Collective Dynamics and Networks

June 10-12, 2022

Description and Aims

Many phenomena in nature, biology, society, and engineering can be modeled through simple systems connected in a network of interactions.

The effect of these interactions is the appearance of non-trivial collective behaviors that cannot be predicted solely by considering the simple systems in isolation.

The study of such collective behaviors is one of the main pillars of modern science with several scientists from different fields, such as physics, mathematics, biology, engineering, and others, working together to push forward the state of the art in understanding the world around us.

The aim of this workshop is to bring together people studying these problems from different points of view, to explore the state of the art through research talks, and consider new applications through open-ended discussions.

The workshop will take place online on June 10-12, 2022 and will be hosted by the Zu Chongzhi Center for Mathematics and Computational Sciences at Duke Kunshan University.

Organizers & Co-organizing Institutes

Konstantinos Efstathiou
Zu Chongzhi Center for Mathematics and Computational Sciences, Duke Kunshan University

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Wei Lin
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Registration and Information

https://sites.duke.edu/dkucmcs/collective-dynamics-and-networks-workshop/

Contact for inquiries

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Schedule

All times are China Standard Time (GMT+8). Each talk is 30 minutes and will be followed by a 10-minute discussion.

Meeting Zoom ID: 984 3594 4644. Password: dkumath.

Day 1 (Friday, June 10)

8:20 – 8:30 — Opening

8:30 – 10:30 — Session 1
8:30 – 9:10 Peng Ji *Impact of network motifs on response dynamics*
9:10 – 9:50 Jingfang Fan *Network approaches to the complex Earth system*
9:50 – 10:30 Meng Zhan *Renewable-dominant power system stability: big challenge and recent progress*

11:00 – 12:20 — Session 2
11:00 – 11:40 Zonghua Liu *Understanding the mechanisms of brain functions from the angle of synchronization and complex network*
11:40 – 12:20 Yuanyuan Mi *A Synaptic Story of Working Memory*

14:20 – 16:20 — Session 3
14:20 – 15:00 Jiwei Zhang *A reduction for spiking integrate-and-fire network dynamics ranging from homogeneity*
15:00 – 15:40 Marc Timme *Nonequilibrium Network Dynamics - Inference, Nonlinear Responses and Tipping Points*
15:40 – 16:20 Jürgen Kurths *Complex Network-based Forecasting of Extreme Climate Events*

16:50 – 17:30 — Session 4
16:50 – 17:30 Tiejun Li *Quantifying the Stemness of Cells by Birth-Death Process in scRNA-seq Data Analysis*

Day 2 (Saturday, June 11)

8:30 – 10:30 — Session 1
8:30 – 9:10 Ying-Cheng Lai *Finding the structures of complex networks from data*
9:10 – 9:50 Zhihong You *Nonreciprocity as a generic route to traveling and oscillatory states*
9:50 – 10:30 Lei-Han Tang *COVID-19 intervention: Quantifying epidemic growth rate reduction under testing and human mobility control*

11:00 – 12:20 — Session 2
11:00 – 11:40 Changsong Zhou *Cost-Efficient Neural Dynamics from Sparse Irregular Spikes to Avalanches: Reconciling Multilevel Spontaneous and Evoked Activity in E-I Balanced Neural Networks at Criticality*
11:40 – 12:20 Haiping Huang *Ensemble perspective for understanding temporal credit assignment: adapting network statistics, stochastic plasticity and disentangled low-dimensional neural dynamics*

14:20 – 16:20 — Session 3
14:20 – 15:00 Yueheng Lan *A variational approach to recurrent patterns in complex systems*
15:00 – 15:40 Jian-Guo Liu *Thermodynamic Limit of Chemical Master Equation via Nonlinear Semigroup*
15:40 – 16:20 Wei Wang *Synchronization and waves among chemically oscillating microparticles: experiments and physio-chemical insights*

16:50 – 18:10 — Session 4
16:50 – 17:30 Shixin Xu *A Tridomain Model for Optic Nerve Microcirculation*
17:30 – 18:10 Gang Yan *Data-driven inference of complex network dynamics*

Day 3 (Sunday, June 12)

