Physics of socio–economic systems

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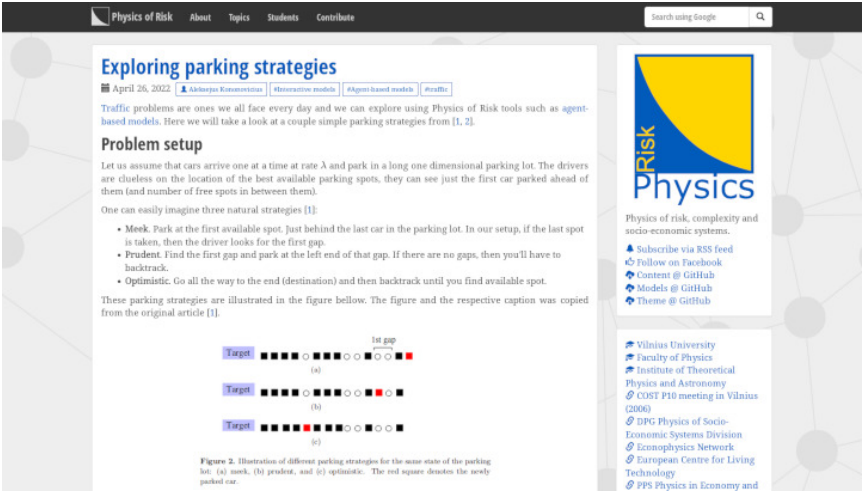
Faculty of Physics

Complex Physical and Social Systems Group

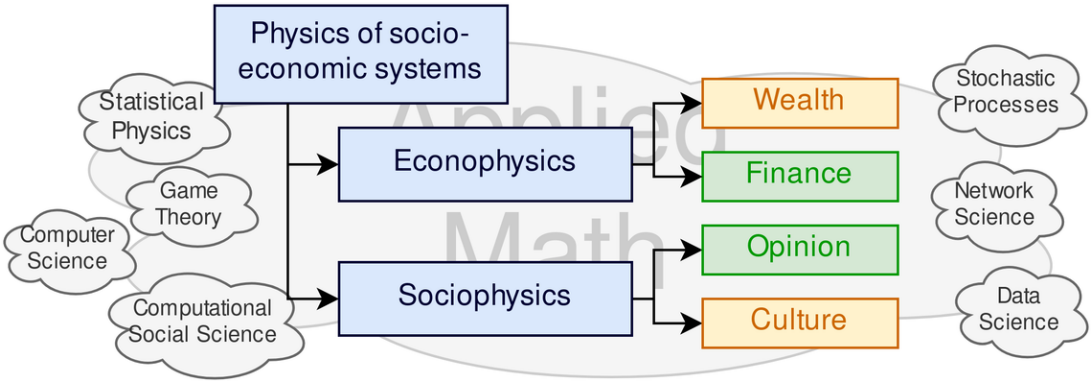
Info: VU Faculty of Physics website. Photos from public Facebook pages.

Physics of Risk blog



Website: https://rf.mokslasplius.lt

What this talk is about?

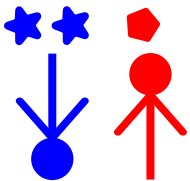


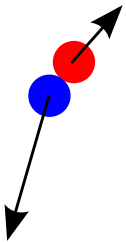
Made with diagrams.net

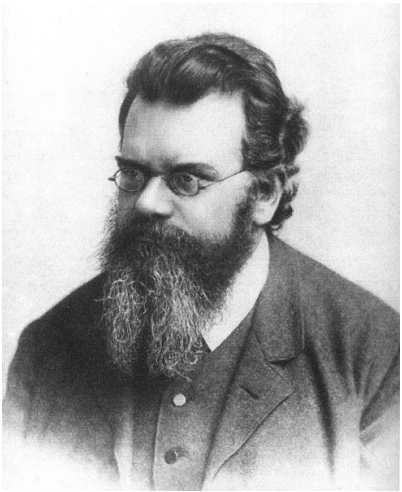
Historical context

XIX century: birth of Statistical Mechanics

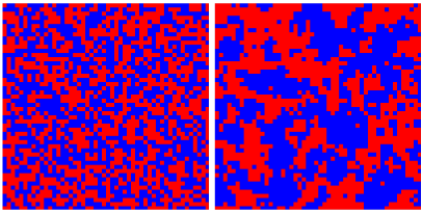
"**The molecules are like so many individuals**, having the most various states of motion, ..." (L. Boltzmann)





