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# 제20차 통계물리 워크숍

THE 20TH  
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STATISTICAL PHYSICS

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대명리조트 변산

# 제 20차 통계물리 워크숍 일정표

장소: 대명리조트 변산

\* 발표 8분, 질의 및 응답 2분

시간	8월 21일 (수)	8월 22일 (목)	8월 23일 (금)
08:00 ~ 09:00		조식	조식
09:00 ~ 10:40		<b>Session 3</b> 통계물리일반 (SP) 좌장: 김동희	<b>Session 5</b> 복잡계 (CS) 좌장: 김범준
10:40 ~ 11:00		휴식	휴식
11:00 ~ 13:00		<b>Session 4</b> 복잡계 (CS) 좌장: 안강현	<b>Session 6</b> 생물물리 (BP) 좌장: 백승기
13:00 ~ 14:00	14:00 ~ 15:00 등록	점심	점심
15:00 ~ 16:40	<b>Session 1</b> 생물물리 (BP) 좌장: 노재동	14:00 ~ 19:00 Excursion	
16:40 ~ 17:00	휴식		
17:00 ~ 19:00	<b>Session 2</b> 복잡계 (CS) 좌장: 육순형		
19:00 ~	저녁식사	19:00~21:00 만찬	

# 발표순서

## Session 1: 생물물리 (BP)

좌장: 노재동 (서울시립대)

- [BP01] Beta-diversity patterns of benthic macroinvertebrate metacommunities  
KyoungEun Lee (EnFRA)
  
- [BP02] Mean field theory of star-shaped block copolymers and the effect of confinement  
정현우 (UNIST)
  
- [BP03] Generalizing the Yamakawa-Stockmayer theory for the looping of a heterogeneous stiff polymer and its application to D-shaped DNA.  
Chan Lim (POSTECH)
  
- [BP04] Exploring genome functionality with neural networks  
Nelli Boichenko(충남대학교)
  
- [BP05] Study of cation- $\pi$  interaction in short peptides  
강원준(UNIST)
  
- [BP06] Heterogeneous dynamics in living cell  
정유림(POSTECH)
  
- [BP07] The Rosenfeld scaling relation in the lateral diffusion of membrane protein-antibody complexes  
주성민 POSTECH)
  
- [BP08] Bioinspired active matter  
김현재(충남대학교)

## Session 2: 복잡계 (CS)

좌장: 육순형 (경희대학교)

- [CS01] First-order phase transition in Kuramoto model with asymmetric interaction  
양성규 (성균관대학교)

- [CS02] The Modified Kuramoto Model with Power Law Coupling and Spatial Time Delay  
이해성 (성균관대학교)
- [CS03] Symmetry-induced Stable Chimeras of Kuramoto Oscillators  
이승재 (전북대학교)
- [CS04] Effective Landau free energy for hybrid synchronization transitions  
송제웅 (서울대학교)
- [CS05] 베이스 추론을 이용한 반복 죄수의 딜레마 게임  
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- [CS06] Prediction of Chaotic Motion Using Reservoir Computing Recurrent Neural Networks  
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- [CS07] 인공 신경망에 의한 행동 결정과 죄수의 역설 게임 전략 진화  
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- [CS08] Prisoner's dilemma game on signed networks  
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- [CS09] 스낫캐스트 데이터를 활용한 투수 특징 파악과 패턴 분석  
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- [SP02] Phase transition of a tricritical directed percolation in long-range interacting systems in low dimensions.  
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- [SP03] Variational Monte Carlo simulation based on an artificial neural network ansatz for a quantum phase transition study  
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- [SP04] Logarithmic finite-size-scaling corrections to the leading zeros in the p-state clock model  
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- [SP07] 진동하는 하모닉 포텐셜 중심에 의해 유도된 비평형 운동  
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좌장: 안강현 (충남대학교)

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## Session 5: 복잡계 (CS)

좌장: 김범준 (성균관대학교)

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- [CS27] Growth of scientific collaborations: scaling of first Betti number in growing  
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- [CS28] 자원 경쟁이 존재하는 상리공생 네트워크 속에서의 생물종의 번성도  
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- [CS29] Effect of Cooperation in Two-Species Microbial System  
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- [CS31] Self-Organized Criticality of Neural Avalanche in a Neural Model on  
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- [CS32] Efficient deep learning  
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- [CS33] 시교차 상해의 일주기 리듬의 다중안정성을 재현할 수 있는 사실적 연결망을 반영한  
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- [CS34] Topographic arrangement of simple and complex cells in neural network of  
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## Session 6: 생물물리 (BP)

좌장: 백승기 (부경대학교)

[BP09] Sound signal processing, where and what

박상현 (충남대학교)

[BP10] 빛 자극과 전기생리학을 이용한 광-유전 형질 감염된 시교차상핵의 신경망 연결 구조에 대한 연구

민철홍 (고려대학교)

[BP11] Dynamics of synaptic vesicle fusion

유재연 (충남대학교)

[BP12] Two-Dimensional Mutual Diffusion Dynamics in Heterogeneous Lipid Domains

정대웅 (KAIST)

[BP13] Intermembrane Closeness Driven Lipid Raft Alignment and Growth

Suho Lee (KAIST)

[BP14] Monitoring Ion Entrance into Vesicle Stern Layers in the Presence of the Number of Lipids Which Is Comparable to the Number of Counterions

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[BP15] Dynamic heterogeneity and collective diffusion of phospholipids in mono layers

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[BP16] Activeness, non-Gaussianity, and correlation in the motion of lipid granules and vacuoles in *Acanthamoeba castellanii*

박선규 (POSTECH)

[BP17] 생태계를 모방한 네트워크 모델에서 방향성과 부호를 고려한 모티프 분석

박영재 (한양대학교)



## [BP01] Beta-diversity patterns of benthic macroinvertebrate metacommunities

KyoungEun Lee (EnFRA)

Aquatic ecosystems are disturbed locally and globally by various source of natural and anthropogenic variability nowadays. Biodiversity has been conventionally measured by point-wise local community data pertaining to sampling sites. We combine the local data for benthic macroinvertebrates collected in the River system in southern peninsula of Korea to collectively address space-wise community structure properties. Community abundance data across different orders of streams were clustered by Geographical SOM (Geo-SOM) in responding to geographical and environmental changes. Metacommunity clustering was formed mainly according to topography and anthropogenic impacts in a river system scale. Beta-diversity, defined as variation in species composition among local sampling sites (alpha-diversity), was measured according to linear and water course distances. Inter-community properties including nestedness and spatial turnover were accordingly reflected in species compositions across different sampling sites. Local and species contributions to beta-diversity also presented topographic and anthropogenic effects on clustered communities. Necessity of dimension extension for ecological point data is further discussed regarding sustainable management of stream biodiversity.

## [BP02] Mean field theory of star-shaped block copolymers and the effect of confinement

정현우 (UNIST)

For decades, block copolymers have attracted researchers because of their ability to form distinct microphases. To study this novel block copolymer property various theoretical and computational tools have been developed and one of the most popular method is the self-consistent field theory (SCFT) in which partition functions of block copolymers are calculated under the mean field assumption.

In this research, we study the phase behavior of star-shaped block copolymers, and their morphology under the thin film confinement is also investigated. The modification of the SCFT for the star-shaped polymers is readily available and we tested parameter spaces to explain recent experimental finding that short tube-shaped microphase is found under thin film confinement.

[BP 03] Generalizing the Yamakawa-Stockmayer theory for the looping of a heterogeneous stiff polymer and its application to D-shaped DNA.

Chan Lim(POSTECH)

Yamakawa and Stockmayer established a seminal theoretical work in 1972 about the looping of a semiflexible short polymer in which the energy cost for bending is dominant and the configurational entropy is negligible. In this study, we generalize this theory for the bending of a heterogeneous stiff polymer where two different stiff polymers are connected to each other such that the bending persistence length changes along the strand. For this chain, we obtain an analytic expression for the shape of the polymer for a given end-to-end distance which minimizes its bending energy cost. As an application, we employ this theory to account for the bending of D-shaped heterogeneous DNAs measured by FRET experiment.

