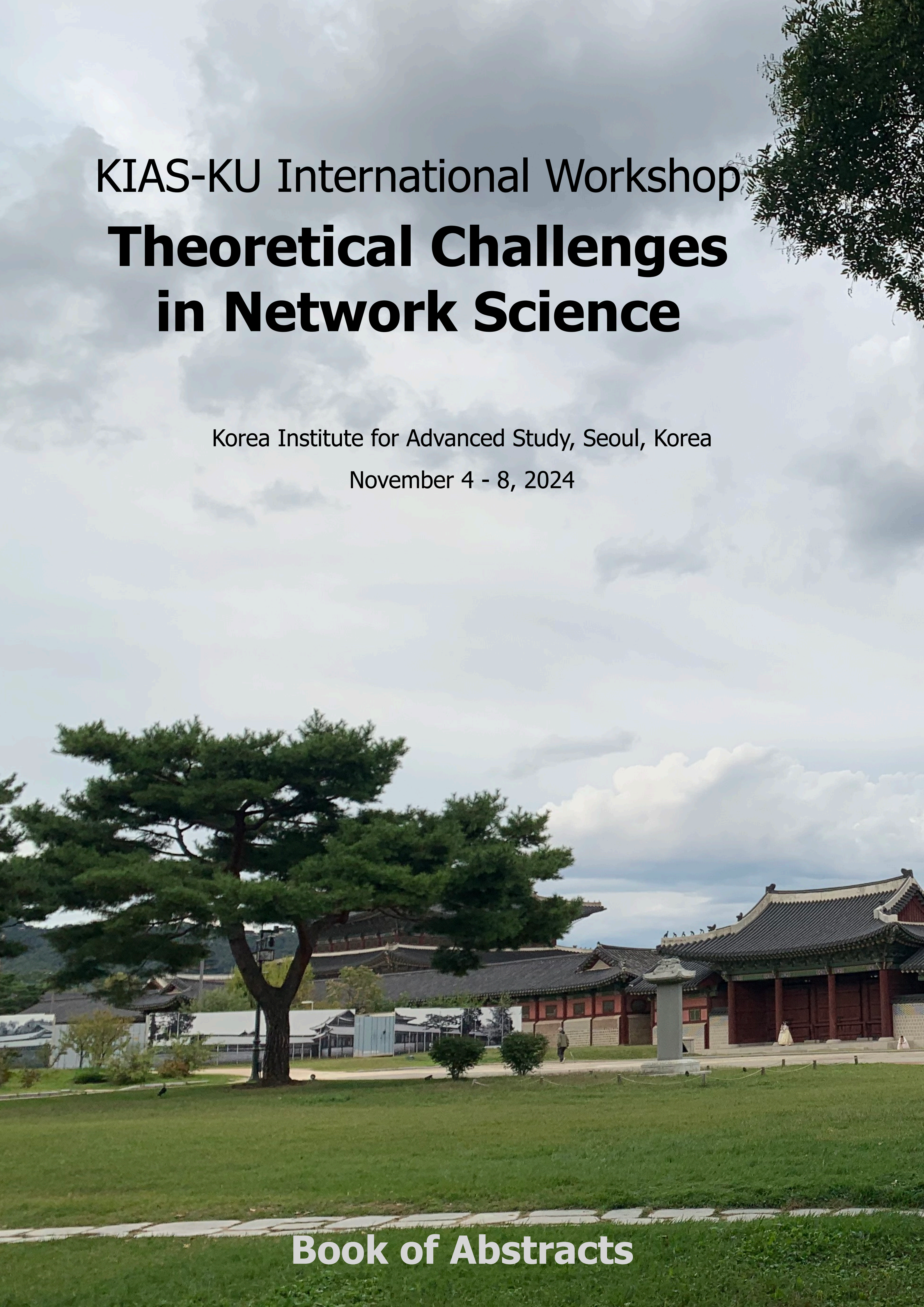
KIAS-KU International Workshop

Theoretical Challenges in Network Science

Korea Institute for Advanced Study, Seoul, Korea

November 4 - 8, 2024



Book of Abstracts

	11/3 Sunday	11/4 Monday	11/5 Tuesday	11/6 Wednesday	11/7 Thursday	11/8 Friday
08:50 - 09:20		Registration, coffee & sandwiches				
09:20 - 10:00		Chair **L.Hébert-Dufresne** **Y. Moreno** Dynamics of information spreading in complex environments	Chair **A. Allard** **B. Min** A new perspective of network stability: Insight from no-exclaves percolation and attractor networks	Chair **A. Arenas** **A. Gabrielli** The Laplacian Renormalization Groups(LRG) unveils the structural organization of	Chair **F. Battiston** **A. Arenas** The Role of Interaction Overlap in the Spread of Complex Contagions on Higher-Order Networks	Chair **G. Bianconi** **I. Iacopini** The temporal dynamics of group interactions in higher-order social networks
10:00 - 10:40		**B. Kahng** Synchronizations in the second-order and the mixed-order Kuramoto models	**C. Castellano** Percolation in networks: beyond nearest neighbors	**A. Allard** Simplicity meets complexity: Challenges in reproducing complex connectivity patterns with simple models	**K. Shin** Mining of Real-world Hypergraphs: Patterns, Tools, and Generators	**L. Keating** An approximate master equation description of the Watts' threshold model on higher-order networks
10:40 - 11:00		**Break**				
11:00 - 11:40		Chair **I. Iacopini** **J.K. Kim** Inference of dynamical networks	Chair **A. Gabrielli** **F. Radicchi** Modeling resource consumption and transit efficiency in transport systems with percolation and	Chair **X. Wang** **S. Suweis** Ecological Network Dynamics and Fluctuations Favour Species Coexistence in Ecological Communities	Chair **F. Radicchi** **S. Scarpino** Epistemic Challenges in Contagion Modeling	Chair **Y. Moreno** **C.H. Kim** A new type of Synchronization: Frequency Resonance
11:40 - 12:20		**I. Kovács** How can we learn from noisy, incomplete or even biased network data?	**Y.-H. Eom** Collective phenomena on urban road networks: From macroscopic congestion spreading to microscopic car	**H.J. Park** Incorporating Heterogeneous Interactions for Ecological Biodiversity	**E. Lee** Structural Inequalities in Faculty Career Trajectories in South Korea	**L.Hébert-Dufresne** Complexity and criticality of heterogeneous or anisotropic cascade models
12:20 - 14:30		**Lunch**				
14:30 - 15:10		Chair **J. Gleeson** **G. Bianconi** Statistical mechanics of higher-order networks	Chair **I. Kovács** **F. Battiston** Social networks with higher-order interactions: structural organization and evolutionary dynamics	**Excursion**	Chair **C. Castellano** **J. Gleeson** Branching processes for cascades on networks	
15:10 - 15:50		**G. Cimini** Grand Canonical ensemble of networks and the transition to Optimal Transport solutions	**Y. Zhang** Dynamics on hypergraphs and hypergraphs from dynamics		**X. Wang** Information diffusion on social networks	
15:50 -16:10		Break			Break	
16:10 - 16:50		Chair **S. Scarpino** **G. Petri** Renormalization and Higher-Order Interactions: Bridging Structure and Dynamics in Complex Systems	Chair **G. Petri** **M. Porter** Complex Networks with Complex Weights		Chair **M. Porter** **A. Aleta** Incorporating Heterogeneity in Epidemic Models	
16:50 - 17:30		**M. Ha** Revisited Finite-Size Scaling of Random Constraint Satisfaction Problems	**C.-M. Ghim** Lost Opportunities in the Innovation Landscape of Genetic Research		**S.H. Lee** Kaleidoscopic reorganization of network communities across different scales	
17:30 - 18:10		**Poster (17:30 ~ 19:00)**	**C. Granell** The role of timing on waning immunity in epidemics: The Rebound Effect			
	Welcome dinner (19:30 -)		**Banguet (18:10 ~20:00)**			

Aim

Anticipating the silver jubilee since its modern reincarnation, the network science is still vigorous in compelling theoretical ideas and challenges. The aim of the Workshop is to summon the leading experts in the frontiers of theoretical network science and to promote the focused and active discourse about the current challenges and future perspectives in network science with emphasis on theoretical aspects. We hope this in-person workshop will provide a timely opportunity to solidify and expand the theoretical foundation of network science.

Topics

Major outstanding theoretical issues and challenges, including but not limited to: Higher-order networks, multiplex networks, network geometry and renormalization, time-varying networks and dynamics, network robustness, complex dynamic processes such as contagions and synchronization, social and economic networks, biological and ecological networks, AI and networks etc.

