Introduction

The conference is the 9th one of the biannual KIAS conferences on statistical physics since 2004. It aims to present new ideas in statistical physics and related fields and to facilitate scientific exchange and collaboration among leading scientists as well as students and postdocs. Please note that the NSPCS2020 was skipped due to the COVID-19 pandemic. This year, we expect that the offline meeting should be possible, but the online or hybrid meeting is also prepared in case of possible continuation of the COVID-19 pandemic.

Topics include

nonequilibrium fluctuations and transport, stochastic thermodynamics, large deviations, extreme value statistics, nonequilibrium phase transitions, disordered and glassy systems, bio-related problems, complex systems and more...

Organizers

Hyunggyu Park (KIAS)
Jae Sung Lee (KIAS)
Jae Dong Noh (UOS)
Yongjoo Baek (SNU)
David Mukamel (Weizmann)
Satya Majumdar (Orsay)

Program Schedule

The program consists of invited talks, contributed talks, and poster sessions.

	Jul 24 Sun	Jul 25 Mon	Jul 26 Tue	Jul 27 Wed	Jul 28 Thur
08:30 - 08:50		Registration	Coffee & Sandwiches		
08:50 - 09:00		Opening			
09:00 - 09:40		H. Chaté	J. Kurchan	M. Kardar (Online)	H. Rieger
09:40 - 10:20		J.S. Lee	J. D. Noh	S. -i. Sasa (Online)	C. Hyeon
10:20 - 10:40		Break			
10:40 - 11:20		L. Cugliandolo	D. Rosa	Y. Baek	J. Lee P.-J. Kim (Online)
11:20 - 12:00		D. -H. Kim	A. Andreanov U. Mishra (Online)	J.-M. Park S. Lee	L. -H. Tang
12:00 - 15:00		Lunch	Photo Lunch	Lunch Excursion(Hiking) (14:00-19:00)	Closing & Lunch
15:00 - 15:40		A. Dhar (Online)	Y. Kafri (Online)		
15:40 - 16:20		D. Mukamel (Online)	S. Majumdar (Online)		
16:20 - 16:40		Break			
16:40 - 17:20		M. Evans (Online)	H. Quan (Online) V. Shaghaghi		
17:20 - 19:00	Pre-Conference Dinner(19:00 ~)	Poster	P.S. Pal Break Banquet(18:00~20:00)		

Day 1 – July 25 (Mon)

08:30-08:50	Registration/Coffee & Sandwiches	
08:50-09:00	Opening	
Morning Session Ⅰ		Chair : H. Park
09:00-09:40	H. Chaté	Fragility of polar flocks
09:40-10:20	J. S. Lee	Speed limit for a highly irreversible process and tight finite-time Landauer's bound
10:20-10:40	Break	
Morning Session Ⅱ		Chair : H. Park
10:40-11:20	L. F. Cugliandolo	Phases and topological defects in two dimensions
11:20-12:00	D.-H. Kim	Perturbative approach to the structure of logarithmic information spreading in the deep MBL regime
12:00-15:00	Lunch	
Afternoon Session		Chair : J. S. Lee
15:00-15:40	A. Dhar (Online)	A blast and a splash in a cold gas
15:40-16:20	D. Mukamel (Online)	Transport and condensation of driven tracers in a narrow channel
16:20-16:40	Break	
16:40-17:20	M. R. Evans (Online)	Interacting Persistent Random Walkers
17:20-19:20	Poster Session	

Day 2 – July 26 (Tue)

08:30-09:00	Coffee & Sandwiches	
Morning Session Ⅰ		Chair : L.-H. Tang
09:00-09:40	J. Kurchan	Quantum bounds to chaos and fluctuation-dissipation relation
09:40-10:20	J. D. Noh	Thermalization and chaos of isolated quantum spin systems
10:20-10:40	Break	
Morning Session Ⅱ		Chair : J. Kurchan
10:40-11:20	D. Rosa	Operator delocalization in quantum networks
11:20-11:40	A. Andreanov	Delayed Thermalization in Mass-Deformed SYK
11:40-12:00	U. Mishra (Online)	Driving enhanced quantum sensing in periodically driven Integrable models
12:00-15:00	Lunch	
Afternoon Session Ⅰ		Chair : H. Rieger
15:00-15:40	Y. Kafri (Online)	The long-ranged influence of disorder on active systems
15:40-16:20	S. Majumdar (Online)	Optimal Resetting Brownian Bridge
16:20-16:40	Break	
Afternoon Session Ⅱ		Chair : Y. Baek
16:40-17:00	H. Quan (Online)	A microscopic theory of Curzon-Ahlborn heat engine based on a Brownian particle
17:00-17:20	V. Shaghaghi	Extracting work from random collisions: A model of a quantum heat engine
17:20-17:40	P.S. Pal	First passage time in stochastic resetting process with finite time return
17:40-18:00	Break	
18:00-20:00	Banquet	

Day 3 – July 27 (Wed)

08:30-09:00	Coffee & Sandwiches	
	Morning Session Ⅰ	Chair : C. Hyeon
09:00-09:40	M. Kardar (Online)	Competitive growth on a rugged front
09:40-10:20	S.-i. Sasa (Online)	Gibbs paradox and quasi-static decomposition in small thermodynamic systems
10:20-10:40	Break	
	Morning Session Ⅱ	Chair : D.-H. Kim
10:40-11:20	Y. Baek	Generic symmetry-breaking motility via negative drag in active fluids
11:20-11:40	J.-M. Park	Enhancing synchronization in the growing systems of oscillators
11:40-12:00	S. Lee	Entropy production estimation
12:00-14:00	Lunch	
14:00-19:00	**Excursion (Hiking) & Dinner**	

Day 4 – July 28 (Thu)

08:30-09:00	Coffee & Sandwiches	
	Morning Session Ⅰ	Chair : J. D. Noh
09:00-09:40	H. Rieger	Capillary action of active matter
09:40-10:20	C. Hyeon	Fluctuations in radiative transitions
10:20-10:40	Break	
	Morning Session Ⅱ	Chair : H. Chaté
10:40-11:00	J. Lee	Poisson distributions in stochastic dynamics of gene expression: What do they count?
11:00-11:20	P.-J. Kim (Online)	How to Generalize Michaelis-Menten Kinetics for Time-Varying Molecular Concentrations
11:20-12:00	L.-H. Tang	Agent-based model of COVID-19 transmission for location-specific risk assessment and control
12:00-15:00	**Closing & Lunch**	

[Talk 1] Fragility of polar flocks

Hugues Chaté
CEA-Saclay, France, & Computational Science Research Center, Beijing, China

Polar flocks, understood in the Vicsek/Toner-Tu sense of the collective flow of self-propelled particles aligning their velocities, have been and remain central in active matter studies. They are a limit case of real situations: the fluid surrounding particles is ignored (“dry”), the particles are pointlike (“dilute”), so that alignment is the only interaction. Even though their relevance in the real world is limited (but not nil), they must be studied thoroughly since understanding them is crucial to approach more complicated and realistic systems. One key property of polar flocks is that they show true long-range (polar) orientational order even in 2D. It is also well-known that a coexistence phase separates homogeneous flocks from the disordered gas phase. This coexistence phase also displays LRO, but it is inhomogeneous, typically made of dense, ordered, traveling bands. Recently, evidence started accumulating that the orientational order of polar flocks is fragile to various kinds of perturbations, whereas the band phase is more robust. I will review these findings and discuss their implications, considering successively the influence of:

*spatial anisotropy[1]
*spatial quenched disorder[2]
*population chirality disorder[3]
*one small obstacle[4]

following the recent publications listed below, whose co-authors are warmly thanked.