## [BP04] Exploring genome functionality with neural networks

Nelli Boichenko(충남대학교)

DNA is a long molecule that contains complete information about us. However, it only serves as a template from which particular instructions are picked up. The code is transcribed from genes into mRNAs that govern the creation of proteins --- building blocks of our body --- understanding how variations in human DNA effect on the production of mRNA is a key to understanding genetic predisposal to disease as well as developing targeted drug treatment.

In our work, we explore Genotype-Tissue Expression dataset (GTEx). We apply recently developed a multi-tissue method for neural networks to predict an individual's gene expression levels from his single nucleotide polymorphisms (SNP). Possible directions for the method improvement are discussed.

## [BP05] Study of cation- $\pi$ interaction in short peptides

강원준(UNIST)

Cation- $\pi$  interaction is the interaction between cations and the charge distribution of aromatic rings, and it is known to be important in many protein systems. Many previous studies suggest that intermolecular cation- $\pi$  interaction is one of the essential origins of adhesion under water, such as the foot attachment of the sea mussel. Experiments show that flanking Lysine next to aromatic amino acid weakens underwater adhesion, but measurement of cation- $\pi$  interaction strength is not consistent with this hypothesis. In this study, using all-atom molecular dynamics simulation, we make statistical analysis of intra- and inter-molecular cation- $\pi$  interaction and analyze the molecular adhesion occurring in our model peptides.

## [BP06] Heterogeneous dynamics in living cell

정유림(POSTECH)

Purinosome is a dynamic multi-enzyme complex of typically tens to hundreds nanometer size, responsible for de novo purine synthesis in a cytoplasm. A single-particle experimental study reported that at in vivo conditions, intriguingly, they tend to be colocalized with the mitochondria [1], but the mechanism of the colocalization remains elusive. Here we analyze the trajectories of purinosomes in terms of physical quantities such as the probability density function, mean-squared displacement, speed distribution, turning angle distribution, and the velocity autocorrelation. Our study finds that the purinosome transport is highly heterogeneous such that while the purinosomes perform mostly passive diffusion in the embedding viscoelastic media that brings about a non-Gaussian, anti-correlated subdiffusion, some of them experience an intermittent active transport presumably driven by motor proteins. Our analysis suggests that the purinosome particles are transported using both the mitochondria and microtubule networks, which provides a clue about the colocalization mechanism of the purinosome.

[1] French, J. B. et al., Spatial colocalization and functional link of purinosomes with mitochondria, *Science* 351 , 733 (2016).

## [BP07] The Rosenfeld scaling relation in the lateral diffusion of membrane protein-antibody complexes

주성민(POSTECH)

The Rosenfeld scaling, originally employed in the dense hard particle systems since 1980s, describes the transport coefficient of, e.g., colloids with excess entropy. The excess entropy contains structural information and the consequent crowding effect such that the degree of freedom is decreased by collisions among the particles. In this study, we investigate the lateral diffusion of membrane protein-antibody complexes where the collision (i.e., crowding) of the binding antibodies is crucial to the reduction of diffusivity of the protein complexes. Followed by a recent single-molecule study, we carry out the Langevin dynamics simulation of the crowded membrane systems including the transmembrane protein Syntaxin 1A and the antibodies of various size that bind onto the Syntaxin 1A. We find that the self-diffusion of the Syntaxin 1A-antibody complexes could have significant reduction of their net diffusivity at concentrated conditions. Moreover, it turns out that the change of the diffusivity follows an exponential law of the Rosenfeld in terms of area fraction, two-body collision, and excess entropy. Based on this relation, we establish a formula explaining the diffusivity reduction of a transmembrane protein due to the attachment of macromolecules in the extracellular domain as functions of protein density and the hydrodynamic radius of the extracellular unit.

## [BP08] Bioinspired active matter

김현재(충남대학교)

사람의 달팽이관은 들어오는 소리의 주파수마다 다르게 반응하는 특성이 있다. 기존 연구들에서는 이러한 달팽이관의 메커니즘을 모사하기 위해 구조적인 특성을 모사하여 수동적인 신호 처리를 통해 음성인식, 화자인식 등 다양한 연구가 진행되어 왔다. 본 연구에서는 인공 기저막을 단순히 수동적인 메커니즘뿐만 아니라 반응 신호에 대한 전자기적 능동 피드백을 구현하였다.



## [BP09] Sound signal processing, where and what

박상현 (충남대학교)

인간은 소음이 심한 환경, 예를 들어 음식점이나 카페와 같은 장소에서도 원하는 사람의 목소리를 인식하고 대화가 가능하다. 이것이 어떻게 가능하며 이러한 기능을 어떻게 구현해 낼 것인가에 대한 문제는 '칵테일 파티 문제'로 알려져 왔다. 이는 보청기와 같이 청력의 손상이 있는 사람들을 위한 청각 보조기구에서 반드시 해결되어야 할 문제이고 인공지능 스피커나 무선 이어폰 등의 성능을 결정짓는 중요한 요소다. 이것을 해결하기 위해 우리는 인공신경망을 통해 인간의 청력을 모사할 수 있는지 연구를 진행하였다. 이를 위해서 인간의 청력을 두 가지 큰 기능으로 나누어 연구하였는데 하나는 단순히 소음을 죽이고 원하는 음성만을 남기는 speech enhancement 방법이고 다른 하나는 원하는 방향에서 오는 소리를 집중해서 듣는 Directional hearing 방법이다. 이 두 가지 기능을 마스킹 기법을 이용하여 주파수 영역에서 처리함으로써 동시에 적용하는 실험을 진행하였다.

## [BP10] 빛 자극과 전기생리학을 이용한 광-유전 형질 감염된 시교차상핵의 신경망 연결 구조에 대한 연구

민철홍 (고려대학교)

물리적인 관점에서 볼 때 시교차상핵의 시계세포들은 비선형 진동자들의 결합으로 볼 수 있는 신경망을 통해 24시간 주기로 일관된 일주기 리듬을 동기화하고 생성한다는 것이 매우 흥미롭다. 주기 잠금의 결과에 따른 세포 대 세포 통신은 이와 같은 시스템이 일주기 리듬을 전체적으로 성취하기 위해서 반드시 필요하다. 따라서, 어떻게 시계세포들이 서로 연결되어 있고, 구조적으로 어떤 네트워크 속성들을 가졌는지는 시교차상핵과 관련하여 중요한 질문이다. 따라서, 최근 시교차상핵의 세포체 칼슘이온 역학, 시계 유전자 일주기 발현, 그리고 AP 매개 통신에 관한 연구가 활발하게 진행되고 있다. 반면, 시교차상핵은 영역과 시계세포의 크기가 매우 작기 때문에 네트워크 연결의 형태학적 구조 및 특성에 대한 연구는 미비하다. 이러한 이유로, 우리는 시계 세포들의 네트워크 구조를 살펴볼 수 있는 기능적 광-유전자 지도화를 수행하였다. 시교차상핵에서 주어진 표적 신경세포의 억제성 수용 필드 (Inhibitory Receptive Field: IRF)는 매우 다양한 크기와 모양을 가졌다. 시교차상핵 신경세포가 AP-mediated 연결을 희소하게 ( $210 \mu\text{m}/\text{h}$ )을 가지고 있었다. 또한 표적세포가 가질 수 있는 독립적인 presynaptic 소스들의 분포 및 개수를 살펴 보기위해, 표적세포와 presynaptic currents 유발지역 사이의 물리적 거리와 유발된 postsynaptic currents의 진폭 차이들을 변수로 DBSCAN CLUSTERING을 수행하였고, 그 결과로 표적 세포의 IRF를 포함하는 독립적인 presynaptic 신경 세포의 수는 평균 8.9의 지수 분포를 대략 따르는 것을 확인하였다.

## [BP11] Dynamics of synaptic vesicle fusion

유재연 (충남대학교)

In auditory hair cells, precise timing of synaptic transmission is important to great features of hearing such as sound localization and speech recognition. Thus, understanding the nature of the synaptic fusion in auditory hair cells is key to understand the hearing mechanism. In a presynaptic nanodomain coupling of calcium inflow-synaptic vesicle release, it is assumed that a single calcium channel may control vesicle release at each docking site. To investigate the relationship between the calcium channel opening and the vesicle fusion, we simulate the whole process with linearized calcium diffusion model. We calculate the fusion timing when multiple vesicle and the single channel with different position, and the single vesicle and multiple channels.