8:30 – 10:30 — Session 1
8:30 – 9:10 Yang Tang *Event-based consensus of multi-agent systems*
9:10 – 9:50 Kai Huang *Patterns in sand*
9:50 – 10:30 Xiaqing Shi *Susceptibility of Orientationally Ordered Active Matter*

11:00 – 12:20 — Session 2
11:00 – 11:40 Xiyun Zhang *Network Physiology: a network perspective of health and disease*
11:40 – 12:20 Yanni Xiao *Modelling COVID-19 pandemic: an insight from multi-scale dynamic models*

13:40 – 16:20 — Session 3
13:40 – 14:20 Xiaosong Chen *Discontinuous phase transition of density and continuous phase transition of collective motion in living systems*
14:20 – 15:00 Xingang Wang *Breathing Cluster in Astrocyte-neuron Networks*
15:00 – 15:40 Muhua Zheng *Self-similar transformation of complex network and its application*
15:40 – 16:20 Stefano Boccaletti *Structure, processes and dynamics of networks with higher order interactions*

16:20 – 16:30 — Closing

Titles and Abstracts

Day 1 — Session 1

Impact of network motifs on response dynamics

Peng Ji
Fudan University

Many collective phenomena such as epidemic spreading and cascading failures in socio-economic systems on networks are caused by perturbations of the dynamics. How perturbations propagate through networks, impact and disrupt their functions may depend on the network, the type and location of the perturbation as well as the spreading dynamics. Previous work has analyzed the effects that the nodes along propagation paths induce, suggesting few transient propagation "scaling" regimes as a function of the nodes' degree, but regardless of motifs such as triangles. Yet, empirical networks consist of motifs enabling the proper functioning of the system. Here, we show that basic motifs along the propagation path may jointly determine the previously proposed regimes of distance-limited propagation and degree-limited propagation, or even cease their existence. Our analysis suggests not only a radical departure from these scaling regimes but provides a deeper understanding of the interplay of self-dynamics, interaction dynamics, and topological properties.

Network approaches to the complex Earth system

Jingfang Fan
Beijing Normal University

Global warming, extreme climate events, earthquakes and their accompanying natural disasters pose significant risks to humanity. Yet due to the nonlinear feedback, multiple interactions and complex structure of the Earth system, the understanding and in particular the predicting of such disruptive events represent formidable challenges for both scientific and policy communities. During the past years, the emergence and evolution of Earth system science has attracted much attention and produced new concepts and frameworks. Especially, novel statistical physics and complex networks-based techniques have been developed and implemented to substantially advance our knowledge for a better understanding of the Earth system. I will present a brief review on the recent scientific progress in the development and application of how combined statistical physics and network science approaches can be applied to complex Earth systems.

Renewable-dominant power system stability: big challenge and recent progress

Meng Zhan
Huazhong University of Science and Technology

With the fast development and increasing integration of renewable energy including wind and solar powers, building a renewable-dominant power system has become one of key national strategies in China. Very recently on July 28, 2021, China association for science and technology has proposed ten key frontier scientific problems, including one problem: "What is the path optimization and stability mechanism of the renewable-dominant power system?" Clearly the renewable-dominant power system stability faces some big, basic challenges, such as complex system, nonlinearity, multi-time scale, complicated dynamical interaction, hybrid dynamics, intermittent behavior, low inertia, unclear instability characteristics, etc. Some are common for any general complex systems. In this talk, I will deep into the renewable-dominant power system dynamical problems, by using not only reductionism but also holism methods. I will also introduce some of our recent works. I hope that these basic problems could arouse general interest of researchers in the fields of not only electrical engineering, but also system engineering, nonlinear dynamics, and complex systems.

Day 1 — Session 2

Understanding the mechanisms of brain functions from the angle of synchronization and complex network

Zonghua Liu
East China Normal University

The human brain is the most complicated and fascinated system and executes various important brain functions, but its underlying mechanism is a long-standing problem. In recent years, based on the progress of complex network science, much attention has been paid to this problem and many important results have been achieved, thus it is the time to make a summary to help further studies. For this purpose, we here make a brief but comprehensive review on those results from the aspect of brain networks, i.e., from the angle of synchronization and complex network. First, we briefly discuss the main features of human brain and its cognitive functions through synchronization. Then, we discuss how to construct both the anatomical and functional brain networks, including the pathological brain networks such as epilepsy and Alzheimer's diseases. Next, we discuss the approaches of studying brain networks. After that, we discuss the current progress of understanding the mechanisms of brain functions, including the aspects of chimera state, remote synchronization, explosive synchronization, intelligence quotient, and remote propagation. Finally, we make a brief discussion on the envision of future study.