Invited speakers

Alberto Aleta (Zaragoza)
Antoine Allard (Laval)
Alex Arenas (Rovira i Virgili)
Federico Battiston (CEU)
Ginestra Bianconi (Queen Mary)
Claudio Castellano (ISC-CNR)
Giulio Cimini (Tor Vergata)
Young-Ho Eom (UoS)
Andrea Gabrielli (Roma Tre)
Cheol-Min Ghim (UNIST)
James Gleeson (Limerick)
Clara Granell (Rovira i Virgili)
Meesoon Ha (Chosun)
Laurent Hébert-Dufresne (Vermont)

Iacopo Iacopini (Northeastern, London)
Byungnam Kahng (KENTECH)
Leah Keating (UCLA)
Cook Hyun Kim (KENTECH)
Jae Kyoung Kim (IBS/KAIST)
Istvan Kovács (Northwestern)
Eun Lee (Pukyong)
Sang Hoon Lee (GNU)
Byungjoon Min (Chungbuk)
Yamir Moreno (Zaragoza)
Hye Jin Park (Inha)
Giovanni Petri (Northeastern, London)
Mason Porter (UCLA)
Filippo Radicchi (Indiana)
Samuel Scarpino (Northeastern, Boston)
Kijung Shin (KAIST)
Samir Suweis (Padova)
Xiangrong Wang (Shenzhen)
Yuanzhao Zhang (Santa Fe)

Organizers

Kwang-Il Goh (Korea University)
Laurent Hébert-Dufresne (Vermont)
Deok-Sun Lee (KIAS)
Yamir Moreno (Zaragoza)

Sponsors

Korea Institute for Advanced Study
Korea University
National Research Foundation of Korea

Webpage

http://events.kias.re.kr/h/TCNS2024/

Contact

Hyemi Kim (KIAS) email: hmkim@kias.re.kr

Program

11/4 Monday

[Morning1] Chair: Laurent Hébert-Dufresne (Vermont)
09:20 - 10:00 Yamir Moreno (Zaragoza) Dynamics of information spreading in complex environments
10:00 - 10:40 Byungnam Kahng (KENTECH) Synchronizations in the second-order and the mixed-order Kuramoto models

[Morning2] Chair: Iacopo Iacopini (Northeastern, London)
11:00 - 11:40 Jae Kyoung Kim (IBS/KAISST) Inference of dynamical networks
11:40 - 12:20 István A. Kovács (Northwestern) How can we learn from noisy, incomplete or even biased network data?

[Afternoon1] Chair: James Gleeson (Limerick)
14:30 - 15:10 Ginestra Bianconi (Queen Mary) Statistical mechanics of higher-order networks
15:10 - 15:50 Giulio Cimini (Tor Vergata) Grand Canonical ensemble of networks and the transition to Optimal Transport solutions

[Afternoon2] Chair: Samuel Scarpino (Northeastern, Boston)
16:10 - 16:50 Giovanni Petri (Northeastern, London) Renormalization and Higher-Order Interactions: Bridging Structure and Dynamics in Complex Systems
16:50 - 17:30 Meesoon Ha (Chosun) Revisited Finite-Size Scaling of Random Constraint Satisfaction Problems

[Posters] 17:30 - 19:00
[P1] Neural Graph Simulator for Complex Systems by Hoyun Choi (SNU)
[P2] Inferring coupling kernel of biological oscillators using Physics-Informed Neural Network by Gyuyoung Hwang (IBS)
[P3] Effects of structural properties of neural networks on machine-learning performance by Yash Arya (GNU)
[P4] scLENS: data-driven signal detection for unbiased scRNA-seq data analysis by Hyun Kim (IBS)
[P5] Dynamical Approach to Braess Paradox due to Enhancing Inertia by Sangjoon Park (KENTECH)
[P6] Discerning Braess' Paradox in the Power Grids Through Strategic Shortcuts by Yunju Choi (KENTECH)
[P7] Exploring Chimera States in Synchronous Oscillators: Focusing Solely on Triadic Interactions by Gugyoung Kim (Hanyang)
[P8] Competition between group interactions and nonlinearity in voter dynamics on hypergraphs by Jihye Kim (Korea)
[P9] Contagion dynamics on hypergraphs with nested hyperedgesby Jihye Kim (Korea)

[P10] Random hypergraph model with higher-order components by Jung-Ho Kim (Korea)

[P11] Collective collapses are mitigated in the international trade hypergraph by Jung-Ho Kim (Korea)

[P12] Local and global wealth condensation on sparse networks & Emergence of cooperation in the social dilemma with wealth-dependent payoffs by Hyun Gyu Lee (KIAS)

[P13] Analyzing the Impact of Sentiment in Naver Stock Forums on Market Trends Using BERT by Jinjoo Yoon (Chosun)

[P14] Correlations in Regional Consumption Patterns in the Republic of Korea during the COVID-19 Pandemic: A Complex Networks Approach by Woori Bong (Chosun)

[P15] Mapping the structure of knowledge acquisition from STEM education data in Korean universities by Gahyoun Kim (GNU)

[P16] Finite Size Scaling Approach for Revealing Inherent Scale-Freeness in Heterogeneous Networks by Yeonsu Jeong (Hanyang)

[P17] Susceptible-Infected-Recovered/Dead-Susceptible (SIR/DS) model with mutation on complex networks by HaeChan Seo (KyungHee)

[P18] Information Dynamics and Phase Transitions on Complex Networks by HwaRang Kim (KyungHee)

[P19] Phase Transitions in the Simplicial Ising Model on Hypergraphs by Gangmin Son (KIAS)

[P20] Role of Spectral Dimension and Edge Overlaps in Mutual Percolation on Multiplex Networks by Gangmin Son (KIAS)

[P21] Inference of the latent hyperbolic organization of networks by Bukyoung Jhun (Central European University)

[P22] Bifurcations and multistability in empirical mutualistic networks by Andrus Giraldo (KIAS)

[P23] Spectral dimension and coarse-graining of hypergraphs for diffusion by Sudo Yi (KIAS)

11/5 Tuesday

[Morning1] Chair: Antoine Allard (Laval)

09:20 - 10:00 Byungjoon Min (Chungbuk) A new perspective of network stability: Insight from no-exclaves percolation and attractor networks

10:00 - 10:40 Claudio Castellano (ISC-CNR) Percolation in networks: beyond nearest neighbors

[Morning2] Chair: Andrea Gabrielli (Roma Tre)

11:00 - 11:40 Filippo Radicchi (Indiana) Modeling resource consumption and transit efficiency in transport systems with percolation and multiplex networks

11:40 - 12:20 Young-Ho Eom (UoS) Collective phenomena on urban road networks: From macroscopic congestion spreading to microscopic car trajectories

[Afternoon1] Chair: István A. Kovács (Northwestern)

14:30 - 15:10 Federico Battiston (CEU) Social networks with higher-order interactions: structural organization and evolutionary dynamics

15:10 - 15:50 Yuanzhao Zhang (Santa Fe) Dynamics on hypergraphs and hypergraphs from dynamics

[Afternoon2] Chair: Giovanni Petri (Northeastern, London)

16:10 - 16:50 Mason Porter (UCLA) Complex Networks with Complex Weights

16:50 - 17:30 Cheol-Min Ghim (UNIST) Lost Opportunities in the Innovation Landscape of Genetic Research

17:30 - 18:10 Clara Granell (Rovira i Virgili) The role of timing on waning immunity in epidemics: The Rebound Effect

11/6 Wednesday

[Morning1] Chair: Alex Arenas (Rovira i Virgili)

09:20 - 10:00 Andrea Gabrielli (Roma Tre) The Laplacian Renormalization Groups (LRG) unveils the structural organization of heterogeneous networks

10:00 - 10:40 Antoine Allard (Laval) Simplicity meets complexity: Challenges in reproducing complex connectivity patterns with simple models

[Morning2] Chair: Xiangrong Wang (Shenzhen)

11:00 - 11:40 Samir Suweis (Padova) Ecological Network Dynamics and Fluctuations Favour Species Coexistence in Ecological Communities

11:40 - 12:20 Hye Jin Park (Inha) Incorporating Heterogeneous Interactions for Ecological Biodiversity

[Afternoon] Excursion

11/7 Thursday

[Morning1] Chair: Federico Battiston (CEU)

09:20 - 10:00 Alex Arenas (Rovira i Virgili) The Role of Interaction Overlap in the Spread of Complex Contagions on Higher-Order Networks

10:00 - 10:40 Kijung Shin (KAIST) Mining of Real-world Hypergraphs: Patterns, Tools, and Generators

[Morning2] Chair: Filippo Radicchi (Indiana)

11:00 - 11:40 Samuel Scarpino (Northeastern, Boston) Epistemic Challenges in Contagion Modeling

11:40 - 12:20 Eun Lee (Pukyong) Structural Inequalities in Faculty Career Trajectories in South Korea

[Afternoon1] Chair: Claudio Castellano (ISC-CNR)