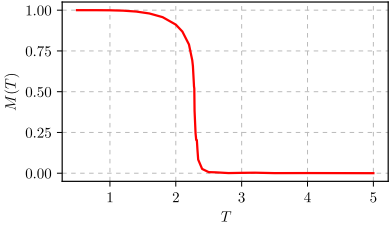


$\sim$ 1920s: Ising model



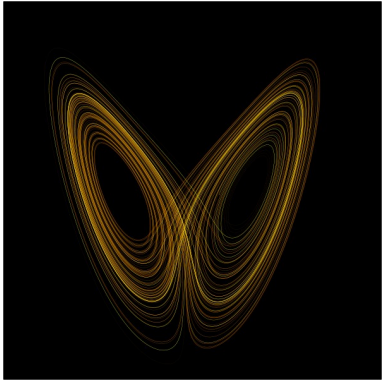
Magnetic spins align with their neighbors to minimize energy:

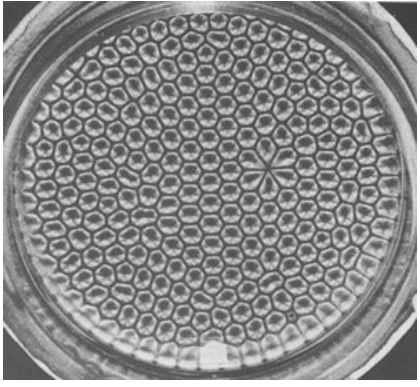
$$\mathcal{H} = -\frac{1}{2}\sum_{\langle i,j\rangle} J_{i,j}\vec{s}_i\vec{s}_j - \vec{H}\sum_i \vec{s}_i,$$



$\sim$ 1950s: Open and non-equilibrium systems

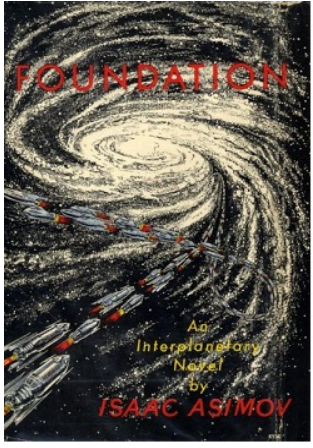
Macroscopic dynamics of certain systems sometimes is **nor sum nor average of the trajectories of its constituent parts**.

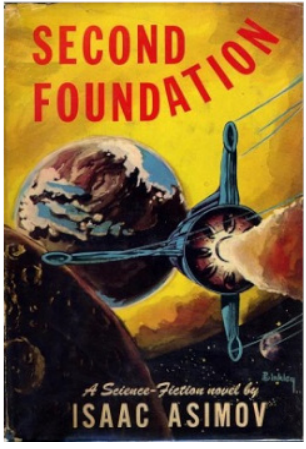




Figs.: Wikimol, idea.tion.to

∼ 1950s: Asimov's Foundation series





Figs.: Wikipedia [1, 2, 3]

1960s – 1970s: Self–similarity

“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)

Fig.: Jacopo Wertherl

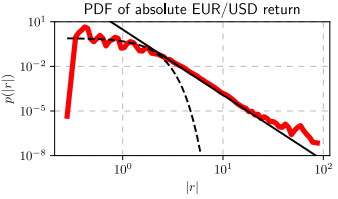
1980s – 1990s: availability of socio–economic data

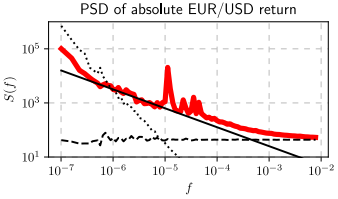
Discontent with financial policy making encourages exploration of economics from physical point of view:

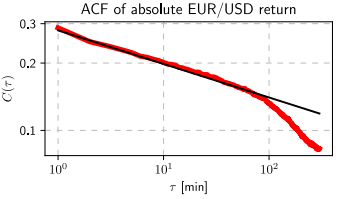
"Econophysics is a little like Biophysics or Geophysics or Astrophysics which tells you that people involved in these fields are interested in Biology or Geology or Astronomy, which they connect from a Physics point of view." (H. E. Stanley, 1995)