A Synaptic Story of Working Memory

Yuanyuan Mi
Center for Neurointelligence, Chongqing University

Working memory refers to the phenomenon that the brain can store and manipulate input information temporally, in order to carry out certain cognitive functions. The neural mechanism underlying working memory has been debated constantly in the field. The synapse-based theory proposes that rather than relying on persistent neuronal firings, the temporally facilitated synaptic strengths due to short-term synaptic plasticity (STP) can carry the memory trace of inputs and thus support working memory. In this talk, I will introduce two studies aligning with this STP-based theory. First, we built up a computational model to analyze the capacity of working memory and found that the model naturally predicts the capacity of 4~6, when the biological plausible parameters are used, and the model works in a way analogy to the theta-gamma oscillation. Secondly, we manipulated the synapse strengths via STP by applying external probe signals, and found that the memory retrieval performances predicted by the model agree very well with the experimental findings. Overall, our studies suggest that STP can serve as the neural mechanism for working memory.

Day 1 — Session 3

A reduction for spiking integrate-and-fire network dynamics ranging from homogeneity

Jiwei Zhang
Wuhan University

In this talk we present a general methodology for systematically reducing the dynamics of homogeneously-structured integrate-and-fire networks down to an augmented 4-dimensional system of ordinary-differential-equations. Our reduction succeeds where most current firing-rate and population-dynamics models fail because we capture the emergence of `multiple-firing-events' involving the semi-synchronous firing of many neurons. These multiple-firing-events are largely responsible for the fluctuations generated by the network and, as a result, our reduction faithfully describes many dynamic regimes ranging from homogeneous to synchronous. Our reduction is based on first principles, and provides an analyzable link between the integrate-and-fire network parameters and the `dynamic-skeleton' underlying the 4-dimensional augmented ODE.

Nonequilibrium Network Dynamics - Inference, Nonlinear Responses and Tipping Points

Marc Timme
Institute for Theoretical Physics and Center for Advancing Electronics Dresden, TU Dresden

Most network dynamical systems are out of equilibrium and externally driven by fluctuations or perturbations. Yet a comprehensive theory about the collective responses of networks under nonequilibrium conditions is missing to date. Here, we sketch three dimensions of recent progress. First, we demonstrate how to identify the number N of dynamical variables making up a network -- arguably its most fundamental property -- from time series of only a small subset of $n<N$ variables recorded during system transients. Second, we show how nonlinear dynamical systems driven by external fluctuations with zero average generically exhibit a non-zero average response that nonlinearly increases with driving strength. Third, we propose a scheme to predict tipping points beyond which nonlinear nonequilibrium systems cease to respond locally in state space, and thus typically entirely loose their dedicated functionality.

This is work with Jose Casadiego, Hauke Haehne, Georg Boerner, Moritz Thuemler and others.

[1] Topical Review: Marc Timme & Jose Casadiego, J. Phys. A 47:343001 (2014).
[2] Casadiego et al., Nature Comm. 8:2192 (2017).
[3] Haehne et al., Phys. Rev. Lett. 122:158301 (2019).
[4] M. Thuemler et al., submitted (2022).

Complex Network-based Forecasting of Extreme Climate Events

Jürgen Kurths
Potsdam Institute for Climate Impact Research & Humboldt University, Department of Physics, Berlin

The Earth system is a very complex and dynamical one basing on various feedbacks. This makes predictions and risk analysis even of very strong (sometime extreme) events as floods, landslides, and heatwaves etc. a challenging task. Additionally, there is a strongly increasing number of extreme events due to climate change.

I will present a recently developed innovative approach via complex networks mainly to analyze strong climate events. This leads to an inverse problem: Is there a backbone-like structure underlying the climate system? To treat this problem, we have proposed a method to reconstruct and analyze a complex network from spatio-temporal data. This approach enables us to uncover relations to global and regional circulation patterns in oceans and atmosphere, which leads to construct substantially better predictions, in particular for the onset of the Indian Summer Monsoon, extreme rainfall in South America, the Indian Ocean Dipole and tropical cyclones but also to understand phase transition in the past climate. These examples clearly show that network-based approaches can gainfully complement numerical modeling.