14:30 - 15:10 James Gleeson (Limerick) Branching processes for cascades on networks

15:10 - 15:50 Xiangrong Wang (Shenzhen) Information diffusion on social networks

[Afternoon2] Chair: Mason Porter (UCLA)

16:10 - 16:50 Alberto Aleta (Zaragoza) Incorporating Heterogeneity in Epidemic Models

16:50 - 17:30 Sang Hoon Lee (GNU) Kaleidoscopic reorganization of network communities across different scales

11/8 Friday

[Morning1] Chair: Ginestra Bianconi (Queen Mary)

09:20 - 10:00 Iacopo Iacopini (Northeastern, London) The temporal dynamics of group interactions in higher-order social networks

10:00 - 10:40 Leah Keating (UCLA) An approximate master equation description of the Watts' threshold model on higher-order networks

[Morning2] Chair: Yamir Moreno (Zaragoza)

11:00 - 11:40 Cook Hyun Kim (KENTECH) A new type of Synchronization: Frequency Resonance

11:40 - 12:20 Laurent Hébert-Dufresne (Vermont) Complexity and criticality of heterogeneous or anisotropic cascade models

invited talk

11/4 Monday
09:20 - 10:00

Dynamics of information spreading in complex environments

Yamir Moreno (Zaragoza)

Abstract

11/4 Monday
10:00 - 10:40

Synchronizations in the second-order and the mixed-order Kuramoto models

Byungnam Kahng (KENTECH)

I present recently disclosed macroscopic features of synchronizations in the second-order and the mixed order of first- and second-order Kuramoto models (KMs), and their respective microscopic origins. This study is motivated by the stabilization of the modernized power grid. Frequency synchronization is a core factor to stabilize the AC in power grid, which is governed by the so-called swing equation, equivalent to the second-order KM. Unlike the first-order KM, the 2nd-order KM implements underdamped dynamics due to its inertia term, which still remains covered. Thus, we uncovered the microscopic dynamics of the second-order KM. Moreover, as inertia-free electricity produced from renewable energy sources increases, the modern power grid is represented by a mixed-order KM of the second-order and first-order KMs, which is absolutely novel. So, our research should be helpful for advancing the stabilization of the modernized power grid.

invited talk

11/4 Monday
11:00 - 11:40

Inference of dynamical networks

Jae Kyoung Kim (IBS/KAIST)

Biological systems are complex dynamic networks. In this talk, I will introduce GOBI (General Model-based Inference), a simple and scalable method for inferring regulatory networks from time-series data. GOBI can infer gene regulatory networks and ecological networks that cannot be obtained with previous causation detection methods(e.g., Granger, CCM, PCM). I will then introduce Density-PINN (Physics-Informed Neural Network), a method for inferring the shape of the time-delay distribution of interactions in a network. The inferred shape of time-delay distribution can be used to identify the number of pathways that induce a signaling response against antibiotics, which solves the long-standing mystery, the major source of cell-to-cell heterogeneity in response to stress. Finally, I will talk how to infer the dynamic information from just network structure information, which can be used to identify the targets (nodes) perturbing the homeostasis of the system.

11/4 Monday
11:40 - 12:20

How can we learn from noisy, incomplete or even biased network data?

István A. Kovács (Northwestern)

Network theory is a powerful tool to describe and study complex systems, and there has been tremendous progress in mapping large networks in all areas of science, leading to a growing library of complex network datasets. Yet, inherent limitations of the measurements lead to errors, biases and missing data and the situation likely gets worse as datasets get larger. Therefore, as in any other quantitative field, it would be of paramount importance to characterize the uncertainty of our maps. Yet, unlike a simple error bar for a single valued quantity, the uncertainty of a network structure itself is expected to have a complex, network structure, requiring novel methodologies. Focusing on biological networks, we show how such detailed information can help us to solve key problems, such as link prediction, noise reduction or functional annotation. I will close by discussing our recent results on assessing and reducing biases in network data. To conclude, putting error bars on our network maps is not a nuisance but an essential ingredient in addressing long standing problems in the field.

11/4 Monday
14:30 - 15:10

Statistical mechanics of higher-order networks

Ginestra Bianconi (Queen Mary)

Higher-order networks capture the interactions among two or more nodes in complex systems ranging from the brain, to chemical reaction networks. Here we provide an overview of the statistical mechanics models for simplicial complexes, covering modelling frameworks for higher-order structures and approaches for best representation of higher-order data.

We will address the crucial question whether different representations (hypergraphs, simplicial complex, and factor graphs) are equivalent and what are the different underlying assumptions and their consequence for dynamical processes such as percolation.

This talk will then focus on triadic interactions, which occur when one or more nodes regulated the activity of an edge or an hyperedge. We will show that triadic percolation can turn percolation into a fully-fledged dynamical process in which nodes can turn on and off intermittently in a periodic fashion or even chaotically leading to period doubling and a route to chaos of the percolation order parameter. Triadic percolation on hypergraphs and on spatial networks with triadic interactions will be also discussed showing that spatially embedded networks with triadic percolation display spatio-temporal patterns of the giant component with distinct topological features.

11/4 Monday
15:10 - 15:50

Grand Canonical ensemble of networks and the transition to Optimal Transport solutions

Giulio Cimini (Tor Vergata)

Statistical mechanics models of complex networks can be formulated by considering the links, rather than the nodes, as the effective particles of the system, possibly endowed with generalized coordinates (e.g. energy). This allows defining a mapping between weighted networks and lattice gases, leading to a formal definition of the grand canonical ensemble of networks. We derive exact expressions for the partition function and thermodynamic quantities, both in the cases of global and local (i.e., node-specific) constraints on the density and mean energy of particles. We further show how to disentangle the binary and weighted statistics of the ensemble, leading to a simplified framework for a range of practical applications – such as network inference or statistical validation of empirical network patterns.
A notable extension of the framework consists in adding a cost function that favors the formation of specific links, modulated by an effective temperature. As temperature decreases the cost term becomes more important, with model configurations at the zero-temperature limit corresponding to solutions of the Optimal Transport (OT) problem. We characterize the phase transition of the model from Maximum-entropy configurations to sparse OT solutions. We outline practical applications of the model in efficiently finding such solutions and in measuring the level of "optimality" (i.e., the distance from the OT configuration) in empirical networks.

11/4 Monday
16:10 - 16:50

Renormalization and Higher-Order Interactions: Bridging Structure and Dynamics in Complex Systems

Giovanni Petri (Northeastern, London)

I will explore the interplay between renormalization techniques and higher-order correlations in both structural and dynamical models. By examining how renormalization can be extended to capture higher-order interactions in complex systems, I aim to highlight the crucial role these correlations play in shaping emergent phenomena. Through recent advancements in higher-order network theory and models of dynamical systems, I will demonstrate how incorporating higher-order structural correlations refines our understanding of collective dynamics. This synthesis provides a pathway to unify topological insights and renormalization group methods, offering a deeper framework for analyzing systems that exhibit both strong interdependence and hierarchical organization. The implications for both theoretical approaches and empirical models will be discussed, with an emphasis on future research directions.

invited talk

11/4 Monday
16:50 - 17:30

Revisited Finite-Size Scaling of Random Constraint Satisfaction Problems

Meesoon Ha (Chosun)

We present the threshold behaviors in random constraint satisfaction problems (CSPs) by stochastic-local-search (SLS) algorithms, which have exhibited great effectiveness in random CSPs. In particular, we employ the finite-size scaling (FSS) technique of nonequilibibrium absorbing phase transitions to apply it near the threshold of SLS algorithms. To provide a comprehensive picture of the solvable (SOL)-unsolvable(UNSOL) in random CSPs, such as random K-satisfiability (K-SAT) and Q-coloring (Q-COL), we focus on the FSS exponent and the universality of the SOL-UNSOL transitions by SLS algorithms. Based on the role of the noise parameter of the heuristic search, we find that the effective energy (E) and the solving time (tau) can indicate the optimal noise value. We claim that the surviving-sample-averaged quantities in the steady-state limit can play a role of good indicators to address the nature and the threshold of the SOL-UNSOL phase transitions in the thermodynamic limit. Using the FSS theory, we show that the density of the effective energy clearly indicates the transition from the solvable (absorbing) phase to the unsolvable (active) phase as the function of the noise parameter and the density of constraints. In the context of the solution clustering percolation-type argument, we conjecture two possible values of the FSS exponent, which are confirmed reasonably well in numerical simulations for $2 le K le 3$ at random K-SAT [1-3]. Finally, we conclude with some remarks and open questions for the recent update of random CSP research [3].