## [BP12] Two-Dimensional Mutual Diffusion Dynamics in Heterogeneous Lipid Domains

정대웅 (KAIST)

While self-diffusion of surfactant molecules has long been investigated with FRAP, studying mutual diffusion involving two or more surfactants remains a challenge in biological physics, chemistry, etc., primarily due to hurdles in preparing well-defined initial conditions. The 'domain insertion method' is newly developed to generate a clear boundary between two lipid domains by coalescing a lipid-coated water droplet onto a planar monolayer of another lipid. In this poster, we present our recent findings on two-dimensional mutual diffusion dynamics of UV-oxidized DOPC and cholesterol. Numerical simulations, NMR and IR spectroscopy results are presented. Miscibility, diffusion coefficient, and inter-domain line tension were also measured. This study can be potentially implicated for assessing the interfacial mixing properties of two or more surfactants.

## [BP13] Intermembrane Closeness Driven Lipid Raft Alignment and Growth

Suho Lee (KAIST)

Lipid raft is a self-organized membrane architecture providing a physical platform that localizes signaling proteins. It is considered that its higher-order assembly is responsible for regulating the collective functions of the raft proteins in intermembrane processes. In this presentation, using fluorescence imaging and synchrotron X-ray reflectivity measurement, we show that the intermembrane columnar ordering and size growth of lipid raft Lo domains emerges at short distances between membranes when the distance is modulated by Ca<sup>2+</sup> ions and PEG.

## [BP14] Monitoring Ion Entrance into Vesicle Stern Layers in the Presence of the Number of Lipids Which Is Comparable to the Number of Counterions

이재희 (KAIST)

The interactions among the charged macromolecules or nanoparticles have been the subjects of numerous studies to date. Understanding these interactions can provide not only an inference of the electrochemical properties of each particle but also the understanding the functioning of the various particles present in nature. However, so far, previous researches carried out experiments and analysis in a situation where a much larger amount of ions exist than the maximum charge that each particle can have. In this study, we quantitatively monitor the ion entrance into Stern layer of charged lipid vesicle in the no added salt regime. Under the control of anionic lipids fraction ( $\gamma$ ) and PEG-grafting ratio ( $\Omega$ ) in lipid vesicles, we carried out “optical bottle”, which is a newly developed technique to probe osmotic second virial coefficient by optically confining the multi-particles. Surprisingly, in our regime, the attachment of ions into Stern layer is strongly increased, accordingly with the effective valence of vesicles be reduced. Also, as  $\Phi$  decreases,  $\alpha$ , which is the degree of reduction in the effective valence, and  $v$ , which is the number fraction of sodium ions outside Stern layer, together increases. As a result, the inter-vesicle interaction strength (i.e. the second virial coefficient) is equalized in vesicle volume fraction ( $\Phi$ ) independent manner. In addition, the inter-vesicle force is also regulated in vesicle size dependent manner. Specifically, as decreasing vesicle size,  $\alpha$  decreases and  $v$  increases. It is caused by the change in the effective charge density of vesicles depending on the vesicle radius. On the other hand, for the PEGylated charged vesicles,  $\text{Na}^+$  ions are entrapped in PEG so that result in the increase of  $\alpha$  and decrease of  $v$ . As a result, the dynamic changes of B2 are observed. Our approach in novel quantitative conditions between ions and particles, which have not been experimentally addressed until now, will give insight for studying intermolecular force between charged particles including proteins, colloids, and drug delivery systems, etc.

## [BP15] Dynamic heterogeneity and collective diffusion of phospholipids in monolayers

김영훈 (POSTECH)

Based on the atomistic molecular dynamics simulation, we investigate the lateral dynamics of lipid molecules in model pulmonary surfactant monolayers at varying membrane compression. We show that, as consistent to the bilayer systems previously studied, the single-particle diffusion in the monolayers is also characterized by fractional Brownian diffusion regardless of thermodynamic conditions, as long as the observation time is limited within sub-nanoseconds. At longer timescales, however, it is found that there is a critical membrane compression above which the lipid motion is no longer Gaussian and non-Gaussianity of the van Hove correlation surges. Moreover, analyzing the statistical correlations between various dynamic quantities of the membranes, we infer that the non-Gaussian particle diffusion in fact stems from the collective dynamics of the lipids. Beyond the threshold compression, a spontaneous membrane undulation is mechanically locked. This gives rise to the long-lived segregated patches of mobile and immobile lipids, which is analogous to the dynamic heterogeneity found in dense amorphous systems. Since the particle-to-particle heterogeneity is not removed for this condition, we observe the stretched-exponential van Hove correlation function. The phenomenological similarity of the collective lipid dynamics to the dynamic heterogeneity in supercooled colloidal systems is discussed.

[BP16] Activeness, non-Gaussianity, and correlation in the motion of lipid granules and vacuoles in *Acanthamoeba castellanii*

박선규 (POSTECH)

*Acanthamoeba castellanii*, a human pathogen, causes critical diseases whose occurrence is known to strongly depend on the active transport of intracellular lipid granules. In our previous study [1], we explored the origin of the active granular motion by tracking the granules in the drug-taken cells that the drugs, e.g., inactivate the dynamics of myosin II motors or depolymerize the actin or microtubule network. Here, we carry out an extensive study analyzing the granule trajectories in the corresponding drug-taken and normal cells and investigate in detail how the active motion is altered in response to the change of the intracellular environment due to the addition of the drugs. We study the statistical and stochastic properties of the granular motion via a number of single-trajectory observables such as the time-averaged mean squared displacements and its fluctuation, angle distribution, non-Gaussian parameter, and velocity autocorrelation function. In addition, we also study the dynamics of the vacuoles in the same cell and investigate their long-time behavior in the confined environment.

[1] J.F. Reverey, J.-H. Jeon, H. Bao, M. Leippe, R. Metzler, and C. Selhuber-Unkel, Superdiffusion Dominates Intracellular Particle Motion in the Supercrowded Cytoplasm of Pathogenic *Acanthamoeba castellanii*, *Sci. Rep.* 5, 11690 (2015).



## [BP17] 생태계를 모방한 네트워크 모델에서 방향성과 부호를 고려한 모티프 분석

박영재 (한양대학교)

생태계에서는 외부로부터 새로운 종이 유입되고도 하고, 기존의 종이 멸종되는 등 흥미로운 동역학을 보인다. 이러한 시스템은 각 종을 노드로, 두 종 사이의 상호작용을 링크로 하는 네트워크로 표현될 수 있다. 특히, 생태계 네트워크에서 링크는 방향성과 부호를 가진다. 링크의 방향은 한 노드에서 다른 노드로의 영향이 들어오거나 나감을 나타내고, 부호는 대상 노드에 대한 영향이 긍정적이거나 부정적임을 의미한다. 네트워크에서 정의되는 모티프는 널 모델로 사용되는 랜덤 네트워크에서 기대되는 정도보다 더 자주 나타나는 패턴이다. 우리는 노드 3개로 구성된 방향성과 부호가 있는 모티프의 수를 생태계 네트워크 모델에서 측정한다. 각 링크의 방향과 부호에 따라 그 모티프의 역할이 크게 바뀔 수 있기 때문에 방향과 부호를 고려한 모티프 분석은 기존의 링크만 고려한 모티프 측정에 비해 네트워크의 구조를 이해하는데 도움을 줄 수 있다. 우리는 특정 모티프들이 네트워크 수의 안정성에 끼치는 영향을 확인한다. 이러한 분석은 생태계 보존을 이해하는데 도움이 될 것이다.

[CS01] First-order phase transition in Kuramoto model with asymmetric interaction

양성규 (성균관대학교)

The Kuramoto model with asymmetric dynamic interaction can describe the off-the-mean synchronous frequency in the real world. In this paper, we find that the discontinuous phase transition arises when the oscillators interact with others whose phases are ahead. Discontinuity of the transition is revealed not only in the probability distribution of the synchronization order parameter, but also in the interaction structure. From the comparison with conventional Kuramoto model with the symmetric interaction, we conclude that dynamically broken symmetry of interactions plays the important role in changing the nature of transition.