[1]A. Solon, H. Chaté, J. Toner, J. Tailleur, Phys. Rev. Lett. 128, 208004 (2022)
[2]Y. Duan, B. Mahault, Y-q Ma, X-q Shi, H. Chaté, Phys. Rev. Lett. 126, 178001 (2021)
[3]B. Ventejou, H. Chaté, R. Montagne, X-q Shi, Phys. Rev. Lett. 127, 238001 (2021)
[4]J. Codina, B. Mahault, H. Chaté, J. Dobnikar, I. Pagonabarraga, X-q Shi, Phys. Rev. Lett. 128, 218001 (2022)

[Talk 2] Speed limit for a highly irreversible process and tight finite-time Landauer's bound

Jae Sung Lee
School of Physics, Korea Institute for Advanced Study

Landauer's bound is the minimum thermodynamic cost for erasing one bit of information. As this bound is achievable only for quasistatic processes, finite-time operation incurs additional energetic costs. We find a "tight" finite-time Landauer's bound by establishing a general form of the classical speed limit. This tight bound well captures the divergent behavior associated with the additional cost of a highly irreversible process, which scales differently from a nearly irreversible process. We demonstrate the validity of this bound via discrete one-bit and coarse-grained bit systems. Our work implies that more heat dissipation than expected occurs during high-speed irreversible computation. (ref: arxiv:2204.07388)

[Talk 3] Phases and topological defects in two dimensions

Leticia F. Cugliandolo
Sorbonne Université, Laboratoire de Physique Théorique et Hautes Energies

Long-range translational order is forbidden in low dimensional systems with short-range interactions: solid phases can only have quasi long-range translational order while they keep long-range orientational order. The standard picture is that the melting transition occurs in two steps: an intermediate phase with quasi long-range orientational order is reached by the unbinding of dislocations while the transition to the liquid is triggered by the unbinding of disclinations. In this talk I will revisit all these issues and I will extend their analysis to systems of self-propelled particles, the constituents of active matter, a new kind of soft matter relevant to describe numerous biological problems. The dynamics across various phase transitions will also be briefly discussed. A new scenario emerges from extensive molecular simulations studies.

[Talk 4] Perturbative approach to the structure of logarithmic information spreading in the deep MBL regime

Dong-Hee Kim
GIST

We present the perturbative calculation of the out-of-time-ordered correlator (OTOC) in the deep many-body localized regime of the disordered Heisenberg XXZ model. We consider the OTOC measured with an eigenstate, showing that the light cone of information propagation is highly structured but confined in logarithmic bounds in both one and two dimensions. We obtain the closed-form expression of the OTOC spectrum associated with the slowest propagation along the upper logarithmic light cone. For the lower light cone of the fastest propagation, we provide an effective Hamiltonian with a reduced Hilbert space representing the lowest order perturbation, revealing a scaling relation of the OTOC spectrum distinguishing between the upper and lower logarithmic light cones.

[Talk 5] A blast and a splash in a cold gas

Abhishek Dhar
International centre for theoretical sciences, Bangalore

We study the response of an infinite system of point particles on the real line, initially at rest, to the instantaneous release of energy in a localized region. The blast generates shock fronts that travel sub-ballistically. The density, velocity, and temperature profiles in the growing region between the shock fronts can be obtained from exact self-similar solutions of the Euler equations. We compare these with the results of direct microscopic simulations. At long times, the results obtained from the microscopic dynamics show a remarkable agreement with the predictions from Euler hydrodynamics except at the blast core where we show that corrections due to heat conduction are important. We will also discuss the " splash" problem where energy is injected from one side of a semi-infinite cold gas

[Talk 6] Transport and condensation of driven tracers in a narrow channel

David Mukamel
Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot , Israel

The effect of particle overtaking on transport in a narrow channel is studied using a 1d model of a driven tracer in a quiescent bath. The model is found to exhibit a phase transition from sub-ballistic transport at low overtaking rates to a more conventional ballistic transport beyond a critical rate. This is in contrast with the well-studied non-driven case, where no transition takes place and the tracer's long-time dynamics is diffusive whenever overtaking possible. It is also shown that the bath mediates strong attractive interaction between driven tracers, which grows linearly with the distance between the tracers and results in condensation in the steady state. These findings are compared with numerical simulations of a model of hard disks moving in a two dimensional narrow channel. 1,2,3

1. A. Miron, D. Mukamel and H. A. Posch, JSTAT, 063216 (2020).
2. A. Miron, D. Mukamel and H. A. Posch, J Phys A 54, 025001 (2021).
3. A. Miron, D. Mukamel and H. A. Posch, Phys. Rev. E 104, 024123 (2021).

[Talk 7] Interacting Persistent Random Walkers

Martin R. Evans
School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, UK

In this talk I will consider persistent random walkers, also known as run and tumble particles, which are emerging as a fundamental microscopic model of active matter. I will first review the properties of a single persistent walker and show that the dynamical spectrum exhibits exceptional points. A familiar example of an exceptional point is the critical damping of the simple harmonic oscillator. I will then consider the case of two persistent random walkers that interact through an exclusion interaction. An exact expression for the stationary state of two such walkers on a periodic lattice reveals how the particles jam and generate an effective attractive potential. The full spectrum of the two-particle problem can also be computed and again exhibits exceptional points, which correspond to dynamical transitions in the relaxation time. Finally, I will discuss a more general `recoil' interaction between the persistent walkers and show how tuning the persistence length can generate attractive or repulsive effective interactions.

A. B. Slowman, M. R. Evans, R. A. Blythe Phys. Rev, Lett. 116 218101 (2016)
E Mallmin, R.A. Blythe, M. R. Evans J. Stat. Mech. 013204 (2019)
M. J. Metson, M. R. Evans, R. A. Blythe 2022 to appear

[Talk 8] Quantum bounds to chaos and fluctuation-dissipation relation

Jorge Kurchan
Laboratoire de Physique, Ecole Normale, Paris

The existence of quantum bounds for transport properties have been long conjectured. At the moment, the only certain result we have is a quantum bound to the Lyapunov exponent, known as the `quantum bound to chaos'. I will discuss how this bound is simply derived from the (quantum) fluctuation-dissipation relation, the KMS condition.   This relation suggests a lead to follow, I will describe a partial result.