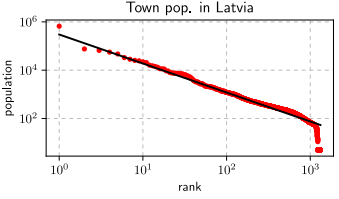
Fig.: KAL (Baltimore Sun)

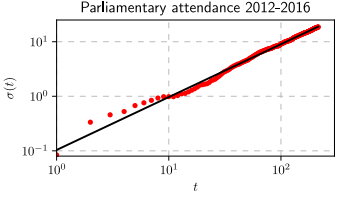
Self–similarity in financial and other social data

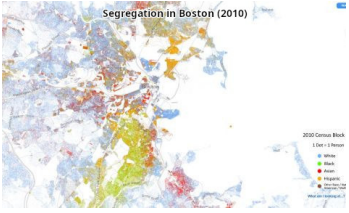








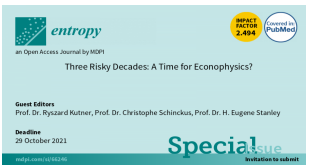




All black solid lines are $f(x) = x^s$. Power–laws are self–similar: $f(a \cdot x) = a^s f(x)$.

Data: histdata.com (Forex EUR/USD), data.stat.gov.lv (town pop. in Latvia), lrs.lt (attendance), demographics.coopercenter.org (segregation).

2020s: Researchers world–wide



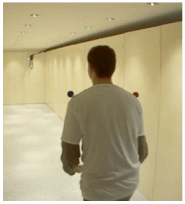
Generated using mapchart.net based on Econophysics Colloquim 2021, Entropy SI, FuturICT 2.0 and personal connections. Latvia: Riga Technical University.

Selected problems and models

Why do the traffic jams occur?

N–S model:

1. Cars accelerate one step up to v_{max}.
2. Slow down if collision imminent.
3. Slow down due to (random) error.

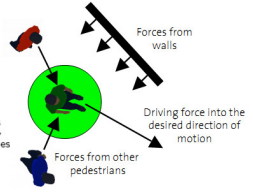


[Helbing & Molnar, 1995]

$$\underbrace{\frac{dx_\alpha}{dt} = v_\alpha(t)}_{\text{acceleration}} \quad \text{(equation of motion)}$$

$$\underbrace{\frac{dv_\alpha}{dt}}_{\text{acceleration}} = \underbrace{\frac{1}{\tau_\alpha}(v_\alpha^0 e_\alpha^0 - v_\alpha)}_{\text{driving force}} + \underbrace{\sum_{\beta(\neq\alpha)} F_{\alpha\beta}^{\text{int}}}_{\text{interactions}} + \underbrace{F_\alpha^{\text{walls}}}_{\text{boundaries}}$$

(acceleration equation)



Interactive model: Nagel–Schreckenberg model. Bottom: [Helbing “Pedestrians, Crowds, Disasters, and the Role of Self–Organization” (2010)].

Power–law distribution of wealth

1. Pick two agents i and j.
2. Assume transfer of wealth Δw from i to j:
$$\Delta w = (1-\varepsilon)\, w_i - \varepsilon w_j.$$
3. Adjust agents' wealth:
$$w_i := w_i - \Delta w,$$
$$w_j := w_j + \Delta w.$$

What if fraction of wealth is saved?

$$\Delta w = (1-\varepsilon)\,(1-\kappa_i)\, w_i - \varepsilon\,(1-\kappa_j)\, w_j.$$

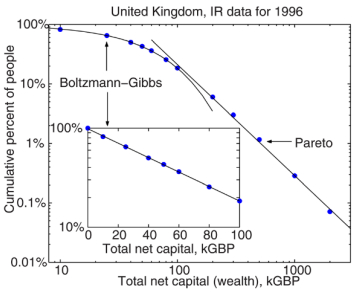
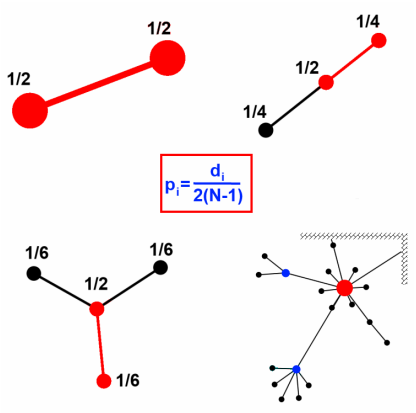