## [CS02] The Modified Kuramoto Model with Power Law Coupling and Spatial Time Delay

이해성 (성균관대학교)

Hand clapping of audience is a well known example of synchronization phenomenon. We observe that the applause gets hardly synchronized if the hall in which audience sits becomes very large. We propose that the finiteness of sound speed and the decay of sound amplitude in distance can play important roles in synchronization of hand clapping in a large hall. In detail, the finite sound speed  $v_s$  introduces the time delay between the hand clapper at  $r_i$  and the listener at  $r_j$  for the clapping sound generated by  $i$  to travel to  $j$ . We also assume that the amplitude of the clapping sound generated by  $i$  decays in distance: At the position of the listener  $j$  at  $r_j$  it becomes reduced in proportion to  $1/(r_{ij})^2$ . We thus implement above two ingredients into the original Kuramoto model. We perform numerical simulations of  $N=L_x \times L_y$  coupled oscillators in two-dimensional square lattice of the size  $L_x \times L_y$  for given values of the sound speed  $v_s$  and the lattice constant "a". We first observe that the smaller value of the sound speed weakens the level of the global synchrony. We believe that the finding can be understood from that the slow sound propagation effectively introduces a cutoff length scale in interaction range. In the extreme limit of  $v_s \rightarrow 0$ , it takes infinite time for the sound to travel to one lattice spacing, and thus the effective interaction range is null to make the system interaction-free. Second, we find that the change of the lattice constant "a" also greatly affects the synchronization behavior: Oscillators are less synchronized as "a" is increased. Finally, we investigate how the aspect ratio of the square lattice affects the global synchronization. It is shown that the overall level of global synchronization is decreased as  $L_x/L_y$  deviates from unity, which can be verified in a real hand clapping experiment.

## [CS03] Symmetry-induced Stable Chimeras of Kuramoto Oscillators

이승재 (전북대학교)

Chimera states where oscillators are partitioned into coherent and incoherent subsets have been considered as interesting phenomena. In this presentation, we introduce the procedure to find stable chimera states in finite-sized Kuramoto systems with Sakaguchi phase frustration parameter. Specifically, we use group-theoretical framework reported in [1] to capture independently synchronizable clusters in each symmetry-induced cluster synchronization. In a small network composed of two independently synchronizable clusters, we control phase frustration parameter to make one cluster stable and the other cluster unstable. By using this approach, we observe a stable chimera which might persist permanently by the periodicity of the dynamics.

[1] [1] Y. S. Cho, T. Nishikawa, and A. E. Motter, Phys. Rev. Lett. 119, 084101 (2017).

## [CS04] Effective Landau free energy for hybrid synchronization transitions

송제웅 (서울대학교)

It was revealed that the Kuramoto model exhibits different types of synchronization transition according to the types of natural frequency distribution. Kuramoto's self-consistency equation approach has been useful for determining the type of synchronization transitions. Here, we construct an ad hoc potential, similar to the Landau free energy, from the self-consistency equation for diverse types of synchronization transitions, and examine the landscapes of these effective free energies. Particularly, for a hybrid synchronization transition in which the order parameter jumps and exhibits a critical behavior, we find that the minimum of the effective free energy displays a plateau across the region to a extent of the jump of the order parameter. In finite systems, we find that the profile of effective potential includes many local minimum at a transition point. We discuss the motion of unlocked oscillators on the landscape of effective potential with many local minimums.

## [CS05] 베이즈 추론을 이용한 반복 죄수의 딜레마 게임

김민재 (부경대학교)

진화 게임 이론에서 보통 경기자들은 다른 경기자들의 점수를 확인하고 높은 점수를 가진 경기자들의 전략을 그대로 복사하는 방법을 사용한다. 이 방법은 점수를 알면 전략도 알 수 있다는 가정을 필요로 하고 있다. 하지만 점수를 확인하더라도 상대의 전략을 바로 알아채는 방법은 실제로 불가능에 가깝다. 우리는 이 연구에서 반복되는 죄수의 딜레마 게임의 전략 복사(copy) 방법이 아닌 베이즈 추론을 이용하여 경기자가 자신의 평균 점수를 최대화시키는 전략을 찾는 방법을 알아본다. 이 게임에서 경기자들의 점수나 전략을 알려주지 않고 모든 경기자가  $M$  번의 게임을 지켜본 후 전략을 동시에 바꾸는 기회를 갖는다. 이 과정을 여러번 반복하여 평균 점수의 최댓값을 주는 전략의 수렴점을 찾아보았다. 그 결과, 협력에 드는 비용이 높더라도 협력할 확률이 완전히 0이 아니라는 것을 찾아냈다.

## [CS06] Prediction of Chaotic Motion Using Reservoir Computing Recurrent Neural Networks

남선호 (한양대학교)

혼돈계는 나비효과처럼 초기 조건 민감성에 의해 예측의 작은 오차가 오랜 시간이 흐른 후에 큰 차이를 만들기 때문에 미래 예측이 쉽지 않다. 반복순환신경망 (Recurrent Neural Network; RNN)은 일간 날씨 예보와 같은 시계열 데이터를 학습하고 미래를 예측하는데 적합한 기계학습 모델이다. 그 중에서 Reservoir Computing (RC) RNN은 혼돈계를 학습하고 예측을 하는데 뛰어난 성능을 보인다고 알려져 있다. 우리는 Reservoir의 무작위 시간적 네트워크의 크기와 네트워크의 노드 사이의 연결될 확률을 조정해가며 예측에 최적화된 네트워크를 찾고 그 RC RNN을 학습시켜 로렌츠 끌개를 예측해본다. Reservoir 내부의 네트워크 크기는 입력 노드의 수에 비해 매우 크다. 이는 RC RNN이 학습을 잘하도록 입력 차원보다 큰 고차원 역학 공간으로 데이터를 퍼트려 주기 때문이다. 하지만 입력 노드보다 얼마나 크고 노드 사이의 연결될 확률이 얼마일 때 학습을 잘하고 예측을 잘하는지는 아직 명확하지 않다. 우리는 비선형 시스템을 가장 잘 예측하는 네트워크 크기와 연결 확률을 알아보았다

## [CS07] 인공 신경망에 의한 행동 결정과 죄수의 역설 게임 전략 진화

박지원 (세종대학교)

죄수의 역설 상황에서도 게임이 반복적으로 이루어지면 협조로 진화할 수 있다는 사실은 잘 알려져 있다. 그러나, 상대방의 직전 행동을 통하여 내 행동을 확률적으로 결정하는 확률적 반응 전략 공간에서 협조 전략은 변이에 대하여 불안정하다. 우리는 확률적 반응 전략 공간을 간단한 신경망으로 표현할 수 있음을 보이고, 신경망에서 사용하는 활성화 함수에 따라, 협조 전략이 안정화 될 수 있음을 보였다. 또한, 부모 전략의 학습에 의해 형성된 신경망을 가지는 자손들의 전략 진화 과정을 유전 알고리즘과 적응 동역학으로 연구하였다. 전통적인 확률적 반응 전략과 비교하여 학습된 신경망에 의해 행동을 결정하는 경우가 더 쉽게 협조로 진화되는 것을 확인하였다.



## [CS08] Prisoner's dilemma game on signed networks

최재한 (인하대학교)

We studied Prisoner's Dilemma (PD) game on signed networks. In signed networks, there are two types of link, positive and negative. We choose the payoff matrix between the players connected with the negative link as multiplying the minus to the payoff matrix between the players connected with the positive link.

To investigate the effect of negative links to cooperating behavior, we perform simulations for different negative link densities. When the negative link density is low, the density of cooperator becomes zero as increasing temptation payoff  $b$ . Here, the parameter  $b$  is the payoff of the defector received from a game with cooperator.

On the other hand, when the negative link density is high, the cooperator density becomes 1 as  $b$  increases. It is due to that the players with negative link will suffer more payoff damage if they do not cooperate with each other. The negative links force players cooperate so that cooperating behavior is enhanced.