[Talk 9] Thermalization and chaos of isolated quantum spin systems

Jae Dong Noh
Department of Physics, University of Seoul, Seoul 02504, Korea

Isolated quantum systems can relax to the thermal equilibrium state under the unitary time evolution. The eigenstate thermalization hypothesis is believed to explain the mechanism for the quantum thermalization although it is not clear a priori whether a particular system satisties the hypothesis. Recently, it is proposed that the growth of a local operator in the Kyrlov space is an indicator of a quantum chaos. We have performed extensive numerical works to investigate the quantum thermalization and the quantum chaos in the quantum spin models. In this talk, we present the numerical results for one-dimensional quantum spin chains, such as the XXZ model and the Ising model with transverse and longitudinal fields. We also present the results for the spin-1/2 XXZ model in two-dimensional square lattices.

[1] J. D. Noh, Phys. Rev. E 104, 034112 (2021).
[2] J. D. Noh, Phys. Rev. E 103, 012129 (2021).
[3] J. D. Noh, T. Sagawa, and J. Yeo, Phys. Rev. Lett. 125, 050603 (2020).

[Talk 10] Operator delocalization in quantum networks

Dario Rosa
IBS-PCS

I will introduce the notion of operator delocalization, to be contrasted with the more conventional notion of operator growth. I will show that even free quantum mechanical systems, once defined on sufficiently connected networks, can exhibit non-trivial delocalization properties. Some preliminary results, based on a current work in progress, on the connection between operator delocalization and quantum many-body chaos will be discussed.

[Talk 11] Delayed Thermalization in Mass-Deformed SYK

Alexei Andreanov
IBS Center for Theoretical Physics of Complex Systems

We study the thermalizing properties of the mass-deformed SYK model, in a regime of parameters where the eigenstates are ergodically extended over just portions of the full Fock space, as an all-to-all toy model of many-body localization. Our numerical results strongly support the hypothesis that, although considerably delayed, thermalization is still present in this regime. Our results add to recent studies indicating that many-body localization should be interpreted as a strict Fock-space localization.

[Talk 12] Driving enhanced quantum sensing in periodically driven Integrable models

Utkarsh Mishra
Institute of Fundamental and Frontier Sciences (IFFS)
University of Electronic Science and Technology of China (UESTC)

The ground state criticality of many-body systems is a resource for quantum enhanced sensing, namely the Heisenberg precision limit, provided that one has access to the whole system. We show that for partial accessibility the sensing capacity of a block in the ground state reduces to the sub-Heisenberg limit. To compensate for this, we drive the system periodically and use the local steady state for quantum sensing. Remarkably, the steady state sensing shows a significant enhancement in its precision in comparison with the ground state and even shows super-Heisenberg scaling for a certain range of frequencies. The The origin of this precision enhancement is found to be the closing of the Floquet gap. This is in close correspondence with the role of the vanishing energy gap at criticality for quantum enhanced ground state sensing with global accessibility.

Refs:
1. Utkarsh Mishra and Abolfazl Bayat, Phys. Rev. Lett. 127, 080504 (2021).
2. Victor Montenegro, Utkarsh Mishra, and Abolfazl Bayat, Phys. Rev. Lett. 126, 200501 (2021).
3. Utkarsh Mishra and Abolfazl Bayat, arXiv:2105.13507.

[Talk 13] The long-ranged influence of disorder on active systems

Yariv Kafri
Technion - Israel Institute of Technlogy

The talk will describe the impact of quenched random potentials on active matter. By developing a methodology for studying these systems both bulk and boundary disorder will be considered. For dilute systems it will be shown that bulk disorder leads to generic long-range correlations, decaying as a power-law, and steady-state currents. Disorder localized along a wall confining the system leads to long-range density modulations and eddies whose amplitude decays as a power law with the distance from the wall, but whose extent grows with it. The talk will also consider dense scalar active systems whose sole hydrodynamic mode is the density. These are known to exhibit a motility induced phase separation in dimensions d \geq 2. It will be shown that bulk potential disorder destroys the transition in dimensions d<4, while boundary disorder destroys it in dimensions d<3.

[Talk 14] Optimal Resetting Brownian Bridge

Satya Majumdar
LPTMS, CNRS, Universite Patis Saclay, Orsay (France)

After reviewing briefly the mechanism for an optimal resetting Brownian motion (RBM), I will discuss a resetting Brownian bridge (RBB). A Brownian bridge is a Brownian motion conditioned to reach a fixed point of space after a fixed interval. When a small resetting rate is switched on, we find a surprising mechanism for bridges that enhances fluctuations, rendering a target search efficient in the case of bridge also. This mechanism for RBB is very different from that of RBM. I'll show that this `fluctuation enhancing mechanism' (FEM) for RBB is robust and occurs in all dimensions. At the end, I will discuss how to derive an effective Langevin equation that generates RBB of a fixed duration very efficiently using a rejection-free algorithm.

B. De Bruyne, S. N. Majumdar, and G. Schehr, Phys. Rev. Lett. 128, 200603 (2022)

[Talk 15] A microscopic theory of Curzon-Ahlborn heat engine based on a Brownian particle

Haitao Quan
School of Physics, Peking University, Beijing, China.

The Curzon-Ahlborn (CA) efficiency, as the efficiency at the maximum power (EMP) of the endoreversible Carnot engine, has significant impact on finite-time thermodynamics. However, the CA engine is based on many assumptions. In the past few decades, although a lot of efforts have been made, a microscopic theory of the CA engine is still lacking. By adopting the method of the stochastic differential equation of energy, we formulate a microscopic theory of the CA engine realized with a highly underdamped Brownian particle in a class of non-harmonic potentials. This theory gives microscopic interpretation of all assumptions made by Curzon and Ahlborn. In other words, we find a microscopic counterpart of the CA engine in stochastic thermodynamics. Also, based on this theory, we derive the explicit expression of the protocol associated with the maximum power for any given efficiency, and obtain analytical results of the power and the efficiency statistics for the Brownian CA engine. Our research brings new perspectives to experimental studies of finite-time microscopic heat engines featured with fluctuations.

[Talk 16] Extracting work from random collisions: A model of a quantum heat engine

Vahid Shaghaghi[1,2,3]
[1]*Center for Nonlinear and Complex Systems, Dipartimento di Scienza e Alta Tecnologia, Universit`a degli Studi dell'Insubria, via Valleggio 11, 22100 Como, Italy*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Milano, via Celoria 16, 20133 Milano, Italy*
[3]*Center for Theoretical Physics of Complex Systems, Institute for Basic Science (IBS), Daejeon - 34126, Korea*

We study the statistical distribution of the ergotropy and of the efficiency of a single-qubit battery ad of a single-qubit Otto engine, respectively fueled by random collisions. The single qubit, our working fluid, is assumed to exchange energy with two reservoirs: a nonequilibrium "hot" reservoir and a zero-temperature cold reservoir. The interactions between the qubit and the reservoirs are described in terms of a collision model of open system dynamics. The qubit interacts with the nonequilibrium reservoir (a large ensemble of qudits all prepared in the same pure state) via random unitary collisions and with the cold reservoir (a large ensemble of qubits in their ground state) via a partial swap. Due to the random nature of the interaction with the hot reservoir, fluctuations in ergotropy, heat, and work are present, shrinking with the size of the qudits in the hot reservoir. While the mean, "macroscopic" efficiency of the Otto engine is the same as in the case in which the hot reservoir is a thermal one, the distribution of efficiencies does not support finite moments, so that the mean of efficiencies does not coincide with the macroscopic efficiency.

