SOE 4: Urban systems, Scaling, and Social Systems

Time: Tuesday 9:30–12:00 Location: H45

Invited Talk SOE 4.1 Tue 9:30 H45

Urban scaling and conflicting goals — •Diego Rybski — Institute of Ecological Urban and Regional Development (IOER) — Complexity Science Hub (CSH)

Urban scaling, the power-law correlations between an urban indicator and city population, represents the most famous theme of contemporary urban science. The vast majority of publications on the topic empirically quantify the scaling properties for given indicators and countries. Other work is dedicated to mathematically explaining the non-linear scaling based on few but plausible assumptions. In this contribution, two approaches to urban scaling are discussed in the context of conflicting goals. First, we compare cities in terms of emitted carbon emissions vs. heat island intensity. We derive a theoretical solution, but we find that empirical parameters do not allow for any optimal size. Instead, the fundamental allometry between area and population should represent an optimum. Thus, second, we propose a simple model that leads to an optimum in the form of the fundamental allometry. Although many cities are challenged, it makes sense that some sort of optimization takes place, which should also be reflected in observed scaling.

SOE 4.2 Tue 10:00 H45

Dynamics of Cities — Airton Deepman[1], •Renan Lucas Fagundes[2], Eugenio Megias[3], Roman Pasechnik[4], Fabiano Lemes Ribeiro[5], and Constantino Tsallis[6,7,8] — [1]USP, Sao Paulo, Brazil — [2]IOER, Dresden, Germany — [3]UGR, Granada, Spain — [4]Lund University, Lund, Sweden — [5]UFLA, Lavras, Brazil — [6]CBPF, Rio de Janeiro, Brazil — [7]SFI, Santa Fe, USA — [8]CSHV, Vienna, Austria

In recent years, the challenge has been to understand urban phenomena and their impact on the lives of people in cities in order to achieve the sustainable development goals. One of the most intriguing urban phenomena to emerge since the 1940s is fundamental allometry, which elucidates the manner in which urban areas evolve in tandem with their population size. However, most of the models in the literature investigate urban phenomena while employing the static properties of cities. In this study, we demonstrate that the combination of nonextensive statistics with fractal geometry provides a powerful tool for investigating the dynamic evolution of cities. We conducted a case study on Brazilian cities. Our findings indicate that cities evolve near the critical point of percolation, which facilitates connectivity and efficiency in space occupation. Additionally, we observed a correlation between the fractal dimension and the allometric exponent, which is associated with fundamental geometric and diffusion aspects. This research has implications for the design of infrastructure in urban areas and the promotion of economic growth. Early version of the respective manuscript: https://doi.org/10.48550/arXiv.2407.12681

SOE 4.3 Tue 10:15 H45

Scale-dependent Power Law Properties in Social Activities — •Kenta Yamada[1], Jiwei Jiang[2], Hideki Takayasu[2], and Misako Takayasu[2] — [1]Univ. of the Ryukyus, Okinawa, Japan — [2]Science Tokyo, Tokyo, Japan

This presentation explores the power-law characteristics of hashtag usage on Weibo, a Chinese social media platform. The study investigates the heavy-tailed distribution of daily hashtag frequencies and proposes a generalized random multiplicative model to understand the formation of these distributions[1].

Data containing approximately 20 million Weibo posts from July to August 2021 were analyzed. The analysis confirmed that hashtag frequency distributions follow a fat-tailed pattern, consistent with previous research[2]. A key finding was that the growth rate of hashtag usage depends on its frequency.

To model this, a generalized random multiplicative process incorporating size dependency was introduced. Simulations demonstrated that increasing granularity in dividing the hashtag frequency range improved the model's accuracy in replicating real distributions. The power-law exponents estimated through theoretical methods aligned closely with observed data.

[1] J. J. Jiang, K. Yamada, H. Takayasu, and M. Takayasu, Sci Rep 13, 1 (2023).

[2] Chen, H. H., Alexander, T. J., Oliveira, D. F., & Altmann, E. G. . Chaos, 30(6), 063112 (2020).

SOE 4.4 Tue 10:30 H45

Dynamical Power Laws in a Multiplicative Growth Model with Resets — •Alexander Jochim and Stefan Bornholdt — Institute for Theoretical Physics, University of Bremen

The observation that wealth distributions follow power laws – dating back to Pareto's 1897 work – has long intrigued physicists, offering a glimpse of universal principles in complex systems. Models based on multiplicative growth with resets are well-known for generating these heavy-tailed distributions, where the power-law exponent depends on the underlying parameters. Yet, such models often treat societal influences as static, ignoring the dynamic feedback between wealth and social behavior.

In this work, we introduce a minimal model where multiplicative growth with resets produces a wealth distribution that evolves dynamically through coupling to social mechanisms. This adaptive feedback leads to time-dependent power-law exponents, reflecting the interplay between wealth inequality and shifting societal behaviors. Our approach captures emergent phenomena in a non-equilibrium toy model for how collective social behaviors influence – and are influenced by – the statistical properties of wealth.

By framing wealth distributions as part of a coupled dynamical system, this work connects statistical physics with the study of adaptive social systems, offering fresh perspectives on the evolving patterns of inequality.