## [CS09] 스탯캐스트 데이터를 활용한 투수 특징 파악과 패턴 분석

임채운 (한양대학교)

야구에서 스탯캐스트 시스템은 투수가 던지는 공, 타자가 때린 공, 주자와 수비수의 움직임 등의 데이터를 측정한다. 이는 각 투구의 구속, 회전수, 궤적, 타구의 궤적, 발사속도, 발사각, 그리고 주자의 주루속도, 수비수의 위치 등의 데이터를 포함하고 있다. 우리는 2011년도부터 2018년도까지 한국프로야구에서 활동했던 외국인 투수 73명의 한국프로야구 입성 전 메이저 리그에서 활동한 시기의 투구에 대한 구속, 구종, 궤적, 타구의 위치, 해당 투구와 타석의 결과가 시간순으로 나열되어 야구의 흐름을 파악할 수 있는 스탯캐스트 데이터를 이용하여, 투수의 구속과 구종에 대한 특징을 파악하고, 해당 투구에 대한 판정, 투수-타자 결과로부터 투구 패턴을 분석하여 경기를 어떻게 운영하는지, 어느 상황에 강한 모습을 보이는지에 대한 정보를 분석하였다. 이러한 결과를 활용하면 기존의 방어율과 출루허용 등의 데이터와 함께 야구 구단들이 유연하게 투수운영을 하기 위해 필요한 유형의 외국인 투수를 영입하는 데 도움이 되고, 투수에 대한 객관적인 평가가 이루어질 수 있는 기준을 제시할 수 있을 것으로 기대된다.

## [CS10] Relation Between Transmission of Malaria and Climate Network In Africa

Biseko Mafwele (인하대학교)

Temperature and rainfall are the most key parameters for climate change and transmission of malaria. Fluctuation of temperature affects the transmission and spreading of malaria. Temperature fluctuation around low mean temperature acts to speed up the rate of transmission of malaria while temperature fluctuation around high mean temperature acts to speed down rate of transmission of malaria. The climate networks and malaria networks are constructed from the cross-correlation between average temperatures of grids on the surface of the earth and monthly average malaria incidences in African countries respectively. In this study we construct and analyze the climate network and malaria network to show how does change of climate relate to transmission of malaria in African countries.

## [CS11] Data analysis on Seoul transportation system

이대경 (성균관대학교)

In the increasingly complex modern city, analyzing and predicting traffic flow is becoming an important part of urban dynamics. Many data-based researches show that the intracity traffic pattern correlates with the various fundamental aspects of urban life, especially for the commuting cycle between residence and workplace. In this work, we analyzed a large scale dataset of the seoul subway system with both theoretical and numerical methodology of network science, including gravity model and community detection. By meliorating the existing null model of traffic flow, we developed a decent numerical algorithm which can be used to find the approximate distance decay function of trip distribution. We also found the structure of the regionalized living spaces, which describes the representative characteristics of each area.

## [CS12] Chirikov map에서 기계학습을 이용한 무질서 궤적과 정칙 궤적의 구분

이우석 (기초과학연구원)

Chirikov-map은 2차원의 고전적인 동역학 시스템으로 무질서의 정도를 결정하는 매개 변수가 존재한다. 이 값이 변함에 따라 Chirikov-map에서 무질서 영역이 변하게 되며 일반적으로 이러한 무질서 궤도는 긴 시간을 이용해 Lyapunov time을 계산함으로써 정량적으로 판별할 수 있다. 우리는 기계학습을 이용해 시스템의 Lyapunov time과 비교해 얼마나 짧은 시간을 이용해 정칙과 무질서 궤적을 구분을 할 수 있는지 조사한다.

## [CS13] Effect of environmental changes on temporal networks

김혜원 (KAIST)

We analyze the complexity of the network dynamics using a multiscale entropy (MSE) method and show that the MSE results of temporal networks are classified according to environmental similarity. To explore the effect of environmental changes on network dynamics, we construct a temporal network model considering the periodic external effects. We find that the collective dynamics resulting from the external effect can cause long-range temporal correlations. Our results show that the temporal networks are adaptive networks in which nodes respond to and adapt to environmental changes.

[CS14] The hidden hyperbolic geometry of journal  
co-citation networks as maps of science

손강민 (KAIST)

In the last decade, hyperbolic geometry has been explored as a framework to explain the ubiquitous properties of real networks (e.g., degree heterogeneity and strong clustering), and as a practical tool for analyzing the networks. Here, we construct an atlas of science by embedding annual journal co-citation networks into a hyperbolic geometry to extract their mesoscale patterns. Our dataset covers a wide range of fields - from natural sciences to sociology to medicine - and a period of six decades. By using the coordinates of the nodes in the hidden space, we investigate how much the networks are hierarchical and localized. In addition, we compare the natural communities and contents-based classification.

## [CS15] Hybrid percolation transitions in the restricted static model

최광종 (서울대학교)

Recently, it was discovered that the so-called global suppression (GS) protocol, in which the growth of giant cluster is suppressed in cluster merging process, changes the type of percolation transition into a discontinuous transition. The half-restricted percolation model contains the GS factor, so that the half-restricted Erdős-Rényi (ER) random graph model exhibits a discontinuous percolation transition. Recently, we notice that the half-restricted ER model contains another factor, a self-organized criticality in inter-event times, leading the cluster-size distribution to exhibit power-law decay. Thus, the restricted ER model exhibits a hybrid percolation transition. Here, we apply the half-restricted rule to the static model for scale-free random networks, and obtain a rich phase diagram including a hybrid percolation transition. Contrary to the explosive percolation model, the relation between the degree exponent  $\lambda$  and the fitness parameter  $\mu$ ,  $\lambda=1+1/\mu$  holds in the restricted static model.



## [CS16] No-exclaves percolation: Unfolding hidden cost of failures in networks

곽상환 (고려대학교)

We introduce and study a new percolation process on networks called the no-exclaves percolation (NExP). The exclaves are isolated from other functioning parts of the network, thereby becoming effectively non-functional. This process defines a new cluster of non-functional nodes, that we call the NExP cluster, formed by the connected union of failed nodes and exclaves.

For instance, an NExP cluster corresponds to the isolated cluster subject to the road closure due to traffic malconditions in the road network or that subject to the farm closure due to quarantine measure against outbreak of infectious disease on networked livestock population.

We provide the theoretical frame for the model on random treelike networks through the generating function method and also provide Monte Carlo simulation to verify it. As a results, we found that the NExP displays two distinct transitions: One between non-percolating to percolating phase at  $p_c$ , and the other between the partially-percolating to fully-percolating phase at  $p^*$ .

We not only confirmed the effect of exclaves clusters through urban road networks and livestock farm networks, but also identified critical behaviors.

## [CS17] Underlying mechanisms of hybrid percolation transitions

박진하 (서울대학교)

Recently, it was revealed that global suppression is an indispensable factor for a discontinuous percolation transition (PT); without which PT exhibits a robust continuous transition. It brings up another perspective : "what are the necessary ingredients of a hybrid PT?" HPT is a discontinuous PT accompanied by one or more critical phenomena. One class of HPT is driven by pruning process. It includes, for example, k-core percolation and a generalized contagion model. The underlying universal mechanism of this HPT was critical branching. A massive cascade failure and a power law distribution of finite avalanches are found together at the transition point. Another class of HPT we present is induced by cluster aggregations. Especially, we pay attention to the self-organized critical development of power-law cluster size distribution in the restricted Erdős-Rényi model. Microscopically, for each cluster, the period of restricted growth alternate with the period of normal growth. Remarkably, the length of periods (inter-event times) follow power-law distributions. This newly discovered dynamic criticality is bridged to the previous static critical exponents of HPT through a universal scaling relation.

## [CS18] Axelrod Model with the Inertia on Complex Networks

최준영 (경희대학교)

본 연구에서는 문화적 다양성이 유지되는 이유를 설명하기 위해서 inertia를 가지는 Axelrod 모형을 연구하였다. 사회계 연결망을 모사하기 위하여 각 개인을 연결하는 연결 구조로 Erdős-Rényi 네트워크와 scale-free 네트워크를 가정하였다. 각 개인이 가지는 inertia에 따라 최 근접 이웃들이 공유하는 문화적 특성의 비율이 특정 문턱값을 초과할때만 그 문화적 특성을 받아들인다. 전산 시뮬레이션을 통하여 complex network 위에서 inertia를 가지는 Axelrod 모형의 상전이 현상은 불연속적임을 발견하였다. Finite-size scaling을 통하여 각 상의 안정성을 조사 하였으며, 발견된 상전이에 대한 이론적 가능성을 논의한다.