[Talk 17] First passage time in stochastic resetting process with finite time return

Priyo Shankar Pal
1 School of Physics, Korea Institute for Advanced Study, Seoul 02455, Korea

Stochastic resetting is a diffusion process whose state is reset to a fixed state at random times. Here we consider a Brownian particle undergoing such a process in a thermal environment, where the position of the particle is reset using a potential trap. Introducing Brownian functionals, we calculate the first passage time to reach a final target and the work done during the process. We study the trade-off between the first passage time and the work done for such process.

[Talk 18] Competitive growth on a rugged front

Mehran Kardar
MIT

After competing species expand into a new territory, the population is dominated by descendants of a few successful ancestors at expansion front. Successful ancestry is stochastic, but biased by fitness of the individual, as well as favorable geographic location. I shall present a simple model of range expansion of competing bacteria, in which reproduction and competition only take place at the growing front. Based on symmetry considerations we construct a pair of nonlinear stochastic partial differential equations that describe the coevolution of the profile of the growing surface and the composition of the bacterial species on the front. From the perspective of critical phenomena, fixation of a competing species (extinction of all other species) belongs to the directed percolation (DP) universality class. Using renormalization group methods we show that coupling to a rough interface leads to a new universality class. If the competing species have different finesses, more rapid growth of the fitter species leads to a jagged front. A less fit species that would go extinct on a flat front is shown to establish a growing niche if its initial location on a bumpy front confers an advantage (in height).

[Talk 19] Gibbs paradox and quasi-static decomposition in small thermodynamic systems

Shin-ichi Sasa
Department of Physics, Kyoto University, Kyoto 606-8502, Japan

The free energy of a classical system consisting of N-interacting identical particles in contact with a heat bath contains the Gibbs factorial $N!$ in addition to the phase space integration of the Gibbs-Boltzmann factor. This formula can be derived as the classical limit in the quantum statistical mechanics with the assumption that the entropy is given by the Shannon entropy of the density matrix, while $N!$ is missing in the formula when the same formulation is considered for classical systems with the Shannon entropy of the canonical distribution. From this fact, one may understand that $N!$ comes from quantum mechanics. However, this interpretation is not logically correct, because it might be possible that the definition of the free energy is not valid. There are several approaches characterizing the Gibbs factorial in classical systems. Our argument stands on a general principle that thermodynamic quantities are defined by experimentally measurable quantities. That is, whether or not $N!$ appears in the formula should be determined by thermodynamic considerations. Concretely, we show that the free energy can be uniquely determined, up to an additive constant proportional to N, from the two conditions†. First, the quasi-static work in any configuration change is equal to the free energy difference. Second, the temperature dependence of the free energy satisfies the Gibbs-Helmholtz relation. In particular, the factor $N!$ is unambiguously found from the work in the quasistatic decomposition of small thermodynamic system with any N. In my talk, I will explain our theory with reviewing several approaches to $N!$.

† S.-i. Sasa, K. Hiura, N. Nakagawa, and A. Yoshida, arXiv:2205.05863

[Talk 20] Generic symmetry-breaking motility via negative drag in active fluids

Yongjoo Baek
Seoul National University

A symmetric object in an active fluid may gain motility due to a ‘negative drag’ which applies in the direction of the object’s velocity. In previous studies, the phenomenon presupposed the presence of polar or nematic order in the active fluid. In this study, we show by a mean-field argument that such symmetry-breaking motility can generally emerge even in dilute and disordered active funds. The phenomenon manifests itself as both continuous and discontinuous transitions associated with the bifurcation of the steady-state velocity of the object. We also numerically show that the critical phenomena accounting for the continuous transition belong to the mean-field Ising universality class regardless of the shape of the object.

[Talk 21] Enhancing synchronization in the growing systems of oscillators

Jong-Min Park
School of Physics, Korea Institute for Advanced Study

We study the optimal condition for enhancing the synchronization of coupled oscillators described by the Kuramoto model on a growing network. The synchronization is observed in a wide range of systems and associated with their function. Although population growth is a common feature of many oscillator systems, such as biological, neural, and power-grid systems, few studies have been conducted on the synchronization of growing systems. We propose strategies to find the approximate optimal natural frequencies of a new oscillator based on the global or local order parameter in the strong coupling regime. We verify that in simple examples our schemes coincide with intuitive expectations. To demonstrate the validity of our results, we apply the strategies to systems on the random growing and the Barabasi-Albert networks and compare them with other plausible strategies. The numerical data show that the proposed strategies outperform others over a wide range of coupling strength, confirming that our strategies provide near-optimal frequencies in various growing systems even far from the strong coupling limit. Our results reveal that appropriate growing schemes can induce a more noticeable synchronization enhancement than other plausible and intuitive methods.

[Talk 22] Entropy production estimation

Sangyun Lee
School of Physics, Korea Institute for Advanced Study

Entropy production is an important quantity in nonequilibrium thermodynamics. With detailed information and heat measurement, we can estimate the entropy production. However, for complex systems including biological systems and experimental setup, accessing all detailed information and estimating heat flow is difficult. Alternatively, direct estimation via its definition, logarithm ratio of forward and backward trajectory probability, is also challenging problem due to the curse of dimensionality. In this talk, we present two indirect strategies to mitigate the curse. One method employs multi-layer perceptron structure and Donsker-Vardhan inequality [1,2], and the other method [3] employs entropic bound derived by Dechant and Sasa [4]. With those methods, we estimate the entropy production of several systems such as Gaussian chain, flashing ratchet, and RNA unfolding process.

[1] DK Kim, Y Bae, S Lee, and H Jeong, Phys. Rev. Lett. 125, 140604 (2020).
[2] DK Kim, S Lee, and H Jeong, Phys. Rev. Res. 4, 023051 (2022).
[3] S. Lee, DK Kim, JM Park, W. K. Kim, H. Park, and J. S. Lee (in preparation).
[4] A. Dechant and S.-I Sasa J. Phys. A:Math. Theor. 52, 035001 (2019).

[Talk 23] Capillary action of active matter

Heiko Rieger
Department of Physics and Center for Biophysics, Saarland University, Germany

In this talk the capacity of active matter to rise in thin tubes against gravity and other related phenomena is discussed, like wetting of vertical plates and spon- taneous imbibition, where a wetting liquid is drawn into a porous medium. This capillary action or capillarity is well known in classical fluids and originates from at- tractive interactions between the liquid molecules and the container walls, and from the attraction of the liquid molecules among each other. We observe capillarity in a minimal model for scalar active matter with purely *repulsive* interactions, where an effective attraction emerges due to slowdown during collisions between active parti- cles and between active particles and walls. Simulations indicate that the capillary rise in thin tubes is approximately proportional to the active sedimentation length λ and that the wetting height of a vertical plate grows superlinear with λ. In a disordered porous medium the imbibition height scales as $\langle h\rangle \propto \lambda\phi_m$, where ϕ_m is its packing fraction. Closer inspection of the particle velocity field shows that a stationary particle current in the form of an extended vortex drives the elevation of the sedimented active material at the walls. We compare our predictions with the capillary action of suspensions of sedimenting active colloids.

