CSH Workshop "Statistical Physics of Opinion Formation & Collective Decision Making"

October 14-15, 2024

Workshop Organizers:

Pawel Romanczuk (Humboldt Universität zu Berlin, Germany),

Yurij Holovatch (Institute for Condensed Matter Physics, National Academy of Sciences of Ukraine, Lviv, Ukraine & Complexity Science Hub Vienna, Austria)

Jan Korbel (Complexity Science Hub Vienna, Austria)

Motivation:

Collective decision making and related problems of opinion formation can be mapped to the phenomenon of spontaneous symmetry breaking, with respect to the emergence of a dominant consensus opinion. Thus, over the past decades various models of corresponding processes have been proposed that were strongly inspired - if not directly analogous - to established models for phase transitions in (equilibrium) statistical physics, such as the Ising model. Despite this past research offering important insights, several fundamental questions remain open: 1) regarding the relevance of idealized physical models (e.g., spin models) for real-world collective decision-making phenomena and their relation to individual-level psychological mechanisms, and 2) the implication of the non-equilibrium, often non-stationary, nature of these processes for their theoretical treatment. The aim of the workshop is to have besides presentations by participants a significant proportion of the time dedicated to discussions and collaborative work on advancing important conceptual questions in the field. Possible research questions to be addressed: Fluctuation-dissipation relations (FDR) & non-reciprocity in collective decision making; Origin of stochasticity in collective decision making and the notion of effective temperature; Mechanisms of self-organized tuning towards/away from critical points; Theoretical treatment of non-stationary collective dynamics.

Invited participants:

- Bryan Daniels, Arizona State University, USA
- Nir Gov, Weizmann Institute of Science, Israel
- Reinhard Folk, JK University Linz, Austria
- Yurij Holovatch, ICMP Lviv, Ukraine & CSH Vienna, Austria
- Janusz Hołyst, Warsaw University of Technology, Poland
- Jan Korbel, CSH Vienna, Austria
- Henrik Olsson, CSH Vienna, Austria
- Romualdo Pastor-Satorras, Universitat Politècnica de Catalunya, Spain
- Fernando Peruani, CY Cergy Paris Université & Université Côte d'Azur, France
- Tuan Minh Pham, Niels Bohr Institute, København, Denmark
- Pawel Romanczuk, HU Berlin, Germany
- Bosiljka Tadic, Jožef Stefan Institute, Ljubljana, Slovenia & CSH Vienna, Austria

ABSTRACTS

Bryan Daniels

Neural tuning for collective decisions

While drift-diffusion models are known to be good at explaining decision dynamics at a coarse scale, there is still no consensus about the detailed neural mechanisms that produce these dynamics. Detailed data from macaque cortical neurons shows that a perceptual decision appears to occur in two phases: slow accumulation followed by fast consensus. We find that accumulation dynamics can be produced by critical slowing near a continuous transition (pitchfork bifurcation), with consensus arising naturally by an increase in effective interactions that pushes the system past the transition. We then examine the tuning necessary to utilize such a mechanism, showing how binary decision dynamics can be produced in random dynamical networks by adjusting two global parameters. Dynamical properties relevant to speed and accuracy of the decision are given by the network's dominant eigenmode.

Nir Gov

Spin model with global inhibition for decision making in the brain

Humans and other organisms make decisions choosing between different options, with the aim to maximize the reward and minimize the cost. The main theoretical framework for modeling the decision-making process has been based on the highly successful drift-diffusion model, which is a simple tool for explaining many aspects of this process. However, new observations challenge this model. Recently, it was found that during high cognitive load and situations of uncertainty, inhibition of neuronal firing increases, but the origin of this phenomenon is not understood. Motivated by this observation, we extend a recently developed model for decision-making while animals move towards targets in real space. We introduce a neurophysiologically-inspired model, based on the Ising model, which includes global inhibition to explore its role in the decision-making process. This model can explain how the brain may utilize inhibition to improve its decision-making accuracy. Compared to experimental results, this model suggests that the regime of the brain's decision-making activity is in proximity to a critical state. Within the model, the critical region near the transition line has the advantageous property of enabling a significant decrease in error with a small increase in inhibition and also exhibits unique properties with respect to learning and memory decay.