## [CS19] Information-theoretic dissection of landscape paintings reveals conceptual overlap in art historiography

Byunghwee Lee, Min Kyung Seo, Daniel Kim, In-seob Shin, Maximilian Schich,  
Hawoong Jeong, Seung Kee Han (KAIST)

Geometric proportion is one of key organizing principle in the composition of a painting. A long-standing question in art history and aesthetics is that is there a certain proportion artists and observers prefer over others. Here, we propose a quantitative systematic framework for assessing the compositional proportion in landscape paintings using an image partitioning algorithm based on information theory. Analyzing 15,092 paintings from the Renaissance to the contemporary period, we uncover that the preferred proportions of landscape painters have evolved systematically. We show that the Jensen Shannon distances between profiles of compositional proportions of various art historical concepts such as centuries, stylistic periods, nationalities, individuals reveal conceptual overlap in art history.

## [CS20] Disentangling single agent from stochastic complex system using Neural Network

하승웅 (KAIST)

Statistical properties and the emergence of collective behavior from active agents are well studied, and many attempts were made to model those systems. But these models were mainly developed by a human insight from nature rather than data itself since it was infeasible to extract a single agent's decision rule from tangled data. In this study, we disentangled single-agent behavior and automatically build a surrogate model of bird in a data-driven manner by employing `Interaction Network`, a neural architecture aim to identify the interaction between agents. We focus to predict the trajectory of a single agent in a group provided that other agents' information is given. Our model successfully recovered the unknown interaction patterns simulated data. Furthermore, by applying the model to empirical data, we propose a novel analysis to obtain a better understanding of the collective system.

## [CS21] fluctuations in complex networks

유형하 (인하대학교)

Synchronization activities and balancing the loads of elements on complex networks have drawn much attention since they have many practical applications, such as brain networks, internet traffic routing, electric power transmission, and parallel computing. We are particularly interested in dealing with those problems on scale-free(SF) networks to promote understanding as to how you can optimize a system in a given circumstances. We mainly use the dynamics, known as the Family model, first proposed by F. Family in 1986. Unlike the cases in regular lattices, the Family model does not have an analytic solution if we extend our view to the complex networks. Even Langevin equation of the model does not exist. However, we know the Family model shows the scaling behavior through empirical evidences, which viably lead you to access the problem by numerical simulations. Our analysis covers the Family model dynamics on SF model networks, the static model and the configuration model. Thinking that the scaling exponent regarding the fluctuation determine the characteristic behavior of a given system, we measure them in various cases, which leads us to understand the crucial factors in determining the system`s synchronizability. We expect the result can be a guideline for many real-world systems and thus can be used to analyze real world data.

## [CS22] The effect of direction on the Griffiths phases in complex networks

QuangAnh Le (인하대학교)

Real world networks are believed to operate at criticality in which control parameters need to be adjusted precisely. The Griffiths phases, that power law dynamics appears in a region around the critical point, can play as a solution to this adjustment problem. Recently, the Griffiths phases have been studied on several types of undirected complex networks. However, Griffiths phases are also observed in brain networks which are composed of both undirected and directed edges. The change in Griffiths phases on different directed complex networks are studied and the rare-regions, which are responsible for the Griffiths phases, in total directed networks are also registered.

## [CS23] 방향 정보를 가지는 페로몬에 의한 먹잇길 형성

배규호 (부경대학교)

많은 종의 개미들은 페로몬을 이용하여 먹이와 집을 잇는 길을 만든다. 이 때 개미 한 마리는 제한된 인지범위를 가지고 지엽적인 정보에 의존하게 되지만 군집에 의해 만들어지는 먹잇길은 거의 최적화된 경로를 가지게 된다. 본 연구에서 제한된 인지범위 안에서 방향 정보를 가지는 페로몬을 읽어 다음 운동을 결정하는 방식의 행위자 기반 모형을 통해 먹잇길이 형성됨을 보였다. 또한 먹잇길이 만들어질 수 있는 모형상수가 넓은 범위에 걸쳐 존재하여 모형이 특정한 모형상수 값에 대한 의존성이 없음을 알 수 있었다. 구체적으로 인지범위 제한정도가 문턱값을 넘을 때 먹잇길의 형성과 그 길의 최적화가 일어난다는 사실로부터 상전이기가 있음을 보였다. 우리는 본 연구에서 쓰인 모형의 핵심 가정인 페로몬의 방향성에 대한 생물학적, 이론적 정당성에 대해 토의하고자 한다.



## [CS24] Statistical Property of Volatility Record in Korean Housing Market

김진호 (경희대학교)

본 연구에서는 한국 주택 시장의 아파트 실거래 가격 데이터를 기반으로, 주택 시장의 가격 변동성에 대한 통계적인 특성을 확인하였다. 주택 시장 가격의 변동성에 대한 record-breaking 이벤트가 발생하는 과정을 Bernoulli process 과정으로 설명하였다. Bernoulli 과정에서 가격변동이 매우 작은 확률  $q$ 의 값에 따라, 시간  $t$ 에서, 평균 record-breaking 횟수 ( $\langle R(t) \rangle$ ) 의 거동이 달라짐을 보였다. 특히 한국 주택 시장에서는 경제 사건 또는 경제 정책 등으로 특정되어지는 기간에 따라  $q \rightarrow 0$ 인 경우와  $q \rightarrow 1$ 인 경우가 번갈아 나타남을 보였다. 또한  $R(t)$ 의 분산 특성에 대한 논의를 진행한다.

## [CS25] Understanding the temporal pattern of spreading in heterogeneous networks: Theory of the mean infection time

이미진 (인하대학교)

For a reliable prediction of an epidemic or information spreading pattern in complex systems, well-defined measures are essential. In the susceptible-infected model on heterogeneous networks, the cluster of infected nodes in the intermediate-time regime exhibits too large fluctuation in size to use its mean size as a representative value. The cluster size follows quite a broad distribution, which is shown to be derived from the variation of the cluster size with the time when a hub node was first infected. On the contrary, the distribution of the time taken to infect a given number of nodes is well concentrated at its mean, suggesting the mean infection time is a better measure. We show that the mean infection time can be evaluated by using the scaling behaviors of the boundary area of the infected cluster and use it to find a nonexponential but algebraic spreading phase in the intermediate stage on strongly heterogeneous networks. Such slow spreading originates in only small-degree nodes left susceptible, while most hub nodes are already infected in the early exponential-spreading stage. Our results offer a way to detour around large statistical fluctuations and quantify reliably the temporal pattern of spread under structural heterogeneity.

## [CS26] Interevent time distribution in the restricted growing random network (r-GRN)

오수민 (서울대학교)

It is known that the infinite-order phase transition of growing random network is changed into discontinuous transition when the growth of large clusters in the system is suppressed. In this growing network, a new node is added to the system at each time step and the total number of nodes becomes  $N(t) = N_0 + t$ , where  $N_0$  is the number of initial node when  $t = 0$ . At each time step, clusters are classified into two sets  $R$  and  $R^C$ . Set  $R$  contains  $gN(t)$  nodes belonging to the smallest clusters, whereas set  $R^C$  contains the nodes belonging to the rest large clusters. Additionally, two selected nodes, one from set  $R$  and the other from the entire system, are linked with probability  $p$ . In this dynamics, each node in the system may move back and forth across the set boundary over time. In contrast to in static network, old nodes that joined in the system in early stage have more chance to be selected than young nodes. Here, we investigate how interevent time distributions of old nodes and young nodes are different in our growing network. As preliminary results, we found that the interevent time distributions of nodes existing in early stage follow the power law with exponent larger than the value in the case of young nodes in the steady state. For instance, the exponent of the interevent time distribution of old nodes for the type that nodes moves from  $R$  to  $R^C$  is about  $-2.5$ , but the one of young nodes is about  $-1.5$  at the critical point for  $g=0.4$ .