† Adam Wysocky and Heiko Rieger, Phys. Rev. Lett. 124, 048001 (2020).

[Talk 24] Fluctuations in radiative transitions

Changbong Hyeon
Korea Institute for Advanced Study

Two case studies of fluctuations in radiative transitions are discussed. First, we consider transition dynamics of an open quantum two-level system driven by a weak external field. Our analysis of the model system suggests that the imaginary part of quantum coherence, which contributes to dissipation to the environment, suppresses the relative fluctuations in the net current of transitions, whereas the real part of the coherence enhances them. Thus, when the imaginary part of quantum coherence is dominant over the real part, the overall fluctuations of the transition dynamics are suppressed, and loosens the bound of thermodynamic uncertainty relation. Second, our model will be extended to discuss the phenomenon of slow light in the medium of atomic vapor characterized with three-level Lambda systems. We show that there is a trade-off between the group velocity of the light and Fano factor of net transition events (or photon current). The Fano factor of the photon current maximizes to 3 at the minimal group velocity of light, which holds true universally regardless of detailed values of parameters characterizing the medium.

[Talk 25] Poisson distributions in stochastic dynamics of gene expression: What do they count?

Julian Lee
Dept. of Bioinformatics and Life Science, Soongsil University

The Poisson distribution is the probability distribution of the number of independent events in a given period of time. Although the Poisson distribution appears ubiquitously in various stochastic dynamics of gene expression, both as time-dependent distributions and the stationary distributions, underlying independent events that give rise to such distributions have not been clear, especially in the presence of the degradation of gene products, which is not a Poisson process. I show that, in fact, the variable that follows the Poisson distribution is the number of independent events where biomolecules are created, which are destined to survive until the end of a given time duration. This new viewpoint allows us to derive time-dependent Poisson distributions as solutions of master equations for general class of protein production and degradation dynamics, including models with time-dependent rates and a non-Markovian model with delayed degradation. I then derive analytic forms of general time-dependent probability distributions by combining the Poisson distribution with the binomial or the multinomial distributions.

[Talk 26] How to Generalize Michaelis-Menten Kinetics for Time-Varying Molecular Concentrations

Pan-Jun Kim
Hong Kong Baptist University

Since introduced in the early 20th century, the Michaelis–Menten (MM) rate law has been the de facto standard for modeling enzymatic reactions. Despite its simple and intuitive interpretation for a wide range of applications in biochemistry, biophysics, cell biology, and many subfields of chemical engineering, the MM rate law as well as its modified form is only valid for quasi-steady states of molecular complex formation, which are not necessarily met under active changes in molecular concentrations over time. Here, we relax this quasi-steady-state requirement and propose the generalized MM rate law where the effective time delay in molecular complex formation comes into pivotal play. The presented scheme consistently improves the approximation of molecular interaction dynamics across various biochemical processes. For example, when protein concentrations are subject to daily biological rhythms--circadian rhythms, our proposed rate law tends to make more accurate predictions for the conditions of oscillations, the oscillation periods, and the emerging rhythmicity in protein degradation rates. Besides, our approach improves kinetic parameter estimation. This mathematical framework, as the revision of the widely-used MM rate law, offers broad applicability for scientific research as well as for high-precision control of molecular systems in engineering domains.

[Talk 27] Agent-based model of COVID-19 transmission for location-specific risk assessment and control

Lei-Han Tang
Department of Physics and Institute of Computational and Theoretical Studies
Hong Kong Baptist University

Since the emergence of the Omicron variant in November 2021, control measures that were highly effective against previous SARS-CoV-2 strains have been shown to be insufficient to stop the virus, leading to sweeping outbreaks or lockdowns. Furthermore, mass qPCR test has been practiced in many places as an ultimate means of source control. Local authorities adjust the frequency of testing according to the overall scale of the outbreak. Public venues such as shopping malls, airports, etc., allow entry only when negative test result within a certain period is presented. So how effective are these measures? To answer this question, we consider an agent-based model of disease transmission which can be adapted to a great variety of community transmission patterns. From the statistics of individual's visit trajectories, a location-based network model for transmission risk propagation can be established. Under a given daily routine of individuals in the community, the model is able to predict the epidemic growth rate λ in terms of the characteristics of disease progression within an infected individual, and of the propagation matrix linking a list of locations. Furthermore, a risk index can be assigned to each location that corresponds to its significance as a transmission node. The effectiveness of testing and quarantine measures in reducing λ can be evaluated quantitatively without going into the details of the visit pattern. On the other hand, transmission hotspots and amplifying mechanisms can be identified through a detailed study of the risk propagation matrix. We illustrate these concepts and results via simplified scenarios which nevertheless could aid the design of more efficient epidemic control measures, particularly when combined with human mobility data and practices.

[P1]

Langevin Neural Network: Inferring Force and Diffusion Fields from Trajectories

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Many living and complex systems exhibit stochastic processes described by the Langevin equation. However, inferring such governing equation of motion from experimental data is a challenging task due to their fluctuating nature, so a general framework is still missing. In this paper, we propose the Langevin Neural Network (LNN) that can infer force and diffusion fields solely from a trajectory. Training our estimators by maximizing the log-likelihood function, we can accurately infer force field as well as diffusion field. Compared with a previous study called stochastic force inference (SFI) [1, 2], we further confirm high performance even in the case of high-dimensional, non-linear force fields, and inhomogeneous diffusion fields.

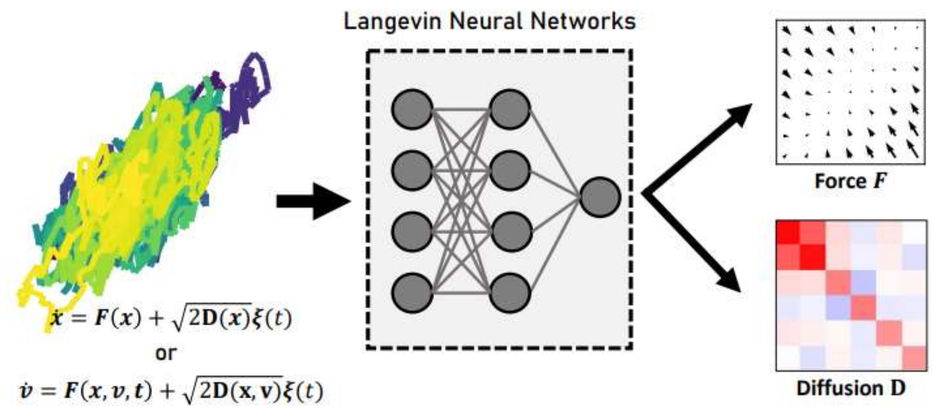

Figure 1: Schematic of the Langevin Neural Networks (LNN). From a trajectory of Brownian system, LNN learns force and diffusion fields by maximizing the log-likelihood function.