Reinhard Folk

After a century: a new look into Ising's thesis

The Ising model – a model within statistical physics, developed to explain the existence of an ordered magnetic phase, but leading to a negative result - turned out to become a basic model in many other disciplines like e.g. econophysics, sociophysics, biology, medicine or environmental science. The thesis defended by Ernst Ising 100 years ago [1] contained not only the solution of what we now call the '1D Ising model' but also other problems. Some of these problems are the subject of this talk.

The one-dimensional model solved by Ernst Ising [1] was based on the old quantum mechanics of Bohr and Sommerfeld [2]. In the original solution, the partition function in the thermodynamic limit can be expressed by the largest root of a certain polynomial [3]. The last coincides with the characteristic polynomial of the transfer matrix, a concept developed much later after the revolution in quantum mechanics in the mid-twenties. Moreover, Ising's thesis contains several generalizations of the model: (i) an extension from a two-state model to a three state one, which can be considered as a forerunner of the Potts model [2], (ii) a model of two chains and (iii) an account of the next nearest neighbour interaction. The new features of phase transition behaviour that are evident in Ising's chain model are also used in non-physical applications (see e.g. [4]).

[1]. E. Ising, Beitrag zur Theorie des Ferro- und Paramagnetismus. Dissertation zur Erlangung der Doktorwürde der Mathematisch-Naturwissenschaftlichen Fakultät der Hamburgischen Universität vorgelegt von Ernst Ising aus Bochum. Hamburg 1924. Available online: https://icmp.lviv.ua/ising/books/isingthesis.pdf

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[2]. R. Folk and Yu. Holovatch, Schottky's forgotten step to the Ising model, Eur. Phys. J. H 47 (2022) 9.

[3]. R. Folk and Yu. Holovatch, Ising's roots and the transfer-matrix eigenvalues, Entropy 26(6) (2024) 459.

[4]. B. J. Zubillaga et al., Three-state majority-vote model on small-world networks, Sci. Rep. 12 (2022) 282.

Yurij Holovatch

Ising model with variable spin/agent strengths: an account of agent diversity and its impact on collective behaviour

Recently, we have suggested a new variant of the Ising model which addresses nonidentical spins or agents [1]. The model is intended for analysis of ordering in systems comprising agents which, although matching in their binarity (i.e., maintaining the iconic Ising features of '+' or '−', 'up' or 'down', 'yes' or 'no'), differ in their strength. To this end, we have introduced varying spin strengths to the Ising model and presented its analysis on network structures of varying degrees of complexity. This enabled us to explore the interplay of two types of randomness: individual strengths of spins or agents and collective connectivity between them. We have solved the model for the generic case of power-law spin strength and network node degree distributions and found that, with a self-averaging free energy, it has a rich phase diagram with new universality classes [2].

In particular, the proposed model offers a new perspective on the phenomenon of ordering in structurally disordered magnets [3]. Its analytical predictions were confirmed in recent MC simulations [4]. However, the generality of the model allows its application in investigating emergent phenomena in many-agent systems in contexts where non-identicality of agents plays an essential role and for exporting statistical physics concepts beyond physics. The possibility of such applications will be discussed with the participants of the workshop.

[1]. M. Krasnytska, B. Berche, Yu. Holovatch, R. Kenna. Ising model with variable spin/agent strengths. J. Phys.: Complexity 1 (2020) 035008.

[2]. M. Krasnytska, B. Berche, Yu. Holovatch, R. Kenna. Generalized Ising Model on a Scale-Free Network: An Interplay of Power Laws. Entropy 23(9) (2021) 1175.