15 min. break

SOE 4.5 Tue 11:00 H45

Statistical mechanics of a voter model with an evolving number of opinion states — Jeehye Choi[1], Byungjoon Min[1,2], and •Tobias Galla[3] — [1]Department of Physics, Chungbuk National University, Cheongju, Chungbuk, Korea — [2]Department of Medicine, University of Florida, Gainesville FL, USA — [3]Institute for Cross-Disciplinary Physics and Complex Systems IFISC, Palma de Mallorca, Spain

The voter model (VM) describes population of interacting individuals. At each step a randomly chosen individual copies the state ("the opinion") of a neighbour.

Here, we introduce and study a VM in which new opinion states can be introduced spontaneously. Opinions can also go extinct via the voter dynamics. This leads to stationary states with a variable number of opinions in the population or network.

We use statistical physics methods to characterise these stationary states, drawing parallels to the evolution of "mating types" in biological populations. Mating types are forms of the sperm-egg system. Unlike for true sexes, there can be more than two mating types (some fungi have thousands). We transfer methods from number theory, previously used to characterise the evolution of mating types [1], to compute how many opinions will ultimately be present in a VM with a dynamic number of states.

[1] E. Berríos-Caro, T. Galla, G. W.A. Constable, Switching environments, synchronous sex, and the evolution of mating types, Theor. Pop. Biol. 138, 28 (2021)

SOE 4.6 Tue 11:15 H45

The noisy voter model with complete and partial aging — •Raul Toral — Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB), Campus UIB, 07122 Palma de Mallorca, Spain

Many agent-based models of social interaction use the Markovian assumption, namely that the transition rates from one to another state depend only on the current state of the system and not on its previous history. This, being obviously wrong in many situations, it is widely used because of its mathematical simplicity. In this work, I will consider the effect that a particular non-Markovian effect, known in the literature as "aging" or "inertia" has on the paradigmatic noisy voter model. This is a widely used model in social and economics situations to describe transitions to consensus or synchronized behavior. While the standard version of the model displays a discontinuous change of behavior from unsynchronized to consensus as a function of a param-

eter which depends on the free-will, or tendency to act independently on the neighbors, this transition is size-dependent and disappears in the thermodynamic limit. I will show that a genuine -second order- phase transition can appear as a consequence of aging, modeled as a reluctance to change state as a function of the length of time that has been spent in the current state. We investigate the situation where aging acts on both socially influenced and random opinion changes (complete aging), and compare it with previous results where aging acts only on pairwise interactions (partial aging).

SOE 4.7 Tue 11:30 H45

Emergence of polarization in an opinion dynamics framework with bimodal random external field — •Jan Korbel[1], Remah Dahdoul[1], Rudolf Hanel[1,2], and Stefan Thurner[1,2,3] — [1]Complexity Science Hub Vienna, Austria — [2]Medical University of Vienna, Austria — [3]Santa Fe Institute, NM, US

We present the opinion dynamics model with an external field, where the individual opinions are coupled as in a standard Ising spin-spin interaction. Furthermore, we consider that the spins are coupled with the random field. Contrary to the common random-field Ising model, the random field is considered to be binary, either +h or -h. The interpretation of this model is that the particles represent the individuals influenced both by their neighborhood as well as external sources, e.g., election campaigns. With increasing field coupling, we observe that the transition from the ferromagnetic to paramagnetic phase becomes the first order. Furthermore, it can be shown that for a high enough field, the system becomes polarized, i.e., the external field is dominating in comparison with the spin-spin interactions. Finally, we show that for low enough temperatures, the system always gets polarized above the threshold external field, no matter whether the magnitude of the positive field is much larger or smaller than the magnitude of the negative field.

SOE 4.8 Tue 11:45 H45

Phase Transitions in Socially Balanced Systems: Why More Interactions Drive Polarization — •Markus Hofer[1,2], Jan Korbel[1,2], Rudolf Hanel[1,2], and Stefan Thurner[1,2,3] — [1]Medical University of Vienna, Center for Medical Data Science, Institute of the Science of Complex Systems, Spitalgasse 23, 1090, Vienna, Austria — [2]Complexity Science Hub Vienna, Metternichgasse 8, 1030, Vienna, Austria — [3]Santa Fe Institute, 1399 Hyde Park Rd, Santa Fe, NM 87501, USA

Survey data show massive evidence that the average number of close social connections has increased over the past two decades. At the same time opinions in societies are becoming increasingly divided. To understand if these phenomena are related, we use a multidimensional spin model [1] that has been experimentally shown [2] to be realistic both in terms of homophily and social balance. Within the model individuals interact dyadically yet realistic triad statistics as expected from social balance theory emerges naturally. We find a phase transition where at a critical connectivity of the underlying social network a rapid transition from practically no to strong polarization occurs. By understanding how increased social connectivity necessarily leads to polarization we discuss strategies to mitigate polarization in highly connected societies.

[1] T. M. Pham, J. Korbel, R. Hanel, and S. Thurner, Proceedings of the National Academy of Sciences 119, e2121103119 (2022).
[2] M. Galesic, H. Olsson, T. Pham, J. Sorger, and S. Thurner, OSF Preprints 10.31219/osf.io/3bmg7 (2023).