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Day 1 — Session 4

Quantifying the Stemness of Cells by Birth-Death Process in scRNA-seq Data Analysis

Tiejun Li
Peking University

We will present some recent study on the landscape theory for the stochastic dynamical system with birth-death effects and its implication on the scRNA-seq data analysis, which is motivated by the population balance analysis (PBA). These results provide new perspectives on the stemness characterization of cell developments. This is a joint work with Dr. Jifan Shi and Prof. Luonan Chen and Kazuyuki Aihara.

Finding the structures of complex networks from data

Ying-Cheng Lai
Arizona State University

In applications of complex networks, a common situation is that the system can be measured, but its structure and the detailed rules of the dynamical evolution are unknown. The inverse problem is to determine the underlying network structure from time series data. A sparse optimization approach was articulated in 2011. In this talk, inferring the full topology of complex oscillator networks and social networks hosting evolutionary game dynamics will be discussed. The history of this area of research will be reviewed and recent progress will be presented.

Nonreciprocity as a generic route to traveling and oscillatory states

Zhihong You
University of California Santa Barbara

Time periodic patterns occur ubiquitously in nature. Most mathematical models that capture such spatiotemporal dynamics, including reaction–diffusion equations, excitable systems, and prey–predator equations, are unified by the fact that the dynamical variables are nonconserved fields. Here, we demonstrate that traveling and oscillatory patterns can arise in multicomponent systems described by purely diffusive conserved fields from nonreciprocal interactions between species. The appearance of time periodic states in a purely diffusive system with no apparent external forcing is unexpected and defies intuition. Our work suggests that nonreciprocity provides a generic mechanism for the establishment of time periodic states, which might be relevant to both biological systems and synthetic systems with nonreciprocal effective interactions mediated by non-equilibrium environments, such as mixtures of active colloids.

COVID-19 intervention: Quantifying epidemic growth rate reduction under testing and human mobility control

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

The high infectivity and asymptomatic transmission of the Omicron variant rendered contact tracing and quarantine insufficient to contain an outbreak. As infections without an apparent source became numerous, community-wide measures such as mass PCR testing and lockdowns have been introduced in many cities. Local authorities adjust the frequency of testing according to the overall scale of the outbreak. Furthermore, 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? Starting from an agent-based contact model, we formulate a location-based risk propagation matrix theory and evaluate reduction in the epidemic growth rate under a combination of case-specific and non-specific measures mentioned above. The possibility of assigning a risk index to individual locations for digital contact tracing and for preventative measures such as raising entry requirements will be discussed from a complex network dynamics perspective.

The work is supported in part by the RGC of the HKSAR under grant 12304020.

Day 2 — Session 2

Cost-Efficient Neural Dynamics from Sparse Irregular Spikes to Avalanches: Reconciling Multilevel Spontaneous and Evoked Activity in E-I Balanced Neural Networks at Criticality

Changsong Zhou
Department of Physics, Centre for Nonlinear Studies, Institute of Computational and Theoretical Studies, Hong Kong Baptist University

The brain is highly energy consuming, therefore is under strong selective pressure to achieve cost-efficiency in both cortical connectivity and activity. Cortical neural circuits display highly irregular spiking in individual neurons but variably sized collective firing, oscillations and critical avalanches at the population level, all of which have functional importance. It is not clear how cost-efficiency is related to ubiquitously observed multi-level properties of irregular firing, oscillations and neuronal avalanches. In this talk, I will introduce our work demonstrating that prominent multilevel neural dynamics properties can be simultaneously reconciled in a generic, biologically plausible neural circuit model that captures excitation-inhibition balance and realistic dynamics of synaptic conductance. Their co-emergence achieves minimal energy cost as well as maximal energy efficiency on information capacity, when neuronal firings are maintained in the form of critical neuronal avalanches. We propose a semi-analytical mean-field theory to derive the field equations governing the network macroscopic dynamics. It reveals that the critical state E-I balanced state of the network manifesting irregular individual spiking is characterized by a macroscopic stable state, which can be either a fixed point or a periodic motion and the transition is predicted by a Hopf bifurcation in the macroscopic field. An analysis of the impact of network topology from random to modular networks shows that local dense connectivity under E-I balanced dynamics appears to be the key "less-is-more" solutions to achieve cost-efficiency organization in neural systems. In the presence of external stimuli, the model at criticality can simultaneously account for various reliable neural response features observed in experiments.