[3]. M. Dudka, M. Krasnytska, J.J. Ruiz-Lorenzo, Yu. Holovatch. Effective and asymptotic criticality of structurally disordered magnets. JMMM 575 (2023) 170718.

[4]. J.J. Ruiz-Lorenzo, M. Dudka, M. Krasnytska, Yu. Holovatch, in preparation.

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Janusz Hołyst

Multilevel Information Overload: Measures, Models and Mitigation

We are now exposed daily to more information than we can process and this has substantial costs. I argue that the information space should be recognized as part of our environment and call for research into the effects and management of information overload.

In today's world, access to information thought of as the resolution of uncertainty; is often considered as a benefit or even as an indisputable human right. There is, however, the “dark side” of information: the abundance of data beyond one’s capacity to process them leads to so-called information overload (IOL). This notion had troubled mankind long before even the print was invented and examined from different points of view, ranging from neuroscience to journalism. IOL is, however, usually considered at the individual level by examining a single factor or a specific level that eventually leads to switching off an active individual. The influence of IOL appearing simultaneously at different levels, i.e., a multilevel information overload is unknown, though. These observations lead to setting the main aim of the international project supported by EU grant: OMINO - Overcoming Multilevel Information Overload. The OMINO project aims to measure multilevel IOL in different systems as well as methods to model IOL and to develop counter-measures to mitigate this phenomenon.

[1]. https://ominoproject.eu

[2]. J.A. Hołyst et al., Protect our environment from information overload, Nature Human Behaviour 8 (2024) 402–403, https://www.nature.com/articles/s41562-024-01833-8

Jan Korbel

Homophily-Based Social Group Formation in a Spin Glass Self-Assembly Framework

Homophily, the tendency of humans to attract each other when sharing similar features, traits, or opinions, has been identified as one of the main driving forces behind the formation of structured societies. Here we ask to what extent homophily can explain the formation of social groups, particularly their size distribution. We propose a spin-glass-inspired framework of self-assembly, where opinions are represented as multidimensional spins that dynamically self-assemble into groups; individuals within a group tend to share similar opinions (intragroup homophily), and opinions between individuals belonging to different groups tend to be different (intergroup heterophily). We compute the associated nontrivial phase diagram by solving a self-consistency equation for “magnetization” (combined average opinion). Below a critical temperature, there exist two stable phases: one ordered with nonzero magnetization and large clusters, the other disordered with zero magnetization and no clusters. The system exhibits a first-order transition to the disordered phase. We analytically derive the group-size distribution that successfully matches empirical group-size distributions from online communities.

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J. Korbel, S. D. Lindner, T. M. Pham, R. Hanel, S. Thurner. Phys. Rev. Lett. 130 (2023) 057401.

Henrik Olsson

Networks of Beliefs: An Integrative Theory of Individual- and Social-Level Belief Dynamics

We introduce the Networks of Belief theory, which explains the interaction between personal beliefs and social beliefs. This theory improves upon previous theories in three key ways: it links individual belief networks with belief dynamics on social networks, recognizes the imperfect alignment between perceived and actual beliefs, and explains diverse belief phenomena through differences in attention to dissonances. Our computational model, based on a statistical physics framework, is supported by findings from two surveys (N1=973, N2=669). We offer insights into belief dynamics, including group consensus, polarization, radicalization, minority influence, and observed belief distributions, and discuss directions for future research.