## [CS27] Growth of scientific collaborations: scaling of first Betti number in growing simplicial representation

이용선 (서울대학교)

The representation of interactions in complex systems by simplicial complexes enables us to understand more deeply complex patterns emerging from diverse types of interactions in complex systems. Here, we reexamine an empirical dataset of the complete trail of coauthorship relations in several research fields using the simplicial complexes. We trace various quantities of simplicial complex representation including the Betti number, and investigate how the structure of coauthorship network changes as time goes on. We show numerically that the first Betti number of the simplicial complex exhibits a scaling with the system size. We also show that authors participating in diverse collaborations strongly affect the Betti number early in the growth of a research field, but this effect decreases as the research field matures.

## [CS28] 자원 경쟁이 존재하는 상리공생 네트워크 속에서의 생물종의 번성도

이현우 (인하대학교)

모든 식물의 영양소는 한정적이다. 서로 다른 종에 속하는 동물 개체들끼리 같은 종의 식물 자원을 얻기 위해 서로 경쟁을 할 수 있다. 꽃가루 매개자들(Pollinators)들이 동일한 꽃식물에서 나오는 영양분을 공유할 경우 같은 꽃을 수분하는 매개자들 사이엔 한정된 영양소를 두고 종간경쟁(Intraspecific competition)을 하게 된다. 이러한 자원 경쟁(Exploitative competition)은 생태계 네트워크에서 꽃가루 매개자들의 종의 번성도(Species abundance)를 감소시킬 수 있다. 우리는 이 논문에서 자원 경쟁의 영향으로 상리공생 네트워크에서 식물과 동물의 종의 번성도의 변화에 관해 탐구했다. 시간에 따라 종의 수가 더 이상 변하지 않는 평형 상태 가정하에서 실제 생태계에서 동 식물간 상호작용을 나타낸 행렬 데이터를 이용하여 일반화된 상호작용 행렬을 계산해서 종의 번성도를 분석했다. 그리고 이론적으로 종의 번성도와 관련되어있는 구조적인 인자들을 계산하여 실제 데이터속 종의 번성도와의 상관관계를 살펴 보았다.

# [CS29] Effect of Cooperation in Two-Species Microbial System

김진현 (고려대학교)

We study a two-species interacting particle system as a model for the emergence of multicellularity in microbial systems. In our model, each species reproduces through self-replication and cooperation with another species and dies through self-destruction. That is, each species behaves like the one in the contact process (CP) except for an additional cooperative inter-species interaction. The evolution of the system depends on which of the two different reproduction methods is dominant. If self-replication is effective, the system is dominated by the segregated single-species domains. In this case, each species lives separated from the other by a well-defined boundary. On the other hand, if the effect of cooperation is strong enough, the mixed-species domain emerges, within which both species live and mingle together. Within such domain, different species tend to locate adjacent to each other and effectively behave like bi-cellular organisms. First, we present the mean-field approximation of the model as a tool for the study of the qualitative features. Next, we perform extensive stochastic simulations of the model in (1+1)-dimension. From the results of the mean-field theory and Monte Carlo simulations, we construct the phase diagram and examine the dynamics of the system. Also, both methods show that there are two types of phase transitions. The first type is an absorbing phase transition which occurs from a fluctuating active state into an absorbing state. Besides, the model displays another phase transition from a segregated domain state into a mixed domain state depending on the cooperation constant. We characterize these two types of phase transitions and critical phenomena from the perspective of non-equilibrium phase transition. We confirm that the first type of transition belongs to the universality class of directed percolation (DP) in most cases. For the second type of transition, we identify that the model shows DP critical behavior in some regions; however, in others, the critical behavior seems to be different from that of the DP.

## [CS30] On the connectivity pattern of wired neural networks discovered by pruning methods

김동겸 (KAIST)

The inter-layer connectivity design in deep convolutional networks has a significant impact on their performance in the image recognition task.

These wiring patterns were either manually designed by human or neural architecture search methodologies.

One of the surprising results in recently is that the neural net mapped to the graph generated by the random graph generator is similar to or better than the existing models.

Pruning methods have been widely used mainly for model compression, but recent studies have shown that the structure found by pruning is advantageous for learning and can perform better than the original model in a certain condition. The lottery ticket hypothesis suggests the possibility of finding optimal subnetworks by pruning and resetting appropriately.

In this paper, we try to find the wiring pattern by pruning at the layer-to-layer connections level.

## [CS31] Self-Organized Criticality of Neural Avalanche in a Neural Model on Complex Networks

정남 (인하대학교)

Avalanche size distribution of neural signals from a variety of neural model represents the Power Law. In LHG Model (Levina, Herrmann, Geisel, Nat. Phys. 2007) which is kind of Integrate-Fire Model, neural firing signals distribution exhibited a self-organized criticality. Critical exponent of the neural firing signal distribution in a fully connected neural network showed a value near 1.5. Self-organized criticality of LHG model were confirmed by computer simulations when the connection of neurons have a complex network structure. We confirm how changed critical exponent of neural firing signal distribution depending on the structure of complex network.



## [CS32] Efficient deep learning

김성원 (충남대학교)

잡음 환경 속에서 사람의 음성 정보만을 추출하는 음성 개선은 딥 러닝 응용 분야 중 하나이다. 컴퓨터 연산을 이용한 음성 개선은 잡음이 심한 상황에서도 비교적 깨끗한 음성 정보를 추출할 수 있을 정도로 많은 발전을 이루었지만 실제 상황에서 기능하는 장비를 만들기 위해서는 시간 지연을 줄이기 위한 적은 계산량과 용량이 작은 뉴럴 네트워크 구조가 필요하다. 이러한 조건을 충족시키는 모델을 구현하기 위해 음성 분류를 성공적으로 수행하는 모델 구조를 이용하여 음성 개선을 수행해보았다.

## [CS33] 시교차 상핵의 일주기 리듬의 다중안정성을 재현할 수 있는 사실적 연결망을 반영한 수학적 모델

김현 (고려대학교)

시교차 상핵은 대략 20000개의 신경세포로 이루어져 있는 작은 영역이다. 이 영역은 우리 몸의 여러 일주기 리듬을 관장하는데, 이 20000개의 신경세포들은 이 일주기 리듬을 따라 동기화 되며, 동기화는 주변세포들과의 연결로 이루어 진다.

우리가 관측한 바에 따르면, 이러한 리듬은 특정상황에서 몇가지 위상파의 형태를 지니게 되고, 이것들은 다중 안정성을 보인다. 게다가 최근 실험에서 우리는 세포 시냅스 연결망의 입력차수가 대략 8~9개 정도 되고 연결되는 시냅스 전 뉴런의 위치 분포가 시냅스 후 뉴런의 세포체로부터 대략 200 um일 때 최대인것을 확인할 수 있었다.

이러한 연결망의 구조를 반영하는 수학적모델을 차용하여, 실험에서 관찰한 시교차 상핵상에서 다중안정성을 재현 하였다. 또한 특정 상황에서 생기는 phase singularity와 같은 위상파 형태의 특징을 관찰하여, 시교차 상핵이 가지는 연결형태중 시냅스의 연결망으로 얼마나 강하게 연결되어 있는지 추론하였다.

## [CS34] Topographic arrangement of simple and complex cells in neural network of visual cortex

김광수 (KAIST)

Simple and complex cells have been considered as two distinct classes of neurons in the primary visual cortex (V1), implying hierarchical stages of visual information processing. However, later studies suggested that two classes can be considered as a continuum, raising questions about what circuits generate such variation. Here, we propose that retinal inputs to V1 can determine the simple/complex tuning, where the spectrum arises from the variation of distance between ON/OFF afferents. Important evidence we found is that simple/complex cells are periodically arranged in cat V1, and the period coincides with that of orientation preference. The observed organizations are explained by model simulation based on retinal mosaic interference. Furthermore, we observed correlated architecture between orientation and simple/complex tuning, which is predicted from their common origin. Our findings suggest that retinal afferents orchestrate the formation of the functional map of simple/complex tuning, resulting in parallel architecture that expands the classical hierarchical understanding of V1.