Ensemble perspective for understanding temporal credit assignment: adapting network statistics, stochastic plasticity and disentangled low-dimensional neural dynamics

Haiping Huang
PMI Lab, School of Physics, Sun Yat-sen University

Recurrent neural networks are widely used in processing complex temporal sequences, like nature language processing and brain dynamics. It remains elusive which neural connections and how weight uncertainty impact the network behavior. In this talk, I will introduce an ensemble method to understand this temporal credit assignment. Our method could precisely identify the critical neural connections, producing an ensemble of candidate networks, which traditional methods could not achieve. Moreover, by theoretical arguments, our statistical model links the network statistics, the emergent neural selectivity, symmetry breaking, stochastic plasticity and low-dimensional learning manifold. Our method can thus be used as a promising tool to explore internal dynamics of widely-used recurrent neural networks.

Refs: W. Zou, C. Li, H. Huang, arXiv:2102.03740.

Day 2 — Session 3

A variational approach to recurrent patterns in complex systems

Yueheng Lan
Beijing University of Posts and Telecommunications

Recurrent patterns play essential roles in the study of complex systems and hence an efficient way of recovering them has long been focus of research. To cope with the instability in the dynamics and the orbital complexity of these cyclic structures, we design a variational method for their determination, which pushes a guess loop with proper topology to the target cycle. Recently, a reduced scheme is practiced in this variational approach, achieving great reduction in both storage requirement and computation time for treating high-dimensional systems.

Thermodynamic Limit of Chemical Master Equation via Nonlinear Semigroup

Jian-Guo Liu
Duke University & Duke Kunshan University

Chemical reactions, at a mesoscopic scale, can be modeled by a random time-changed Poisson process on countable states. The macroscopic behaviors in the large size limit, particularly the estimates for the large fluctuations, can be studied via the WKB reformulation, a.k.a. nonlinear semigroup for the chemical master equation (CME) and the backward equation. The WKB reformulation for the backward equation is Varadhan's discrete nonlinear semigroup and is also a monotone scheme which approximates the limiting first order Hamiltonian-Jacobi equations (HJE). We obtain the wellposedness of CME and the backward equation with "no reaction" boundary conditions and prove the convergence from the monotone schemes to the viscosity solution of HJE via the nonlinear semigroup theory. Our construction of a viscosity solution to HJE automatically inherits the boundary conditions of CME and the backward equation. The convergence from the monotone scheme to HJE solution indeed leads to the large deviation principle for the chemical reaction process at any single time. The convergence from a reversible invariant measure to an upper semicontinuous viscosity solution to the stationary HJE is also proved. This is a joint work with Yuan Gao from Purdue University.

Synchronization and waves among chemically oscillating microparticles: experiments and physio-chemical insights

Wei Wang
Harbin Institute of Technology (Shenzhen)

It is well known that chemically active microparticles can self-assembly and exhibit collective behaviors, mediated by inter-particle interactions. The recent discovery of chemically oscillating particles has ushered in new forms of collective behaviors to synthetic populations such as synchronization and motion waves that highlight temporal rather than spatial order. Understanding the physio-chemical nature of these collective dynamics is important for fundamental and applied reasons. In this talk, I will first give a brief introduction to the concept of chemically active colloids, and review the recent progress of their collective behaviors. In the second half, I will focus on chemically oscillating microparticles, and present our recent findings on their individual oscillation, synchronization, and the emergence of motion waves. These oscillating microparticles can serve as a convenient and versatile model system for the study of nonlinear dynamics, as well as a biomimetic strategy for controlling a swarm of microrobots.