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[2] D. B. Brückner, P. Ronceray, and C. P. Broedersz, Phys. Rev. Lett. **125**, 058103 (2020).

[P2]

Dynamics of vibrated active particles in a crowded circular confinement

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Self-propelled particles immersed in a dense granular medium provides an interesting way to build a self-organizing system with both structural stability and flexibility. Here we experimentally and theoretically investigate the dynamics of such a system, namely a few self-propelled polar particles placed among a crowd of densely packed nonpolar disks in a two-dimensional circular confinement. First, we observe that each self-propelled particle exhibits anomalous diffusion within the granular medium, eventually reaching and sticking to the boundary of the system. The anomalous diffusion is accompanied by the $1/f$ noise and the power-law interevent time distribution, whose characteristics depend on the aspect ratio and the polarity of the self-propelled particles. Second, we observe that multiple self-propelled particles eventually form a stable cluster at the boundary, which persistently moves in one direction if the number of constituent self-propelled particles are below a certain threshold. We propose a simplistic model describing how the motile cluster can be maintained via symmetry-breaking mechanism and why the motility cannot be maintained when the cluster becomes too large. These results show that merely changing the particle shape and number can effectively modulate the collective motion of a self-organized structure.

[P3]

Effects of synchronization on the coding capacity and spike spreading in neural networks

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We introduce a neural network model to study the effect of the synchronization on the encoding capacity and spreading spikes in more realistic situation. In this model the neural network is composed of excitatory and inhibitory neurons and long-lasting synaptic current operated by heterogeneous Poisson synaptic input. Based on the numerical integrations, we find three different regimes depending on the ratio of coupling strength between the inhibitory and the excitatory neurons. In each regime, we study the relationship among the synchronization, information coding capacity, and spreading of spikes. We also discuss possible relation between the observed regimes and physiological disorders.

[P4]

Deep reinforcement learning for optimal mechanism in active Brownian particles

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In this study, each particle of the active Brownian particle system is regarded as an agent; and we used a deep reinforcement learning framework to find optimal mechanisms that can maximize the transportation ability. The results show that global ordering and collision-avoiding mechanisms are shown when there is no cost for control, while polar clustering of particles appears when there is a cost.

[P5]

Bias-bias-variance tradeoff in unsupervised learning

Gilhan Kim
Seoul National University

How does a machine learning algorithm achieve the minimum generalization error? For traditional examples of supervised learning (*e.g.*, linear regression and k-means clustering), it is well known that the minimization involves a tradeoff between two different error components, namely *bias* and *variance*. In those cases, lowering the bias by making the model more complex entails an increase in the variance, producing the bias-variance tradeoff. Meanwhile, in unsupervised learning, little has been studied about whether the same tradeoff phenomenon occurs. In this study, using the structure of the Kullback-Leibler divergence, we propose a three-component decomposition of the generalization error for general unsupervised learning. Using our scheme, the generalization error is the sum of model bias, data bias, and variance, which account for model limitations, deficiencies in the training data, and the variability of the training dynamics, respectively. By training the Restricted Boltzmann Machine (RBM) to generate the configurations of the two-dimensional Ising model and the totally asymmetric simple exclusion process with open boundaries, we observe that as the model complexity increases, the model bias decreases while the data bias and the variance increase. These indicate that the generalization error of unsupervised learning exhibits the *bias-bias-variance tradeoff* between the three error components. We also discuss how the optimal model complexity depends on the complexity of the training data, which is controlled by the temperature of the 2-d Ising model and the entry/exit rate of TASEP.

[P6]

Roughening transition of information landscape in social networks

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We study the dynamical properties of the information landscape caused by social contagion. To model the information dynamics and competition between influencers, Halvorsen-Pedersen-Sneppen (HPS) integrated asymmetric social interactions into a static undirected social network†. By mapping the information value in the HPS model to the height of the interface, we find that the fluctuation of the information landscape $W(L,t) =< (h - \bar{h}(t))^2 >^{1/2}$ shows a non-trivial transition when the dimension of the static social network structure is larger than one. From the numerical simulations, we find that $W(L,t)$ scales as $W(L,t) = L^{\alpha} f(t/L^{z})$ when the static undirected social network is given by the 1-dimensional lattice, regardless of the value of the parameters. Here $f(x)$ is a scaling function. On the other hand, for the 2-dimensional static social networks, we find that the information landscape undergoes a roughening transition due to the competition between influencers.

† Halvorsen et al.[Phys Rev. E 103, 022303(2021)].

[P7]

Inter-record time distribution for the Korean stock market and housing market

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Record statistics for the Lévy walks with constant drift is known to be classified by five different regimes depending on the tail exponent of the Lévy distribution and drift-constant †. The statistical property of each regime is closely related to the first-passage probability which corresponds to the inter-record time (IRT) distribution for the given time series. When only small numbers of the time series are available, we show that the IRT distribution can be a useful measure to classify its underlying stochastic process. In this study we analytically derive the IRT distribution for the 1-dimensional Lévy walks with constant drift. Based on the obtained results, we analyze the statistical properties of records in the Korean stock market and housing market.

† S. N. Majumdar, G. Schehr, and G. Wergen, J. Phys. A **45**, 355002 (2012).

[P8]

Efficiency at maximum power of fuel-consuming active engines

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Recent researches have reported that heat engines powered by active matter can apparently exhibit super-Carnot behavior. To obtain the full thermodynamic picture enabling the unconventionally high performance, we construct a thermodynamically consistent model of active heat engine driven by fuel consumption. We introduce the 'composite' efficiency containing both notions of heat injection and fuel consumption, whose upper bound is precisely given by the second law of thermodynamics. Using the entropic bounds of energetic currents involved, we rigorously show that the upper bound of composite efficiency is not reachable simultaneously with finite power, ruling out the possibility of so-called "dream engine". Next, we analytically investigate some properties of the composite efficiency at maximum power (EMP). First, we discuss the effect of the parity of the self-propulsion force under time-reversal. A competition between two length scales - engine's spatial size and persistent length of the particle's self-propulsion - gives a clear criterion of which parity being more beneficial to EMP. Furthermore, when the temperature difference between two thermal reservoirs are sufficiently large, we report the superiority of the active engine's composite EMP compared to that of the passive case. Consequently, the power and efficiency can be simultaneously improved by the activity even in the thermodynamically complete description. With these observations, we discuss optimal design principles of actively driven microscopic machines under prescribed spatiotemporal scales and self-propulsion mechanisms.

[P9]

The Effect of Risk Sharing between Syndicated Loan Networks on Loan Pricing

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July 2022

Abstract

This study scrutinized the effect of network centrality on the price determination of loans. This study aims to verify that banks use personal information from firms or industries and macroscopic information generated from the inter-bank loan market when signing loan contracts. Using the loan data provided by the Dealscan database from 2000 through 2020, the monthly inter-bank network was formed through the similarity of the global bank's loan portfolio to listed firms in the united states. The main results of this study are as follows. The network centrality of each bank plays a critical role in forming loan prices. In particular, the pattern of risk exposure between banks during the financial crisis was similar. Through these results, it can be inferred that banks do not only have existing loan relationships but also personal information delivered through the loan portfolio comprehensively, affecting the bank-firm relationship. This result could help us to understand the mechanism of the bank-firm relationship for assessing the quality of them and identify a channel affecting the relationship by using a complex network.

