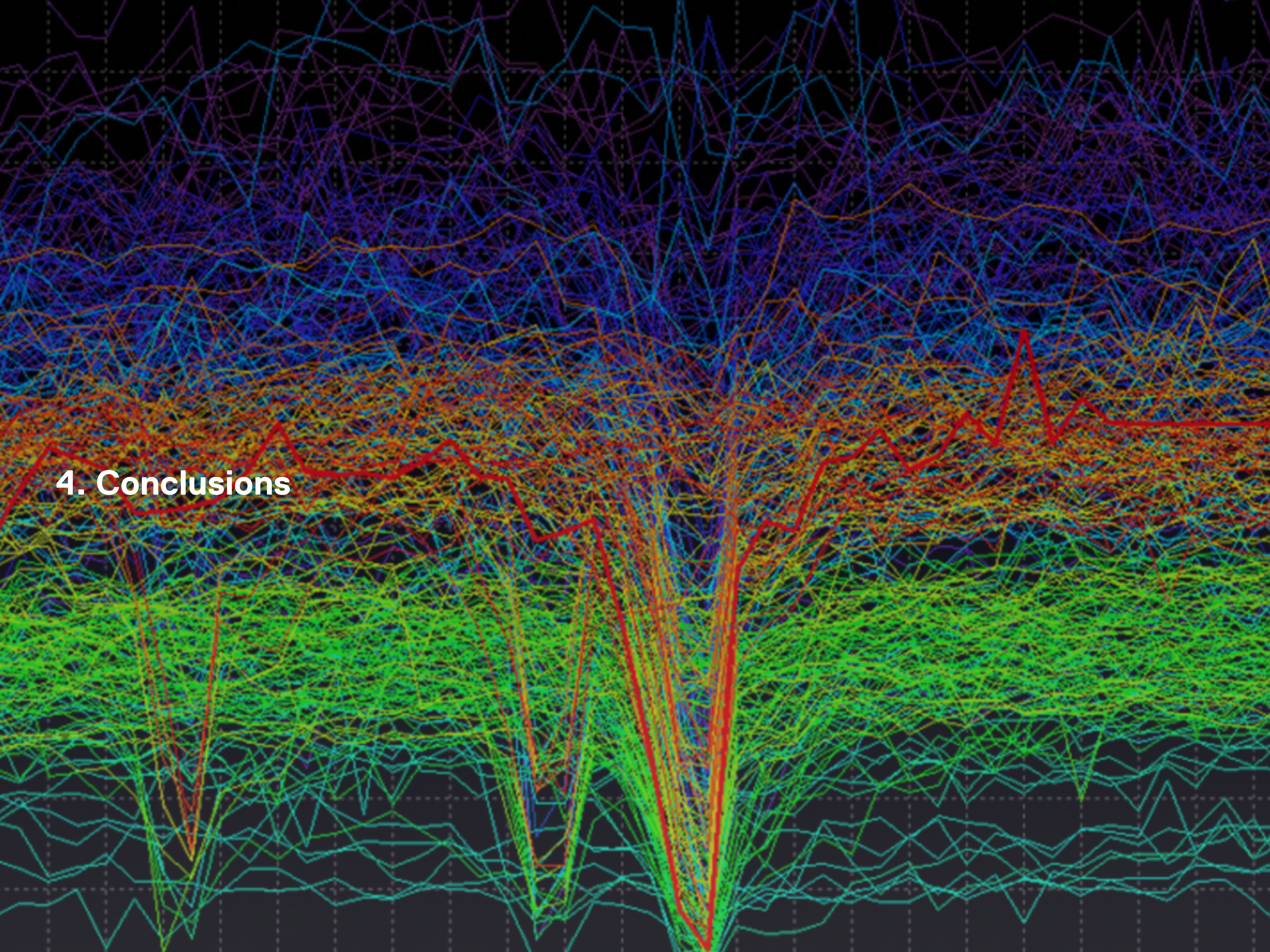
- **Self-excited Hawkes Process Applied to Financial HFT Data**

  Calibration of Hawkes process on time series of price changes in S&P 500 E-mini futures and several commodity futures market data shows (cf. Filimonov and Sornette 2012; 2014, Filimonov et al. 2014):

  - possibility to identify endogenous and exogenous dynamics in price behaviour
  - More than one out of two price changes is triggered by another price change, indicating a self-reinforcing reflexive mechanism

- Reflexivity-level does not depend on information-intensity about exogenous events
- Increased reflexivity → slower convergence of prices towards fundamental values → “inefficient” price-formation process
- Reflexive process enhances system’s sensibility to exogenous influences
- Endogenous feedback mechanisms in trading activity → amplification of small initial shocks that might cascade into large crashes (cf. Filimonov et. al 2014)

4. Conclusions



- Reflexivity can be quantified
- Application of Hawkes process model represents a first step in the quantification of reflexive market processes (cf. Filimonov and Sornette 2012; 2014, Filimonov et al. 2014)
- Scientific understanding of financial markets can be enhanced by methods, tools, and concept of physics
- Methodological compatibility / continuity of social and natural sciences → c.f. laws and regularities in physics and biology → reflexivity of biological / ecological phenomena (cf. Beinhocker 2013; Rosenberg 2013)

- Simplified analogies / extrapolations between physical and financial systems → danger of overgeneralizations

- Caution about unified theory of financial markets (cf. “self-organized criticality” (cf. Sornette 2002, Derman 2010)

- Certain classes of physics-based models are organized by formal analogies (cf. Frigg 2003)

- Analogizations between physical and social systems can stimulate new research and expand scientific knowledge

- Scientific understanding of financial markets should not exclusively have physics-based foundations → intersection of finance and the biological, cognitive and behavioral sciences (cf. Sornette 2014)
- Econophysics should not be considered as isolated from other scientific approaches
- A science of financial markets should include knowledge of other fields and extend beyond disciplinary boundaries

Thank you