Day 2 — Session 4

A Tridomain Model for Optic Nerve Microcirculation

Shixin Xu
Duke Kunshan University

Complex fluids flow in complex ways in complex structures. Transport of water and various organic and inorganic molecules in the central nervous system are important in a wide range of biological and medical processes. However, the exactdriving mechanisms are often not known. In this work, we investigate flows induced by action potentials in an optic nerve as a prototype of the central nervous system. Different from traditional fluid dynamics problems, flows in biological tissues such as the central nervous system are coupled with ion transport. They are driven by osmosis created by concentration gradient of ionic solutions, which in turn influence the transport of ions. Our mathematical model is based on the known structural and biophysical properties of the experimental system used by the Harvard group Orkand et al. Asymptotic analysis and numerical computation show the significant role of water in convective ion transport. The full model (including water) and the electrodiffusion model (excluding water) are compared in detail to reveal an interesting interplay between water and ion transport. In the full model, convection due to water flow dominates inside the glial domain. This water flow in the glia contributes significantly to the spatial buffering of potassium in the extracellular space. Convection in the extracellular domain does not contribute significantly to spatial buffering. Electrodiffusion is the dominant mechanism for flows confined to the extracellular domain.

Data-driven inference of complex network dynamics

Gang Yan
Tongji University

The availability of empirical data that capture the structure and behavior of complex networked systems has been greatly increased in recent years, however a versatile computational toolbox for unveiling a complex system's nodal and interaction dynamics from data remains elusive. In this talk I will introduce a two-phase approach for autonomous inference of complex network dynamics recently developed by my group. The effectiveness of this novel approach is demonstrated by the tests of inferring several neuronal, genetic, social, and coupled oscillators dynamics on various synthetic and real networks. Importantly, the approach is robust to incompleteness and noises, including low resolution, observational and dynamical noises, missing and spurious links, and dynamical heterogeneity. The approach is applied to infer the early spreading dynamics of H1N1 flu upon the worldwide airline network, and the inferred governing equation can also capture the spread of SARS and COVID-19 diseases. These findings together offer an avenue to discover the hidden microscopic mechanisms of a broad array of real networked systems.

Day 3 — Session 1

Event-based consensus of multi-agent systems

Yang Tang
East China University of Science and Technology

In this talk, we will discuss our recent works in an event-based consensus of multi-agent systems with respect to linear dynamics, attitude dynamics, and security-based control. We first introduce a novel adaptive event-triggered consensus framework for linear multi-agent systems with directed graphs. The fully distributed event-triggered consensus protocols are then designed to solve the leader-follower tracking consensus. As a typical nonlinear dynamic system, the event-triggered attitude consensus problem is considered for multiple rigid body systems. The balance between the consensus performance and triggering times is further investigated in this topic. At last, several results of event-based control of nonlinear systems with security-based control are presented. Based on a hybrid event-triggered framework, we propose the event-based formation control protocol under DoS attacks. Some experiments with quadrotors and mobile robots are shown to verify our theoretical results.

Patterns in sand

Kai Huang
Duke Kunshan University

Understanding the collective behavior of granular matter, such as sands, powders and grains, is crucial to widespread applications ranging from predicting natural disasters to increasing the efficiency of pharmaceutics, additive manufacturing along with other industrial sectors. One of the challenges in deciphering granular dynamics, from a theoretical perspective, is the lack of a continuum description that accounts for both of its static and dynamic behavior, as well as transitions in between. On the one hand, this is largely due to the fact that granular systems are typicall driven far from thermodynamic equilibrium, as many biological systems in our daily lives do. On the other hand, vibrofluidised granular materials are rich pattern forming systems, and the time and length scales associated with which can serve as a model system for the invesgiation of nonequilibrium statistical mechanics in general. In this talk, I will provide a brief overview of pattern formation in this model system, from Faraday crispations to density wave fronts, including both experimental and numerical results. Hopefully, this overview can trigger interest in understanding collective dynamics in systems driven far from thermodynamics in general, from the development of fingerprints to to the clustering of bacteria colonies.

Susceptibility of Orientationally Ordered Active Matter

Xiaqing Shi
Soochow University

We investigate the susceptibility of long-range ordered phases of two-dimensional dry aligning active matter to population disorder, taken in the form of a distribution of intrinsic individual chiralities. Using a combination of particle-level models and hydrodynamic theories derived from them, we show that while in finite systems all ordered phases resist a finite amount of such chirality disorder, the homogeneous ones (polar flocks and active nematics) are unstable to any amount of disorder in the infinite-size limit. On the other hand, we find that the inhomogeneous solutions of the coexistence phase (bands) may resist a finite amount of chirality disorder even asymptotically.