Fig. 1. Cumulative probability distribution of the net wealth, composed of assets (including cash, stocks, property, and household goods) and liabilities (including mortgages and other debts) in the United Kingdom shown on log-log (main panel) and log-linear (inset) scales. Points represent the data from the Inland Revenue, and solid lines are fits to the Boltzmann-Gibbs (exponential) and Pareto (power) distributions (Ref. 15).

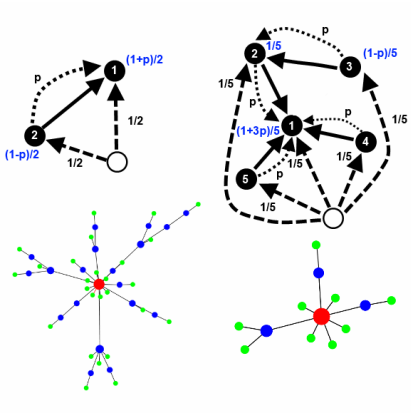
Fig.: [Patriarca & Chakraborti (2013)]; Interactive model: Kinetic model with heterogeneous saving.

Why are some papers extremely well cited?

Barabasi–Albert model

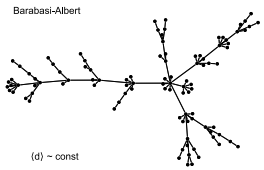


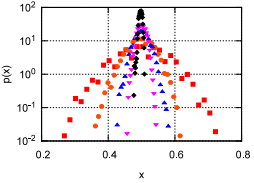
Edge redirection model

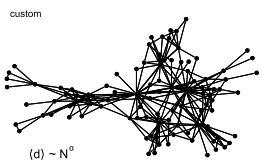


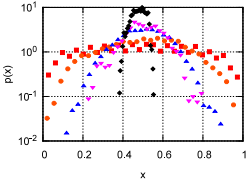
Interactive models: Barabasi–Albert model, Edge redirection model

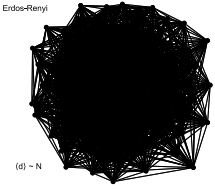
How do the networks impact dynamics?

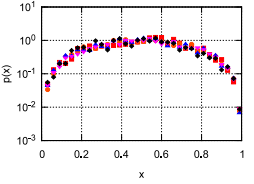


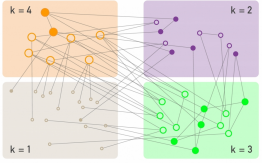


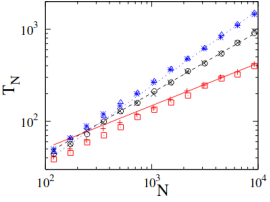










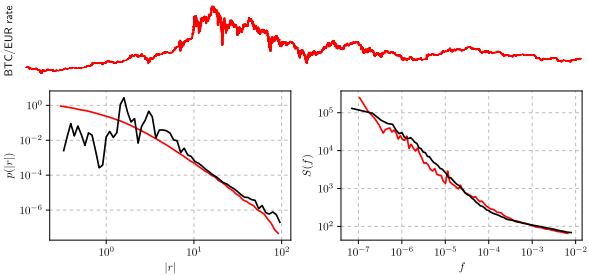


Figs.: [Kononovicius & Ruseckas (2014)], [Barabasi “Network Science”], [Sood & Redner (2005)].

Madness of the financial markets

Homo economicus is:

- informed
- rational
- self–interested

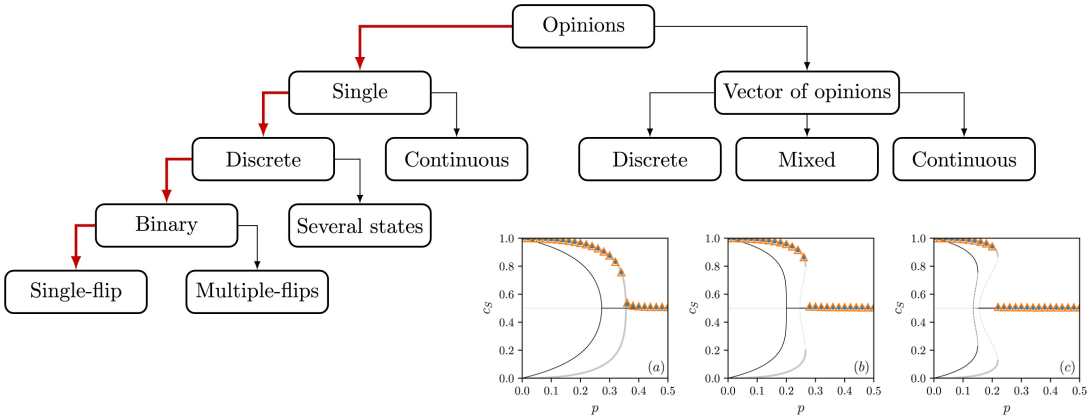


- **Noise trader** trades based on the market mood.
- **Fundamental trader** trades based on the fundamental price.

Fig.: Jeff Parker (caglecartoons). Related: [Kononovicius *et al.*(2012), (2019)], [Cristelli *et al.*(2012)], [Kanazawa & Sornette (2021)].

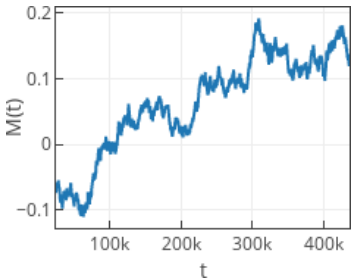
Interactive models: #financial-markets.

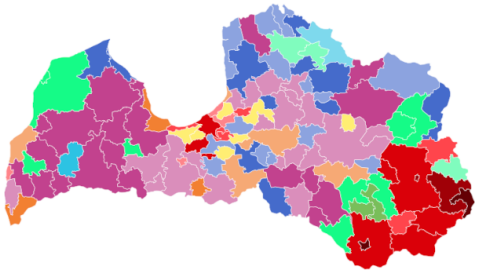
Idealized opinion dynamics

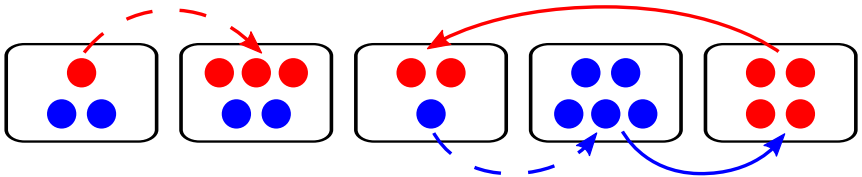


Figs.: [Jedrzejewski *et al.*(2018), (2019)]. Related: [Castellano *et al.*(2009)], [Peralta *et al.*(2023)]. Interactive models: #opinion-dynamics.

Opinion dynamics and data



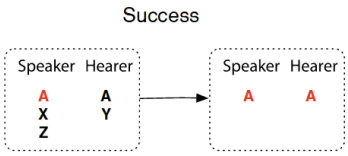


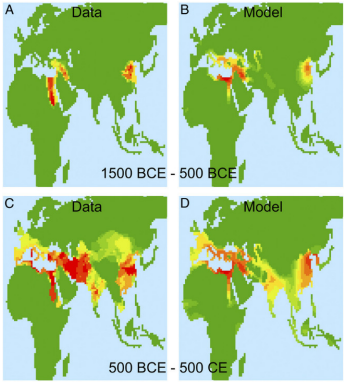


Figs.: q-Voter model, Gajmar@Wikipedia, Compartmental voter model. Related: [Kononovicius (2017), (2019)], [Peralta *et al.*(2023)].

Other problems

- Economic complexity
- Group formation
- Language dynamics
- History
- Corruption
- Military conflict
- Epidemiology
- Attention dynamics





Figs: [Baronchelli (2011)], [Turchin *et al.*(2013)]. Related: [Cristelli *et al.*(2015)], [Villamil *et al.*(2022)], [Aruka *et al.*(2022)], [Lee *et al.*(2020)].

Summary

Key points

- Highly varied field
- Universality
- Interactions over components
- Emergent behavior

Fig.: Internet + spinsons from papers by Sznajd–Weron group

Thank you!

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Faculty of Physics