[SP01] Phase transition and universality of percolation processes on multiplex lattices

최지혜 (APCTP)

We investigate the phase transitions and the critical behaviors of multiplex percolation processes in two-dimensional lattices with two-layer. This model is a generalized percolation model on multiplex systems comprised of two distinct processes establishing the viability, termed the cascade of activations (CA) and the cascade of deactivations (CD), depending upon the viability is established. To address the universality issue of this model, here we perform extensive Monte Carlo simulations and show that in two-layer square lattices the processes have not only different percolation transition points but also exhibit different critical behaviors with a distinct set of critical exponents. For the activation process, the transition points are found to share the same critical exponents as the ordinary percolation in two-dimensional lattices. For the deactivation process, the transition exhibits a different set of critical exponents from the ordinary percolation but shows critical behaviors consistent with those two-dimensional mutual percolation model.

To achieve a self-contained and self-consistent scaling picture of the transitions we introduce a novel definition of the cluster that hyperscaling relations such as  $d\nu = 2\beta + \gamma$  and  $\tau = d\nu/d_f + 1$ .

## [SP02] Phase transition of a tricritical directed percolation in long-range interacting systems in low dimensions.

조민재 (서울대학교)

We investigate non-equilibrium absorbing phase transitions of one- and two-dimensional tricritical contact process (TCP) with long-range interactions. Recently, the long-range quantum contact process reveals that the universality class belongs to the long-range tricritical directed percolation (TDP) class at a tricritical point. In our previous work, the mean-field (MF) critical exponents were calculated and upper critical dimension was determined to be  $d_u=1.5p$  using the scaling theory, where  $p$  is defined through the long-range interaction probability  $P_{ij} \sim r_{ij}^{-d-p}$  in  $d$  dimensions, where  $r_{ij}$  is the distance between two positions  $i$  and  $j$ . However, the tricritical behaviors below the upper critical dimension are not determined yet. Here, we investigate those behaviors using Monte Carlo (MC) simulations. We observe that the critical exponents vary continuously up to the ones of the original TCP model as  $p$  is increased to the boundary point  $p = p^*$ . MC simulations in two dimensions show that  $p^*$  is bigger than two in contrast to the field-theoretical expectation. In one dimension, the tricritical point does not exist in the short-range interaction. However, we find numerically for long-range interactions case that the tricritical point exists at finite  $p^*$  and obtain the critical exponents at the point.

[SP03] Variational Monte Carlo simulation based on an artificial neural network ansatz for a quantum phase transition study

김동규 (GIST)

We present that a multilayer neural network can describe a ground-state wave function involving the quantum phase transition via variational Monte Carlo for the transverse-field Ising (TFIM) model. We find that the neural network can provide sufficient accuracy to describe the critical behavior of the TFIM with only two hidden layers. We perform the standard finite-size scaling to obtain the critical exponents and critical points by calculating spontaneous magnetization, magnetic susceptibility, and Binder cumulant. We confirm that the values provided by the neural network are compatible with the known results of the Ising universality class. It demonstrates that the application of neural network based on VMC can be a way to describe quantum critical phenomena.

## [SP04] Logarithmic finite-size-scaling corrections to the leading zeros in the p-state clock model

홍성표 (GIST)

We investigate the finite-size-scaling (FSS) behavior of the leading Fisher zeros in the complex temperature plane in the p-state clock model for  $p=5$  and  $6$ . We employ the higher-order tensor renormalization group (HOTRG) method to estimate the location of the leading zeros numerically. We find that the contributions of the logarithmic correction are essential especially at the low-temperature transition, explaining the arc-like shape of the FSS trajectory of the leading zeros at the lower transitions. The FSS analysis shows that the critical behavior at the high- and low-temperature transitions are indeed of the BKT type, explaining the inconsistency between the previous Fisher zero studies and other approaches based on the helicity modulus and the phenomenological FSS analysis.

## [SP05] Multiple and reentrant phase transitions on K-selective percolation

김정호 (고려대학교)

Enzymatic degradation of polymer networks is emerging as an important future industry. We approach the substrate specificity, an essential characteristic of enzymes, from percolation perspective and develop a new percolation model, called the K-selective percolation. Our model has following rules: On the network, which represents the polymer network architecture, if a randomly-chosen node has degree exactly K, then we delete the node. This process continues iteratively until there remain no nodes with degree K left in the network. We apply the K-selective percolation model to Erdős-Rényi network, random regular network and simple cubic lattice as models of polymer architecture.

Multiple phase transitions and reentrant phase transitions are observed, and also three phases are identified in the K-selective percolation. We conclude continuous phase transitions belong to same universality class with ordinary percolation, and we obtain similar critical exponents with k-core percolation and cascading failure model. Phase transition between phase II and III, on Erdős-Rényi network with  $K=2$ , has intermediate property between continuous phase transition and hybrid phase transition. We obtain new critical exponents on this point. We hope this study to be a stepping stone in understanding both the enzymatic degradation of polymer networks with percolation perspective and the fundamental physics of multiple phase transitions.



## [SP06] Degree-Weighted Majority-Vote model on Complex Networks

김민석 (경희대학교)

본 연구에서는 복잡계 네트워크 위에서의 Majority-Vote model(MV model)의 상전이 현상을 연구하였다. 각 투표자의 불균질한 영향력을 모사하기 위하여 각 투표자들은 자신의 연결 선 수에 비례하는 가중치를 가지고 이웃에 영향을 미친다. 이때 가중치를 조절하는 parameter  $\alpha$  와 투표자가 다수결을 따르지 않을 확률에 대한 parameter  $q$  의 변화에 따라 계의 질서-무질서 상전이 현상을 연구하였다. 전산 시뮬레이션을 통하여  $\alpha$  가 변함에 따라 임계지수들이 변함을 발견하였다. 이 결과로부터 복잡계 네트워크에서의 의견형성에 허브가 미치는 영향을 논의한다.

## [SP07] 진동하는 하모닉 포텐셜 중심에 의해 유도된 비평형 운동

Youngchae Kwon (Myongji University)

콜로이드 입자의 트랩 조화포텐셜의 중앙을 일정 진동수로 변화시킬 때 주기적 변화를 나타내는 비평형 상태를 조사한다. 우선 랑주뱅 방정식(Langevin Equation)을 이용하여 전산 모의실험을 진행한다. 시간에 따른 일률의 평균을 계산하고 이론 계산과 비교한다. 기존의 오일러 방법(Euler Method)에서 발생하는 이론 계산 결과와의 오차를 고차 룽게-쿠타 방법(Lunge-Kutta Method)으로 충분히 감소시킬 수 있음을 확인한다. 일의 확률분포를 구하여 일에 대한 요동정리를 확인한다. 외부 추진 진동수가 조화포텐셜의 내적인 진동수와 같을 때 정상상태에서 발생하는 일률이 최대가 되는 공명(resonance) 현상이 나타남을 확인한다. 최대 일률 공명진동수는 콜로이드 입자 진동의 최대 진폭 공명진동수와 달리 유체의 점도 계수에 무관한 점에 주목한다. 일의 확률분포를 시뮬레이션을 통하여 가우시안 분포와 일치함을 확인한다.

## [SP08] Solvable finite-time quantum Otto heat engine

Sangyun Lee (KAIST)

The smaller device, the more dominant of the quantum effect. It is important how to control the quantumness in the miniaturization technology. In this talk, we present the comparison of the classical heat engine with the quantum one. In particular, we focus on the finite-time Otto engine, whose cycle consists of isochoric and adiabatic processes. By choosing a specific protocol in adiabatic process, we show that this cycle is exactly solvable with the close form of its efficiency and power for both quantum and classical cases. We also discuss the resonant behaviors against the cycle time.

## [SP09] Inertial effects in the Brownian Gyrotor

배영경 (KAIST)

The Brownian gyrotor is a two-dimensional single-particle device that converts heat flux between two heat baths into torque, which exerts on the particle in an elliptical potential. Recently, it is experimentally realized in electronic and colloidal systems, confirming a systematic gyrating motion of the particle with a definite mass. However, there are few theoretical reports including the inertial effect explicitly. Thus, we study how the mass enters the physical quantities such as torque or angular momentum and check the results using the underdamped Langevin simulation.

[SP10] Entropy production in the majority-vote model on  
multiplex networks with two layers

노다해 (고려대학교)

Entropy production in the majority-vote model is studied. The critical points are verified for AND- and OR-rule voters on multiplex-network with 2 layers and compared with voters on single-network system to confirm multiplexity.