[1] S.H. Lee, MH, and H. Jeong, "Finite-size scaling in random K-satisfiability problems (K-SAT)", Physical Review E 82, 061109 (2010).
[2] MH, "Stochastic Local Search in Random Constraint Satisfaction Problems", New Physics: Sae Mulli 63, 995 (2013); MH, "Finite-Size Scaling in q-Coloring Problems", New Physics: Sae Mulli 67, 1023 (2017).
[3] E. Aurell et al., "Theory of Nonequilibrium Local Search on Random Satisfaction Problems" Physical Review Letters 123, 230602 (2019); G. Bresler and B. Huang, "The Algorithmic Phase Transition Random k-SAT for Low Degree Polynomials", 2021 IEEE 62nd Annual Symposium on FOCS, 298 (2022).

11/5 Tuesday
09:20 - 10:00

A new perspective of network stability: Insight from no-exclaves percolation and attractor networks

Byungjoon Min (Chungbuk)

In this talk, we explore network stability through insights from no-exclaves percolation (NExP) and attractor networks in Boolean dynamics. We first introduce and study no-exclaves percolation, a nonlocal percolation phenomenon that examines both occupied and fully enclosed empty nodes, highlighting its role in structural integrity and phase transitions. Additionally, we explore the structure of attractor networks of Boolean networks, focusing on transition probabilities between attractors. By using the approaches, we show how network structure and dynamic interactions contribute to overall stability of networks.

11/5 Tuesday
10:00 - 10:40

Percolation in networks: beyond nearest neighbors

Claudio Castellano (ISC-CNR)

Standard percolation theory assumes that two active nodes belong to the same cluster if there is a path of adjacent active nodes between them. In this talk, I will discuss two types of processes defined in a more general way, with percolation clusters not necessarily coinciding with topologically connected components. In Extended-Range Percolation (ERP) the path between two nodes in the same cluster may contain up to $R-1$ inactive consecutive nodes. Generating functions and message-passing can be adapted to this process in both single and multi-layer networks, showing the emergence of nontrivial properties different from those exhibited by standard percolation.

In Cumulative Merging Percolation (CMP) nodes are endowed with a mass m and interact up to a topological distance r(m). If the interaction range of both nodes is larger than the mutual distance, nodes can merge into clusters even if they are topologically distant. A rich phase transition scenario occurs, depending on the functional form of r(m). A specific case of CMP, with linearly growing r(m), is connected with the susceptible-infected-susceptible (SIS) dynamics for epidemics, and this allows to clarify the long debated asymptotic behavior of SIS in power-law networks.

invited talk

11/5 Tuesday
11:00 - 11:40

Modeling resource consumption and transit efficiency in transport systems with percolation and multiplex networks

Filippo Radicchi (Indiana)

In the first part of the talk, I introduce a percolation model aimed at mimicking the consumption, and eventual exhaustion, of resources in transport networks. In the model, edges forming minimum-cost paths connecting demanded origin-destination nodes are removed if the cost associated with these paths is below a certain budget. As pairs of nodes are demanded and edges are removed, the macroscopic connected component of the graph disappears, i.e., the graph undergoes a percolation transition. I characterize such a transition by means of finite-size scaling analysis, showing that different critical properties emerge depending on whether the budget parameter of the percolation model is bounded or not. In the second part of the talk, I consider a multiplex network with a fast layer embedded in a slow one. To move between any pair of nodes, one can then use either the fast or slow layer, or both, with a switching cost when going from one layer to the other. I take advantage of analytical and numerical arguments to show that the optimal structure minimizing the transit time in the network is characterized by symmetry breaking, indicating that it is sometimes better to avoid serving a whole area in order to save on switching costs, at the expense of using more the slow layer. I finally discuss the relevance of the model to estimate the efficiency of the subway system in the cities of Atlanta, Boston, and Toronto.

11/5 Tuesday
11:40 - 12:20

Collective phenomena on urban road networks: From macroscopic congestion spreading to microscopic car trajectories

Young-Ho Eom (UoS)

Various collective phenomena are observed in the flow of traffic on urban road networks that have a significant impact on city dwellers. For example, local congestion on one road can cause congestion on other roads, creating macroscopic congestion. In addition, among the seemingly random trajectories of individual vehicles on a road network, patterns can be observed that characterize the collective movement of vehicles. In this talk, we analyze traffic flow speed data and vehicle travel trajectories collected from urban road networks to understand congestion propagation and recovery phenomena, percolation features of macroscopic congestion, and emergent features in collective car travel trajectories.

11/5 Tuesday
14:30 - 15:10

Social networks with higher-order interactions: structural organization and evolutionary dynamics

Federico Battiston (CEU)

The complexity of many biological, social and technological systems stems from the richness of the interactions among their units. Over the past decades, a variety of complex systems has been successfully described as networks whose interacting pairs of nodes are connected by links. Yet, from human communications to ecological systems, interactions can often occur in groups of three or more nodes and cannot be described simply in terms of dyads. Until recently little attention has been devoted to the higher-order architecture of real complex systems. However, a mounting body of evidence is showing that taking the higher-order structure of these systems into account can enhance our modeling capacities and help us understand and predict their emergent dynamical behavior. Here I will focus on social networks beyond pairwise interactions, and describe their higher-order organization at different scales. I will then discuss new emergent phenomena characterizing dynamical processes when extended beyond pairwise interactions, with a focus on game-theoretic applications and the emergence of cooperation in social dilemmas.

11/5 Tuesday
15:10 - 15:50

Dynamics on hypergraphs and hypergraphs from dynamics

Yuanzhao Zhang (Santa Fe)

I will discuss some recent results on how higher-order interactions shape collective dynamics. For example, do higher-order interactions promote synchronization? What role does the hypergraph structure play? In the other direction, I will discuss how to infer hypergraphs from time-series data and demonstrate its applications in neuroscience. For example, how important are higher-order interactions in the brain? How do we know when are network models adequate and when are they not?

11/5 Tuesday
16:10 - 16:50

Complex Networks with Complex Weights

Mason Porter (UCLA)

Abstract

11/5 Tuesday
16:50 - 17:30

Lost Opportunities in the Innovation Landscape of Genetic Research

Cheol-Min Ghim (UNIST)

Technological revolutions in areas such as artificial intelligence, mRNA vaccines, and quantum computing are increasingly led by industry. While commercial interests often drive cutting-edge innovation, there are concerns that they may restrict scientific exploration from broader perspectives, which is essential for fostering long-term innovation. In this study, we explore the relationship between scientific exploration and industrial influence by analyzing around 20 million research papers and patents from the U.S., China, and Europe in the field of genetic research, an area with profound societal impact. Our findings show a decline in the discovery of new genes since the early 2000s, though the study of novel gene combinations continues to fuel biotechnological progress. We also observe that commercially focused fields are less likely to adopt innovative approaches, leading to diminished research vitality. Crucially, while continuous scientific exploration creates opportunities for breakthroughs, industrial R&D efforts tend to be shorter in duration. Our analysis suggests that as much as 42.2–74.4% of these opportunities could be lost if scientific research is overly influenced by commercial interests. Given the increasing dominance of industry in emerging technologies, our work highlights the importance of balancing short-term industrial gains with sustained scientific exploration to safeguard innovation, maximize the potential of genetic research, and tackle complex global challenges.

11/5 Tuesday
17:30 - 18:10

The role of timing on waning immunity in epidemics: The Rebound Effect

Clara Granell (Rovira i Virgili)

In this talk, I explore how the timing of vaccination campaigns interacts with waning immunity to shape epidemic dynamics. Using an SIRS model, we uncover a counterintuitive "rebound effect," whereby misaligned timing in vaccination efforts can inadvertently lead to a larger secondary peak of infections. This effect is driven by the interplay between vaccine-induced immunity decay and the replenishment of the susceptible population, particularly when campaigns conclude as immunity wanes. By testing different start times and campaign lengths, we demonstrate how the timing of vaccination can either increase or prevent this resurgence. These findings highlight the importance of precise vaccination timing to avoid unintentional spikes in infections and offer guidance for future epidemic control strategies.

invited talk

11/6 Wednesday
09:20 - 10:00

The Laplacian Renormalization Groups (LRG) unveils the structural organization of heterogeneous networks

Andrea Gabrielli (Roma Tre)

Abstract

11/6 Wednesday
10:00 - 10:40

Simplicity meets complexity: Challenges in reproducing complex connectivity patterns with simple models

Antroine Allard (Laval)

Since its inception about 25 years ago, Network Science has relied heavily on (simple) mathematical models to reproduce and better understand the intricate patterns of connection observed in empirical complex networks. Yet, despite several impressive achievements, the fundamental building blocks of complex networks remain to be fully identified and integrated into a comprehensive mathematical framework. In this talk, I will discuss some promising approaches toward this goal, and discuss the challenges that will need to be tackled moving forward.