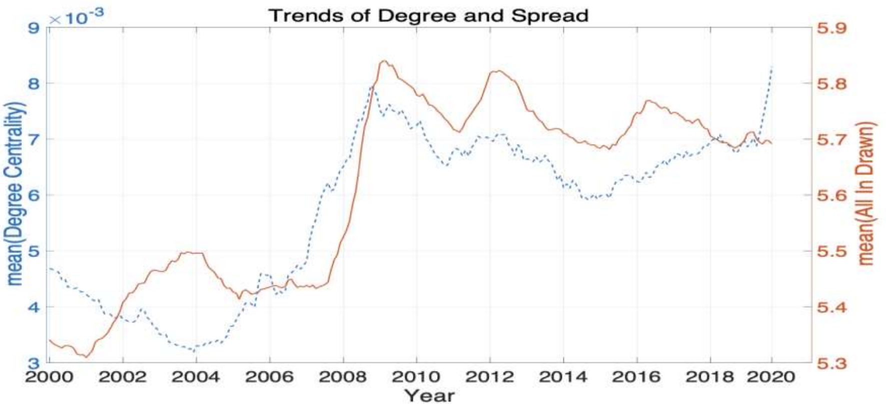

Figure 1: Degree centrality of syndicated loan networks and cost of financing. We construct syndicated loan networks of global banking based on the loans originated during 12 months to firms listed in the U.S by Planar maximally Filtered Graph (PMFG) (Tumminello et al., 2005) from 2000 through 2020. The cost of financing is estimated by natural logarithm of All-in Spread Drawn(AISD), defined as total (fees and interests) annual spread paid over LIBOR for each dollar drawn down from the loan.

Keywords— Inter-bank Network, Loan Pricing, Risk Sharing, Connectedness

Acknowledgements

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[P10]

Finite-Size Scaling and the Multi-Crossover Critical Behavior in a 2D Incompressible Flocking Model

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We study the disorder-order phase transition in 2D incompressible systems of polar self-propelled particles with alignment interaction, by comparing numerical simulations of the incompressible Toner-Tu equation against finite-size scaling theory. A perturbative renormalization group analysis near 4D showed that the model undergoes a continuous transition, and it belongs to a new non-equilibrium universality class where both the advective nonlinearity and the ferromagnetic nonlinearity are relevant [1].

Our numerical simulations in 2D agree with the scenario of a continuous transition. We further find multi-crossover behavior near criticality as the system size increases. At smaller sizes, the model can behave like the equilibrium dipolar XY model, showing a first crossover at an intermediate size. At larger sizes, it deviates from the dipolar XY behavior, as the advective nonlinearity comes in to decrease the dynamical exponent, suppress large-scale fluctuations and help stabilize the order. The small-size regime before the first crossover shows the interesting feature that mean-field exponents are observed for the $k = 0$ mode, whereas the Gaussian statistics is found for $k > 0$. We propose a reduced hydrodynamic theory that quantitatively captures the critical behavior in this small-size regime [2].

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[2] W. Qi, L.-H. Tang, and H. Chaté (to be published).

[P11]

Relation of the first passage time to the entropy change

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In [1-3] a distribution is introduced containing the first passage time (FPT) as a random thermodynamic parameter. The conjugate thermodynamic parameter is expressed in terms of the change in entropy during the first passage time. Thus, changes in entropy in a nonequilibrium system are taken into account, which, as a rule, are not taken into account. In [4] it is shown that the influence of whom accounting can be significant. The procedure resembles the operation carried out in [5], when the stationary distribution is replaced by a quasi-stationary one after the introduction of an additional thermodynamic force. When finding the maximum of the Kullback entropy, the thermodynamic force is expressed in terms of the average value of the thermodynamic variable. The expression of the conjugate FPT thermodynamic variable in terms of the change in entropy makes it possible to take into account various kinds of effects on the system, which are included in the change in entropy. In this case, it is possible to take into account not only stationary changes in entropy.

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4. Ryazanov, V.V., First passage times of mesoscopic charge transport and entropy change**,** https://arxiv.org/abs/2201.06497.
5. R. L. Stratonovich, *Nonlinear Non-equilibrium Thermodynamics*, Springer, Heidelberg, 1992.

[P12]

Thermodynamic uncertainty relation in degenerate and nondegenerate maser heat engines

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[2] Center for Nonlinear and Complex Systems, University of Insubria, 22100 Como, Italy

[3] Department of Physics, Koç University, 34450 Sarıyer, Istanbul, Turkey

In this work, we investigate the thermodynamic uncertainty relation, which represents a trade-off between entropy production rate and relative power fluctuations, for non-degenerate three-level and degenerate four-level maser heat engines. For the non-degenerate case, we study two slightly different configurations of three-level maser engine and compare degree of violation of thermodynamic uncertainty relation in both models. We highlight that in the high temperature regime, conventional thermodynamic uncertainty relation is always violated in three-level maser heat engine. We also show that the thermodynamic uncertainty relation remains invariant when we scale the matter-field coupling constant and system-bath coupling constants by the same factor. Further, for the degenerate four-level engine, we study the effects of noise-induced coherence on the thermodynamic uncertainty relation. We show that depending on the parametric regime of operation, the phenomenon of noise-induced coherence can either enhance or suppress the relative power fluctuations.

[P13]

Multiscale nature of geometric correlations and robustness against targeted attack in multiplex networks

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We investigate the role of the multiscale nature in multiplex networks with geometric correlations and the robustness against attacks. Based on recent studies [1,2], it has been revealed that real multiplex networks have geometric correlations, so that the robustness of multiplex networks is improved against the ordinary targeted attack. We provide a comprehensive view of multiscale geometric correlation spectra as measuring geometric correlations for coarse-grained replicas of multiplex networks. In case of real multiplex networks with the multiscale nature, we observe anomalous correlation patterns. To speculate the effect of such anomalous patterns on the robustness of multiplex networks against attacks in diverse manners, we compare the geometric multiplex model (GMM) [1] with a newly suggested multiscale GMM. In particular, we focus on effective attack strategies in the multiscale nature of geometric correlations and scaling properties. Finally, we discuss the types of phase transitions and its origins, where we consider overlap edges and weak percolation clusters as well.

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[P14]

Ferromagnetic phase transition of diffusing spin systems

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We investigate the phase transitions of the Brownian Potts and clock models in two dimensions. In these models, particles carrying the Potts or clock spin diffuse freely and interact ferromagnetically with others within a fixed distance. In the Brownian q-state Potts model, we find a continuous phase transition from a paramagnetic to a ferromagnetic phase even for $q > 4^{\dagger}$. This is in contrast to the existence of a discontinuous phase transition in the corresponding equilibrium q-state Potts model in 2D. In the p-state clock model, on the other hand, the particle diffusion does not modify the nature of the phase transitions for $p > 4$. The system undergoes phase transitions from a ferromagnetic phase through a quasi-long-range ordered (critical) phase to a paramagnetic phase. The critical behaviors are consistent with the renormalization group picture for the equilibrium p-state clock model.