Romualdo Pastor Satorras

Opinion depolarization of interdependent topics in heterogeneous social interactions

The presence of opinion polarization (i.e. two groups holding opposite and possibly extreme opinions in a population) has been extensively observed with respect to several controversial topics, ranging from religion to political ideology. Modeling the process of reducing opinion polarization among the population, or depolarization, has been the object of much recent work. In most cases, such efforts address the simplest case of one-dimensional opinions with respect to a single topic. However, the process of opinion formation may involve multiple topics at the same time, requiring a proper multidimensional modeling framework for opinion dynamics. Here we present an analytically tractable model of opinion dynamics in a space of D interdependent topics, the so-called "Social Compass Model" (SCM). In the SCM, opinions are represented in hyperspherical coordinates, where the orientation represents the opinion and the radius the conviction of individuals. We postulate a dynamics inspired by the classic Friedkin-Johnsen, in which the orientation of individuals, subject to an initial, preferred orientation and to social influence by peers, experience a depolarization phase transition for a sufficiently large social influence level. By means of a mean field analysis, we observe that the transition of the SCM is continuous for correlated initial opinions, while it has an discontinuous, explosive nature for uncorrelated initial opinions. These results are checked against numerical simulations in two dimensions using as initial opinions real data extracted from the American Nation Election Studies (ANES) surveys. Finally we discuss the effects of an heterogeneous pattern of contacts on the depolarization transition of the SCM model.

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Fernando Peruani

Imitation, democratic leadership, and collective intelligence in groups of sheep

We will see how we can quantitatively describe the collective behavior of sheep groups and understand the emergence of various collective behaviors from simple imitation rules that allow the group to reach consensus, develop collective strategies such as democratic leadership, and display collective intelligence. The developed ideas may prove useful to describe other animal groups, including humans.

Tuan Minh Pham

Adaptation under Non-equilibrium Genotype-Phenotype Maps: a Statistical Physics Approach

Biological networks are adaptive - their connections slowly change in response to the state of the system constituents. It has been challenging to understand the dynamics of such adaptive networks, in particular, how they can robustly perform their designated functions despite various sources of stochasticity. To solve this open problem we present a general statistical-physics framework for the evolution of genetic architecture, where phenotypes are shaped by stochastic gene-expression fast dynamics, while genotypes are encoded by the temporal configurations of genetic regulations that slowly evolve, depending on how adapted the shaped phenotypes are. Using this framework, we elucidate analytically how genotype and phenotype achieve their optimal values via a non-equilibrium phase transition within an intermediate level of external noise while losing their robustness at either small or high noise levels.

Pawel Romanczuk

Collective decision making with heterogeneous preference, local non-linearity and noise

We explore a spin model for binary collective decision-making in higher organisms proposed by [A.T. Hartnett et al., Phys. Rev. Lett.116 (2016) 038701]. Depending on the assumptions about the nature of social interactions, two different Hamiltonians can be formulated, allowing for analytic solutions for the thermodynamics of the model on complete graphs. Our analytical predictions are validated through individual-based simulations, which also enable us to investigate how system size and initial conditions impact collective decision-making in finite-sized systems, particularly in terms of convergence to metastable states. Furthermore, we extend our analysis to different network topologies beyond the complete graph (Erdős–Rényi random graphs and Watts-Strogatz graphs), discuss different measures of susceptibility, and impact of model and network parameters on the location of critical points.

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Bosiljka Tadic

Self-Organized Criticality in Complex Systems

Self-organized criticality (SOC) is a type of out-of-equilibrium critical dynamics associated with an attractor of interacting nonlinear systems driven by external forces on a slower scale. It is recognized as a robust, steady state with long-range spatiotemporal correlations without an apparent phase transition point. The signatures of SOC have been observed in many complex systems, from physical and biological to social systems, where the emergence of novel features on a larger scale can be attributed to its collective dynamic behavior. However, the occurrence of SOC mechanisms and their precise role in each case still need to be understood.

We briefly describe the essential characteristics of SOC states and give a suitable classification of the supporting-network's evolution regarding the required time-scale separation. Further, we argue for two fundamental interactions leading to SOC in higher-order networks. In addition, we provide three examples where projecting SOC ideas can be helpful for theoretical considerations and interpretation of empirical data. Specifically, we mention the creation of collective knowledge through social dynamics, the "quantum" view of adaptive systems under external influence, and the brain's non-synchronizability.