11/6 Wednesday
11:00 - 11:40

Ecological Network Dynamics and Fluctuations Favour Species Coexistence in Ecological Communities

Samir Suweis (Padova)

Consumer Resources (CR) or Generalised Lotka Volterra (GLV) models are paradigmatic theoretical framework to describe species abundance dynamics in ecological communities. Most of the previous works considered fixed ecological networks, typically focusing their attention on quenched random disorder in the interaction strengths. The biodiversity of the ecological communities in these cases is limited by the competition exclusion principle (CEP), i.e. the number of coexisting species cannot be larger than the number of resources in the community. However several experimental evidences indicate that CEP in real ecological systems is typically violated. I will show how considering deterministic or stochastic dynamics in the species interactions strengths, favour species coexistence both in CRM and GLV models. In both cases, I will show how the implementation of time dependent interactions allows such models to describe ecological patterns found in empirical microbial communities.

11/6 Wednesday
11:40 - 12:20

Incorporating Heterogeneous Interactions for Ecological Biodiversity

Hye Jin Park (Inha)

In ecological systems, species interactions shape community composition by determining which species survive or perish. Understanding these coexistence mechanisms is crucial for preserving biodiversity, yet the complexity of these systems increases rapidly with the number of species, making analysis challenging. To address this, researchers have investigated how the statistical properties of interaction structures influence population-level traits in large ecosystems rather than focusing on specific small networks. Applying dynamical mean-field theory to ecological models has provided insights into principles such as how biodiversity and stability depend on randomness in interaction strength. However, the fully connected structures assumed in previous studies are unrealistic, as empirical data reveals. In this study, we derive a generic formula for species abundance distribution that accounts for an arbitrary degree distribution, leading to degree-dependent abundance patterns [1]. Notably, in contrast to well-mixed systems, heterogeneous interaction structures can reduce the number of surviving species when species enhance the growth of others on average. This occurs because heterogeneities in both interaction structure and strength can generate large hub species that drive peripheral species to extinction. This finding aligns with the idea that the emergence of dominant species decreases biodiversity [2]. Our study, therefore, demonstrates that properly accounting for heterogeneity in interaction structures is essential to understanding diversity in large ecosystems, and our general theoretical framework can be applied to a much wider range of interacting many-body systems.

[1] J. I. Park, D.-S. Lee, S. H. Lee, and H. J. Park, Incorporating Heterogeneous Interactions for Ecological Biodiversity, arXiv:2403.15730
[2] S.-G. Yang and H. J. Park, Enhancing biodiversity through intraspecific suppression in large ecosystems, arXiv:2305.12341.

invited talk

11/7 Thursday
09:20 - 10:00

The Role of Interaction Overlap in the Spread of Complex Contagions on Higher-Order Networks

Alex Arenas (Rovira i Virgili)

Contagion processes that rely on exposure to multiple sources are prevalent in social systems and are effectively represented by hypergraphs. In this talk, I will present a derivation of a mean-field model that extends beyond node- and pair-based approximations. I will demonstrate how the stability of the contagion-free state is determined by both two- and three-body interactions, and how this stability is directly related to the degree of overlap between these interactions. These findings reveal the dual effect of increased overlap: it lowers the invasion threshold but leads to smaller outbreaks. Supported by numerical simulations, our results underscore the importance of the chosen representation in describing higher-order processes.

11/7 Thursday
10:00 - 10:40

Mining of Real-world Hypergraphs: Patterns, Tools, and Generators

Kijung Shin (KAIST)

Group interactions are prevalent in various complex systems (e.g., collaborations of researchers and group discussions on online Q&A sites), and they are commonly modeled as hypergraphs. Hyperedges, which compose a hypergraph, are non-empty subsets of any number of nodes, and thus each hyperedge naturally represents a group interaction among entities. The higher-order nature of hypergraphs brings about unique structural properties that have not been considered in ordinary pairwise graphs.
In this talk, I'll offer a comprehensive overview of an emerging research topic called hypergraph mining. First, I'll present recently revealed structural properties of real-world hypergraphs, including (a) static and dynamic patterns, (b) global and local patterns, and (c) connectivity and overlapping patterns. Together with the patterns, I'll introduce advanced data mining tools used for their discovery. Lastly, I'll describe simple yet realistic hypergraph generative models that provide an explanation of the structural properties.

invited talk

11/7 Thursday
11:00 - 11:40

Epistemic Challenges in Contagion Modeling

Samuel Scarpino (Northeastern, Boston)

Abstract

11/7 Thursday
11:40 - 12:20

Structural Inequalities in Faculty Career Trajectories in South Korea

Eun Lee (Pukyong)

Academic faculty play a crucial role in the science and innovation ecosystem by driving discoveries, training future scientists, teaching, and shaping policy. However, there is limited understanding of how faculty production in developing countries like South Korea connects to advanced higher education systems globally. This study presents an analysis of faculty hiring and career trajectories, using data from 2,514 faculty members in Biology, Computer Science, and Physics. The findings reveal a heavy reliance on foreign training, with significant inequalities in faculty production concentrated in top-tier institutions, perpetuating hierarchies within academia. Additionally, postdoctoral experiences were found to play a critical role in career progression, with a strong association between postdoctoral training and institutional prestige, further reinforcing disparities. Prestige and geographic factors also impact the distribution of faculty, with institutions farther from Seoul generally having lower prestige and fewer foreign-trained faculty. These insights underscore the systemic structural inequalities that characterize faculty career development and hiring in South Korea, highlighting the interplay of prestige, training opportunities, and socio-economic factors.

11/7 Thursday
14:30 - 15:10

Branching processes for cascades on networks

James Gleeson (Limerick)

Cascade dynamics can occur when the state of a node is affected by the states of its neighbours in the network, for example when a Twitter user is inspired to retweet a message that she received from a user she follows, with one event (the retweet) potentially causing further events (retweets by followers of followers) in a chain reaction. In this talk I will review some mathematical models that can help us understand how social contagion (the spread of cultural fads and the viral diffusion of information) depends upon the structure of the social network and on the dynamics of human behaviour.

11/7 Thursday
15:10 - 15:50

Information diffusion on social networks

Xiangrong Wang (Shenzhen)

Information diffusion serves as one of the key functional properties of social networks. However, the mechanisms behind are typically complex and context-dependent. Here, I will present several scenarios of information spreading and the corresponding diffusion models, including induced percolation model, branching-like contagion model and social learning models. I will conclude with potential applications of social diffusion on collective intelligence.

11/7 Thursday
16:10 - 16:50

Incorporating Heterogeneity in Epidemic Models

Alberto Aleta (Zaragoza)

This talk explores the impact of incorporating heterogeneity in epidemic models. We will discuss the consequences of modeling interventions using networks rather than homogeneous mixing, how to construct age-structured networks, and how higher-order networks may help capture dynamics that are currently not well understood, including the challenge of defining the basic reproduction number (R0) in networked populations. Finally, we present a data-driven agent-based model that links epidemic dynamics to economic outcomes across industries and socio-economic groups, validated using data from the COVID-19 pandemic. Our findings highlight key distinctions between the economic and public health effects of non-pharmaceutical interventions (NPIs) and spontaneous behavioral changes, with important implications for targeted public health policies.

11/7 Thursday
16:50 - 17:30

Kaleidoscopic reorganization of network communities across different scales

Sang Hoon Lee (GNU)

The notion of structural heterogeneity is pervasive in real networks, and their community organization is no exception. Still, a vast majority of community detection methods assume neatly hierarchically organized communities of a characteristic scale for a given hierarchical level. In this work, we demonstrate that the reality of scale-dependent community reorganization is convoluted with simultaneous processes of community splitting and merging, challenging the conventional understanding of community-scale adjustment. We provide the mathematical argument on the modularity function, the results from the real-network analysis, and a simple network model for a comprehensive understanding of the nontrivial community reorganization process characterized by a local dip in the number of communities as the resolution parameter varies. This study suggests a need for a paradigm shift in the study of network communities, which emphasizes the importance of considering scale-dependent reorganization to better understand the genuine structural organization of networks.

invited talk

11/8 Friday
09:20 - 10:00

The temporal dynamics of group interactions in higher-order social networks

Iacopo Iacopini (Northeastern, London)

Abstract

11/8 Friday
10:00 - 10:40

An approximate master equation description of the Watts' threshold model on higher-order networks

Leah Keating (UCLA)

In this talk I will present ongoing work in which we derive an approximate master equation (AME) description of the Watts threshold model on hypergraphs. In this work, we use the extension of the Watts' threshold model to higher-order networks of Chen et al. [1], which is a discrete-time description and study it in continuous time. Mean-field approximations are inadequate to accurately model these dynamics [2]. Instead, to ensure accuracy, we use AMEs to describe both the node and the group dynamics – this is unusual as most AME models of dynamics on higher-order networks use AMEs to track the group dynamics and a mean-field approximation for the node dynamics. In this talk I will present some preliminary results including a cascade condition.