† C.-U. Woo, H. Rieger, and J. D. Noh, Physical Review E **105**, 054144 (2022).

[P15]

Grouping effect of social media activity on investor types

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Abstract

The interactions among objects in the financial market are often understood by information created from social media activity. For the financial system, numerous datasets generated from the equity market and social median exist that possible the analysis of investor behavior. In contrast to neoclassical economics, that assumes rational agents, complexity or behavior economics relaxes restricts assumption of traditional economic theory. Thus an agents have imperfect information about what might happen in the future. This paper investigates an inter-connection relationship between social media and financial market. We used a social media activity obtained from the Naver finance website, one of representative social media in South Korea. The average number of message per day is 39,504 and the average number of views is 15,608,238. Heterogeneous agents, including retail, institutional, and foreign investors in financial market appear to describe the mechanism of relevant financial market characteristics, such as fluctuations in equity return and interactions among firms. Especially, the types of agent in equity market that characterize these firm depends on firms-suggesting that heterogeneity of investors in the financial market may depend on the characteristics of the firm. Here, we propose an entropy method, based on the assumption of heterogeneity of investors that can measure the diversity of investors in a firm. We find that the group with high entropy showed high grouping coefficient in the network among firms, while companies with low entropy ad relatively little grouping effect.

PACS numbers: 05.45.Df, 05-10-a, 05.40.Fb, 05.90+m

Keywords: Social media activity, Grouping effect, Heterogeneous investor

[P16]

Robust estimation of entropy production via alpha-divergence

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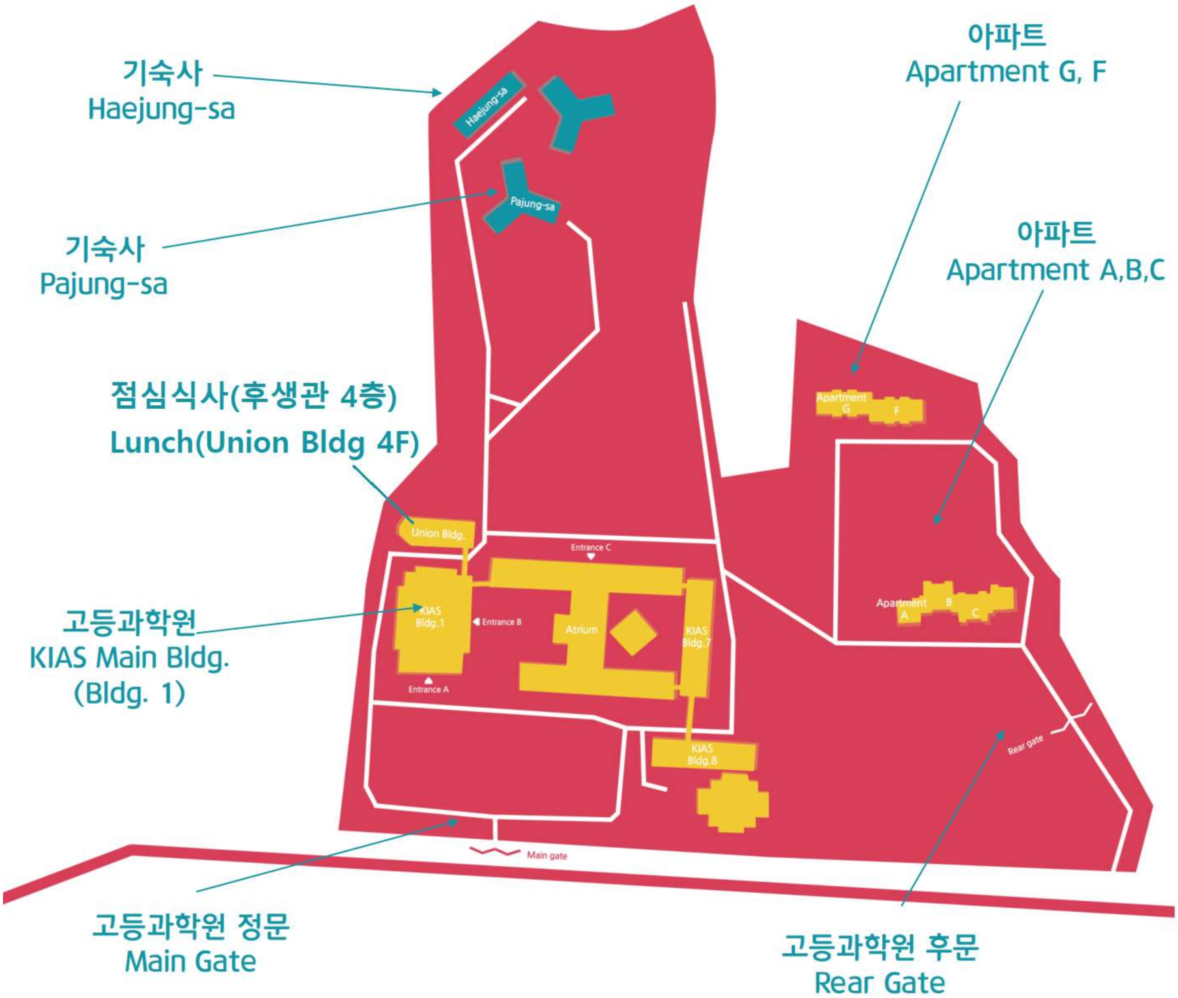
Recent years have seen a surge of interest in the algorithmic estimation of stochastic entropy production (EP) from the trajectory data via machine learning. A crucial element of such algorithms is the identification of a loss function whose minimization guarantees the accurate EP estimation. In this study, we show that there exists a host of loss functions, namely those implementing a variational representation of α-divergence, which can be used for the EP estimation. Among these loss functions, the one corresponding to $\alpha=-0.5$ provides the most robust estimation of EP, maintaining high accuracy even when the existing method based on Kullback-Leibler divergence (corresponding to $\alpha=0$) becomes inaccurate in the presence of strong nonequilibrium driving. To describe this phenomenon, we present an exactly solvable simplification of the EP estimation problem, which shows that the minimum of the loss function is least affected by the insufficient sampling of rare data precisely when $\alpha=-0.5$. While we illustrate our findings using the method of deep learning, they are also applicable to other machine learning techniques in general.

Campus Map



기숙사
Haejung-sa
Haejung-sa
기숙사
Pajung-sa
Pajung-sa
아파트
Apartment G, F
아파트
Apartment A,B,C
점심식사(후생관 4층)
Lunch(Union Bldg 4F)
Union Bldg.
Entrance C
고등과학원
KIAS Main Bldg.
(Bldg. 1)
KIAS
Bldg.1
Entrance B
Atrium
KIAS
Bldg.7
Entrance A
KIAS
Bldg.8
Apartment
G
F
Apartment
A
B
C
Rear gate
Main gate
고등과학원 정문
Main Gate
고등과학원 후문
Rear Gate