[1] L. Chen, Y. Zhu, Z. Ruan, R.-R. Liu, and F. Meng, A simple model of global cascades on random hypergraphs, arXiv preprint arXiv:2402.18850, (2024).
[2] J. P. Gleeson, Binary-state dynamics on complex networks: Pair approximation and beyond, Phys. Rev. X, 3 (2013), p. 021004.

11/8 Friday
11:00 - 11:40

A new type of Synchronization: Frequency Resonance

Cook Hyun Kim (KENTECH)

Synchronization is a crucial topic in nonlinear dynamics. Dynamical systems typically reach a steady state, often characterized by frequency synchronization. As a result, considerable research has focused on identifying the synchronization states that emerge in various dynamical systems, such as the Kuramoto model, and the phase transitions between them. However, previous studies have primarily considered states in which particles within a cluster orbit at the same frequency. In this study, we demonstrate that frequency resonances between oscillators can lead to the emergence of new steady states in the Kuramoto model with inertia. We further explore how these resonance-driven steady states form and how prevalent this phenomenon is. By introducing a new class of steady states previously overlooked in nonlinear dynamics, our work offers essential insights into the necessity of considering more diverse forms of steady and synchronized states. This can significantly advance our understanding of nonlinear dynamics and inspire further research.

11/8 Friday
11:40 - 12:20

Complexity and criticality of heterogeneous or anisotropic cascade models

Laurent Hébert-Dufresne (Vermont)

Models of how things spread often assume that transmission mechanisms are fixed over space and time. However, social contagions, like the spread of ideas, beliefs, innovations, depend on local norms and culture, and they can lose or gain in momentum as they spread. Ideas can get reinforced, beliefs strengthened, and products refined. We study the impacts of these mechanisms in cascade dynamics. Using different modelling tools, we find that complexity and criticality are the norm. Superlinear dynamics can emerge from linear systems and power-law distributions can be observed outside of critical points.

11/4 Monday
17:30 - 19:00

[P1] Neural Graph Simulator for Complex Systems

Hoyun Choi (SNU)

Numerical simulation is a predominant tool for studying the dynamics in complex systems, but large-scale simulations are often intractable due to computational limitations. Here, we introduce the Neural Graph Simulator (NGS) for simulating time-invariant autonomous systems on graphs.Utilizing a graph neural network, the NGS provides a unified framework to simulate diverse dynamical systems with varying topologies and sizes without constraints on evaluation times through its non-uniform time step and autoregressive approach. The NGS offers significant advantages over numerical solvers by not requiring prior knowledge of governing equations and effectively handling noisy or missing data with a robust training scheme. It demonstrates superior computational efficiency over conventional methods, improving performance by over 10^5 times in stiff problems. Furthermore, it is applied to the traffic forecasting, demonstrating accuracy that is comparable to the state-of-the-art models. The versatility of the NGS extends beyond the presented cases, offering numerous potential avenues for enhancement.

[P2] Inferring coupling kernel of biological oscillators using Physics-Informed Neural Network

Gyuyoung Hwang (IBS)

Abstract

[P3] Effects of structural properties of neural networks on machine-learning performance

Yash Arya (GNU)

In recent times, neural-network-based machine learning techniques such as deep learning or graph neural networks have earned significant attention. One important recent study based on relational graph representation (defining neural networks as a message exchange function over graphs) called “graph2nn” aims to understand the relationship between the graph structure of the neural network and its predictive performance, based on elementary types of model networks. In this work, we extend it to an even more general network structure, i.e, random networks with prescribed communities and study the effect on the predictive performance of a 5-layer multilayer perceptron (MLP). We found out that the network performance increases proportionally with the inter-community and edge density of the respective subgraphs. Additionally, there exists a sweet spot of relational graphs, which leads to neural networks with significantly improved predictive performance.

[P4] scLENS: data-driven signal detection for unbiased scRNA-seq data analysis

Hyun Kim (IBS)

High dimensionality and noise have long posed challenges to uncovering novel biological insights from scRNA-seq data. In this presentation, we introduce scLENS, a dimensionality reduction tool designed to address these issues without relying on manual intervention. Unlike traditional tools that often require user-determined signal dimensions, scLENS leverages random matrix theory to enable data-driven determination of signal thresholds, eliminating user bias. Additionally, it resolves signal distortion introduced by common log normalization by uniformizing cell vector lengths using L2 normalization. With a built-in signal robustness test and noise filtering mechanism, scLENS demonstrates superior performance over 11 existing tools, particularly in handling sparse and highly variable scRNA-seq datasets. To enhance accessibility, we provide a user-friendly package, automating accurate signal detection without manual tuning and ensuring fast and reliable biological discoveries.

[P5] Dynamical Approach to Braess Paradox due to Enhancing Inertia

Sangjoon Park (KENTECH)

Inertia plays an essential role in reducing frequency fluctuations in power grids. However, with the increasing production of renewable energy sources, the inertia of power grids has been decreasing. Various methods have been proposed to reinforce inertia, but paradoxically, these methods can sometimes lead to adverse effects, known as the Braess paradox. Therefore, understanding the relationship between inertia and grid stability is crucial for effectively improving power grid stability. Power variations in the grid lead to frequency fluctuations. The resulting changes in the phase and frequency of nodes can be described by the second-order Kuramoto model. The dynamics of these nodes are influenced by various factors, including power-induced accelerations and interactions with neighboring nodes. The factors governing these dynamics are different over time, allowing the system`s behavior to be classified into different dynamical regimes based on the prevailing effects. Inertial reinforcement affects these dynamical regimes, leading to either a reduction in the size of cascading failures or the emergence of the Braess paradox. In this study, we identify the dynamical regimes where the Braess paradox emerges and analyze the underlying causes of this phenomenon.

[P6] Discerning Braess' Paradox in the Power Grids Through Strategic Shortcuts

Yunju Choi (KENTECH)

The modern power grid is rapidly expanding due to the rising demand for renewable energy and electrification. However, this growth brings significant challenges in maintaining stability. In this era of rapid change, ensuring strong synchronization stability becomes increasingly important. Although substantial modifications to the power grid structure are necessary, practical challenges arise due to economic, political, and geographical constraints. Modifying the structure of an operational power grid requires careful consideration, particularly in finding ways to reduce instability with minimal adjustments. In this study, we explore the synchronization stability of power grid nodes within a ring structure that represents a simplified model, featuring concentrated production and consumption areas. Our focus is on identifying the best strategy for adding a single connection, referred to as a `shortcut,` that may enhance power grid performance. By measuring Basin stability across various scenarios, we observe that a dichotomous ring grid becomes more stable when the shortcut links nodes with different roles, such as a producer and a consumer. This effect is most pronounced when the shortcut is placed between nodes in central positions within groups of producers or consumers. Interestingly, our findings also reveal a decrease in stability, caused by Braess` Paradox, when shortcuts connect nodes with significantly different characteristics from their neighboring nodes. These results offer valuable insights into improving power grid stability with minimal structural changes, contributing to technological advancements and addressing challenges in the evolving field of power grids.

[P7] Exploring Chimera States in Synchronous Oscillators: Focusing Solely on Triadic Interactions

Gugyoung Kim (Hanyang)

Understanding the impact of higher-order interactions on collective dynamics is a challenge in complex systems. Recent research has emphasized the important contribution of higher-order interactions in the real world, ranging from brain functioning to the spread of diseases. Especially, in the brain system, a variety of partial synchronous patterns can be observed across brain regions when performing cognitive tasks or sleeping, leading to chimera states. Some studies have found the possibility of the emergence of the chimera states in the presence of the pair-wise interaction only and the mixture of the pair-wise and higher-order interactions. However, investigating the chimera states exclusively in higher-order interactions is at an early stage. This study explores the effects of triadic interactions of coupled phase oscillators, considering phase lag α. We assign either of two group labels to each oscillator, introducing the inter-group interaction β and examine the Daido parameter Q, which describes the cluster synchrony on the α-β plane. We discover the transition of Q from Q=1 to wavelike patterns on the plane and find the transition boundary (α_c, β_c) in a theoretical approach. Furthermore, increasing $\beta(\alpha)$ reduces (enlarges) the radius of the limit cycle, respectively. This study elucidates the significance of triadic interactions in chimera states and contributes to a deeper understanding of system dynamics involving higher-order interactions, thereby facilitating further investigation into synchronization dynamics within complex networks.

[P8] Competition between group interactions and nonlinearity in voter dynamics on hypergraphs

Jihye Kim (Korea)

Social dynamics are often driven by both pairwise (i.e., dyadic) relationships and higher-order (i.e., polyadic) group relationships, which one can describe using hypergraphs. To gain insight into the impact of polyadic relationships on dynamical processes on networks, we formulate and study a polyadic voter process, which we call the group-driven voter model (GVM), in which we incorporate the effect of group interactions by nonlinear interactions that are subject to a group (i.e., hyperedge) constraint. By examining the competition between nonlinearity and group sizes, we show that the GVM achieves consensus faster than standard voter-model dynamics, with an optimum minimizing exit time {tau} . We substantiate this finding by using mean-field theory on annealed uniform hypergraphs with N nodes, for which {tau} scales as A ln N, where the prefactor A depends both on the nonlinearity and on group-constraint factors. Our results reveal how competition between group interactions and nonlinearity shapes GVM dynamics. We thereby highlight the importance of such competing effects in complex systems with polyadic interactions.

[P9] Contagion dynamics on hypergraphs with nested hyperedges

Jihye Kim (Korea)

In complex social systems encoded as hypergraphs, higher-order (i.e., group) interactions taking place among more than two individuals are represented by hyperedges. One of the higher-order correlation structures native to hypergraphs is the nestedness: Some hyperedges can be entirely contained (that is, nested) within another larger hyperedge, which itself can also be nested further in a hierarchical manner. Yet the effect of such hierarchical structure of hyperedges on the dynamics has remained unexplored. In this context, here we propose a random nested-hypergraph model with a tunable level of nestedness and investigate the effects of nestedness on a higher-order susceptible-infected-susceptible process. By developing an analytic framework called the facet approximation, we obtain the steady-state fraction of infected nodes on the random nested-hypergraph model more accurately than existing methods. Our results show that the hyperedge-nestedness affects the phase diagram significantly. Monte Carlo simulations support the analytical results.

[P10] Random hypergraph model with higher-order components

Jung-Ho Kim (Korea)

Higher-order component (HOC) is ubiquitous in various classes of real-world hypergraphs. It is characterized by multiple common nodes shared between hyperedges, indicating stronger cooperation between them. Our recent study of empirical hypergraphs and higher-order-connected hypergraphs (HOCHs) shows that the presence of the giant HOC significantly alters higher-order contagion dynamics [Phys. Rev. Lett. 132, 087401 (2024)]. In the HOCH model, 'subgroups' of nodes are present, and hyperedges are formed by repeatedly selecting such a subgroup with probability p or a node with probability 1-p. It has been shown that the giant HOC may emerge with non-zero p. In this presentation, we will show the various structural properties of the generalized HOCH model. First, we analytically derive the relative size of the giant HOC as well as the node degree and the hyperedge size distributions. We validate the analytical results by extensive Monte Carlo simulation. We also investigate the property of the (k, q)-core of the HOCH model with uniform subgroup size and find the formation of an extensive number of finite (k, q)-cores, which are not observed in ordinary HOC-less random hypergraphs. Additionally, for the geometric subgroup size distribution, we obtain the optimal geometric distribution parameter yielding the smallest critical mean degree, forming the giant HOC of a given order. Lastly, we propose a scale-free HOCH model inspired by real-world hypergraphs. We found that the finite but large HOC may exist when the degree or size exponent is 2.5 or 3, even when p=0; nevertheless, their relative size vanishes for p=0 in the thermodynamic limit. It is observed that while the degree exponent has a greater effect on the size of the giant first-order component than the hyperedge size exponent does, the latter has a greater effect on the size of the giant HOC than the former. The HOCH model studied in this presentation would serve as a basis for future studies on the effects of HOC on various collective behaviors in hypergraphs.

[P11] Collective collapses are mitigated in the international trade hypergraph

Jung-Ho Kim (Korea)

Fluctuations are common in economic systems, sometimes turning into global crises. Understanding the fundamental nature and dynamics of fluctuations is crucial for assessing the current economic state and guiding future developments. Here we analyze the world trade data to investigate `collapsed trades` - those experiencing significant declines in annual volume. By mapping these collapsed trades onto the international trade hypergraph (ITH), where countries and products are grouped by weighted hyperedges representing individual trades with annual volumes as weights, we find that collapsed hyperedges (trades) are not distributed uniformly but tend to cluster, like infectious disease outbreaks in social networks. This suggests that collapse may propagate by infection between adjacent hyperedges, moreover with inhomogeneous rates, as indicated by the observed algebraic decay of collapse probability with hyperedge weight. To uncover the mechanisms driving collective collapse, we propose and analyze an inhomogeneous collapse propagation model within the ITH. Using both analytical and numerical methods, we demonstrate that the positive correlation between a hyperedge`s degree and weight - robustly identified in the real-world ITHs - suppresses the onset of global collapse under the inhomogeneous infection rates, potentially serving as a stabilizing mechanism for the global economy.

[P12] Local and global wealth condensation on sparse networks & Emergence of cooperation in the social dilemma with wealth-dependent payoffs

Hyun Gyu Lee (KIAS)

The yard-sale (YS) model, in which a portion of the smaller wealth is transferred between two individuals, culminates in the concentration of almost all wealth to a single individual, while distributing the rest of the wealth with a power law of exponent one. By incorporating redistribution to the model, in which the transferred wealth is proportional to the sender's wealth, we show that such extreme inequality is suppressed if the frequency ratio of redistribution to the YS-type exchange exceeds the inverse of the population size. Studying our model on a sparsely-connected population, we find that the wealth inequality ceases to grow for a period, when local rich nodes can no longer acquire wealth from their broke nearest neighbors. Subsequently, inequality resumes growth due to the redistribution effect by allowing locally amassed wealth to move and coalesce. Analyzing the Langevin equations and the coalescing random walk on complex networks, we elucidate the scaling behaviors of wealth inequality in those multiple phases. These findings reveal the influence of network structure on wealth distribution, offering a novel perspective on wealth inequality.

As a second project, we investigated the evolutionary dynamics of the Prisoner’s Dilemma game with wealth-dependent payoff magnitudes on a one-dimensional lattice. Our findings reveal that cooperation can emerge more readily compared to the conventional models where payoffs are independent of wealth. Specifically, we focus on a simplified version of the game, the “donation Prisoner’s Dilemma,” where payoffs are defined by the cost and benefit of cooperative actions. The magnitude of these payoffs depends on the wealth of the players, with the benefit being set as a small fixed fraction of the minimum wealth between the two players, inspired by the Yard-Sale model of wealth exchange. The players’ wealth is initially equal but accumulates by collecting the payoffs through games with neighbors. Players adopt the strategy of the nearest neighbors based on a payoff-driven probability, resulting in the strategy evolution. We explore the dynamics of strategy evolution as a function of the cost-benefit ratio, $c \in [0, 1]$, and identify a threshold, c^*, below which cooperation dominates. Unlike the the conventional 1-dimensional Prisoner’s Dilemma, where $c^* = 1/2$, our model shows that cooperation can emerge even when $c > 1/2$ as clusters of cooperators manage to accumulate sufficient wealth so that the payoffs of cooperating neighbors may exceed those of defecting ones. We also observed the enhancement of cooperation in 2-dimentional lattice.

[P13] Analyzing the Impact of Sentiment in Naver Stock Forums on Market Trends Using BERT

Jinjoo Yoon (Chosun)

In recent years, the relationship between investor sentiment and financial market behavior has become an important area of study. This research focuses on analyzing the sentiments expressed in Naver stock discussion forums and their correlation with stock price fluctuations. By employing a BERT-based Korean language model, we conduct a sentiment analysis of posts to identify patterns that may be linked to market trends. Furthermore, we investigate how the activity patterns of specific authors within the forums contribute to shifts in stock prices. Our findings indicate that online sentiment serves as a significant predictor of market dynamics. This study suggests that the sentiment expressed in online discussions can be used to gain insights into the factors influencing market volatility, presenting an alternative approach to understanding the interaction between social sentiment and financial systems.

[P14] Correlations in Regional Consumption Patterns in the Republic of Korea during the COVID-19 Pandemic: A Complex Networks Approach

Woori Bong (Chosun)

This study uses nonlinear dynamics and complex network theory to analyze the interaction between regional factors, the COVID-19 pandemic, and inflationary pressures on consumption behavior, using credit card transaction data from 2019 to 2022 in the Republic of Korea. We examine the influence of geographical, economic, and demographic variables on consumer spending, drawing parallels with complex systems in physical sciences. By integrating credit card data with indices such as the COVID-19 Fear Index and Economic Stability Indices, we establish correlations between shifts in spending patterns and economic disturbances induced by the pandemic. Our analysis also highlights the differential impact of the COVID-19 Fear Index and government policies on regional and sectoral consumption patterns. The findings reveal significant regional variations, emphasizing the role of localized economic conditions and demographics. This research enhances understanding of consumer dynamics amid global crises and demonstrates the value of transactional data in analyzing complex socio-economic systems. Given the substantial impact of the COVID-19 pandemic on human mobility and consumption patterns, our study suggests that economic effects should be considered in pandemic management strategies.

[P15] Mapping the structure of knowledge acquisition from STEM education data in Korean universitiess

Gahyoun Gim (GNU)

Most of the current research topics on "science of science" are centered around journal-based research activities, while those research activities are based on knowledge acquisition during formal education and training in science, technology, engineering, and mathematics (STEM) from undergraduate years. Therefore, it is essential to map the structure of STEM education in universities for a comprehensive understanding of contemporary scientific progress. As a first step toward that goal, we assess the raw data composed of 126,347 undergraduate courses from 2,841 STEM departments across 161 institutions for the 2024 spring semester, publicly provided by the Ministry of Education in Korea. To remove the effectively duplicated entries and errors in the raw course data, we process the raw data by considering higher-order interactions following the data preprocessing conducted via a large language model (LLM) and establish 24,467 standardized courses as nodes used in the following network analysis. This yields the bipartite network of standardized courses and institution departments conducting the courses, weighted by the course credit. From the scale-dependent community analysis of its department-mode projection, we observe a semi-hierarchical reorganization of departments, starting from the division of "hard", "soft", and "technical" science/engineering in the lowest resolution. Another notable example is a nontrivial reorganization of interdisciplinary departments across different scales. From the standardized course data, we plan to extract mesoscale structures, e.g., local hubs forming the core courses for each discipline and interdisciplinary courses connecting different communities, and directional information, e.g., curriculum prerequisite and postrequisite courses. Based on the analysis, we expect a more systematic assessment of the current university-level STEM education structure in Korea and possibly provide a quantitative guideline to design a new curriculum for newly emerging or interdisciplinary academic units.

[P16] Finite Size Scaling Approach for Revealing Inherent Scale-Freeness in Heterogeneous Networks

Yeonsu Jeong (Hanyang)

Most systems exhibit a scale-free distribution, where the degree distribution follows a power law, but the discussion about the ``scale-freeness`` of empirical networks has recently re-entered due to the inherent finiteness of real-world systems. A recent study [1] has suggested a method to identify the true scale-freeness in networks using finite-size scaling, which can classify a network into whether it is a SF network or not. It has shown good performance about the well known model networks including the Barabási-Albert (BA) model, providing the optimal value of degree exponent. In this study, to detect the scale-freeness and find the optimal degree exponent, we apply to other heterogeneous networks such as the static-model network and the generalized BA network whose degree exponents can be freely adjusted. That is because we want to a confirm whether this method works in networks with different underlying mechanisms. Next, we extend the considered networks to the node-removed network depending on a different removal strategy, explored in Ref.[2]. In the previous study, the regime diagram of SF-like and Poisson-like regimes is obtained by the relative entropy. To overcome the intrinsic limitation of the entropy measure, we reconfirm the boundary by this method.

[1] M. Serafino, G. Cimini, et al, Proc. Natl. Acad. Sci. U.S.A. 118, e2013825118 (2021).
[2] M. J. Lee, J.-H. Kim, et al, Phys. Rev. E 106, 064309 (2022)..

[P17] Susceptible-Infected-Recovered/Dead-Susceptible (SIR/DS) model with mutation on complex networks

HaeChan Seo (Kyung Hee)

In contrast to the previous studies on epidemic spreading models which assume that pathogen mutation rates are much slower compared to the dynamics of the epidemic itself, we propose an extension of the classical susceptible-infected-recovered-susceptible (SIRS) model to study the effect of the pathogen mutations and disease-induced mortality on the dynamical properties of epidemic spreading. In our model, called the susceptible-infected-recovered/dead-susceptible (SIR/DS) with mutation, pathogens mutate during transmission with a mutation probability μ, which affects both the fatality probability η and transmission probability β. From numerical simulations, we find that changes in the mutation probability μ and immunity loss probability ξ lead to observable drifts in pathogen characteristics within the parameter space, which in turn alter the overall infection state of the system. We also analyze and discuss the underlying mechanisms responsible for these phenomena.

[P18] Information Dynamics and Phase Transitions on Complex Networks

HwaRang Kim (Kyung Hee)

In this study, we analyze the epidemic SIS model on complex networks, demonstrating that the behavior of the von Neumann entropy, derived from the density matrix, changes when it crosses the critical point. Our findings show how von Neumann entropy seamlessly integrates nonlinear dynamics, network structure, and phase transitions into a cohesive framework for identifying critical points through entropy—a key concept in statistical physics. Additionally, we extend this framework to various nonlinear systems that also exhibit phase transitions.

[P19] Phase Transitions in the Simplicial Ising Model on Hypergraphs

Gangmin Son (KIAS)

The common assumption of pairwise interactions relies on the superposition principle; when it fails, higher-order interactions (HOIs) become essential. As a prototypical model for understanding the role of HOIs, we study the simplicial Ising model defined on hypergraphs where energetic gain for each hyperedge is achieved only when the member spins are aligned unanimously, as proposed in [arXiv:2401.11588]. Using the mean-field approximation, we show that HOIs lead to diverse scenarios of phase transitions, depending on the size of hyperedges. Specifically, for ell-uniform hypergraphs, discontinuous transitions occur when $ell>4$ and the transition temperatures show nonmonotonic behavior due to an intrinsic tradeoff of the simplicial rule. Furthermore, when pairwise interactions and HOIs coexist, there appears a region where continuous and discontinuous transitions successively occur in the phase diagram, especially when the size ell of HOIs is $ell>8$. Finally, we find that during the double transitions, HOIs barely contribute to the magnetization before the discontinuous transitions.

[P20] Role of Spectral Dimension and Edge Overlaps in Mutual Percolation on Multiplex Networks

Gangmin Son (KIAS)

Both geometric and topological properties govern the dynamical processes and phase transitions of not only networks but also multiplex networks. To explore the role of spectral dimension and edge overlaps, we numerically study mutual percolation on one-dimensional multiplex networks with long-range connections and without edge overlaps. In each layer, the connection probability between two nodes with distance r scales as $sim 1/r^{(1+sigma)}$ where $sigma$ is related to the spectral dimension d_s by $d_s approx 2/sigma$ [1]. Our results indicate that in this setup, the lower bound of $sigma$ for continuous transitions is approximately $sigma > 1/3$, corresponding to $d_s < 6$. Finally, we compare our results with previous studies, including mutual percolation on the geometric multiplex model [2], which uses a similar setup but induces correlated edge overlaps, and on hypercube-based interdependent networks [3,4].

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[P21] Inference of the latent hyperbolic organization of networks

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Many real-world and model networks are embedded in latent space. If two nodes are close in the latent space, there is a disproportionately high probability that a link connects them. In most cases, the latent coordinates of each node are not provided, hence it must be discovered by an appropriate method. Estimation of the latent coordinate of each node, along with the determination of the dimension of a network is a core topic in network geometry. Here, we present an effective algorithm that maps a given network into its hyperbolic latent geometry by exploiting the mathematical properties of the hyperbolic model. We discuss the dimension of the latent space and spectral properties of networks.

[P22] Bifurcations and multistability in empirical mutualistic networks

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Individual species may experience diverse outcomes, from prosperity to extinction, in an ecological community subject to external and internal variations. Despite the wealth of theoretical results derived from random matrix ensembles, a theoretical framework still remains to be developed to understand species-level dynamical heterogeneity within a given community, hampering real-world ecosystems' theoretical assessment and management. Here, we consider empirical plant-pollinator mutualistic networks, additionally including all-to-all intragroup competition, where species abundance evolves under a Lotka-Volterra-type equation. Setting the strengths of competition and mutualism to be uniform, we investigate how individual species persist or go extinct under varying these interaction strengths. By taking a dynamical systems approach, we meticulously study how increments in these interactions create particular sequences of extinctions and find the interaction strengths threshold values in which multistability arises. Hence, we are able to elucidate interaction strength regimes where, depending on the initial abundances of the species, different extinction scenarios arise within an ecological network.

[P23] Spectral dimension and coarse-graining of hypergraphs for diffusion

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We explore a diffusion process on hypergraphs represented in bipartite network form [1], focusing on their spectral dimensions and effective coarse-grained representations for late-time behaviors. First, we introduce a Barabási-Albert-type hypergraph model that includes a tunable correlation between node degree and hyperedge size. This model reveals that correlated hypergraphs exhibit lower spectral dimensions, indicating that diffusion is impeded by structural correlation. We then extend the recently proposed Laplacian Renormalization Group (LRG) and the Kadanoff supernode procedure [2] to hypergraphs such that the spectral density function for small eigenvalues, effectively capturing the late-time diffusion behavior, is preserved and the dynamic variables are aggregated additively under the LRG transformation. We apply this coarse-graining procedure to obtain effective hypergraphs and analyze their structural characteristics.

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