Day 3 — Session 2

Network Physiology: a network perspective of health and disease

Xiyun Zhang
Jinan University

Traditionally human physiological states and pathological conditions are defined based on the dynamics and functions of single organs. However, the human body is a complex network. Organs coordinate through network interactions to maintain health and to generate distinct physiological functions. Dysfunction of this physiological network can also lead to disease or even death. Therefore, exploring the dynamical interaction network among organs is essential to deeper understand the human physiology and the emergence of disease. Utilizing the concept of time delay stability, we quantify the dynamical interactions among key organs and build the physiological network. Taking healthy sleep as a example, we show that there is a association between network topology and physiological states, which is robust and does not change with age. Comparing the healthy subjects and Parkinson patients, we find that this dynamical interactions network between organs can serve a novel hallmark for diagnosis and prognosis.

Modelling COVID-19 pandemic: an insight from multi-scale dynamic models

Yanni Xiao
School of Mathematics and Statistics, Xi'an Jiaotong University

The global outbreak of COVID-19 has caused worrying concern amongst the public and health authorities. Modeling of this novel coronavirus also presents us a great challenge. In this talk I initially summarize what we have done on the prediction of COVID-19 pandemic and effect of massive movement on the possible outbreak. I then present our recent work on COVID-19 infection, including a multi-scale models describing the multiple outbreaks and a stochastic individual based model on complex networks with four layers. We would like to investigate how behavior changes, vaccination and relaxation of non-NPIs affect the development of COVID-19 infections. Finally I shall give some considerations and thoughts on modelling COVID-19 infections and concluding remarks.

Day 3 — Session 3

Discontinuous phase transition of density and continuous phase transition of collective motion in living systems

Xiaosong Chen
School of Systems Science, Beijing Normal University

Living systems are full of astonishing diversity and complexity of life. Despite differences in the length scales and cognitive abilities of these systems, collective motion of large groups of individuals can emerge. It is of great importance to seek for the fundamental principles of collective motion, such as phase transitions and their natures. Via an eigen microstate approach, we have found a discontinuous transition of density and a continuous transition of velocity in the Vicsek models of collective motion, which are identified by the finite-size scaling form of order-parameter. At strong noise, living systems behave like gas. With the decrease of noise, the interactions between the particles of a living system become stronger and make them come closer. The living system experiences then a discontinuous gas-liquid like transition of density. The even stronger interactions at smaller noise make the velocity directions of particles become ordered and there is a continuous phase transition of collective motion in addition.

Breathing Cluster in Astrocyte-neuron Networks

Xingang Wang
Shaanxi Normal University

The brain activities are featured by non-stationary dynamical patterns, yet the underlying mechanism remains not clear. Here, by introducing astrocyte-induced adaptive couplings between neurons, we investigate the collective behaviors on adaptive astrocyte-neuron networks. It is found that during the process of network evolution, a portion of the neurons are synchronized in an intermittent fashion, while the whole network remains as desynchronized. We conduct a detailed analysis on the properties of the cluster, and give the necessary conditions for observing this phenomenon. This type of non-stationary pattern, which is named breathing cluster, reveals from a new perspective the interplay between network structure and dynamics, and has implications to the functionalities of brain system.

Self-similar transformation of complex network and its application

Muhua Zheng
Jiangsu University

Symmetries in physical theories denote invariance under some transformation, such as self-similarity under a change of scale. The renormalization group provides a powerful framework to study these symmetries. Here, we provide a framework for the investigation of complex networks at different resolutions. Firstly, we introduce a geometric renormalization (GR) protocol by decreasing the resolution in complex networks. Then we show that the GR model produces a multiscale unfolding of the network in scaled-down replicas, which can be used to predict the multiscale self-similar properties of human connectomes. In the end, we present an inverse renormalization transformation in the Geometric Branching Growth (GBG) model, which is designed to predict self-similar branching growth in the evolution of real networks and explain the symmetries observed. Practical applications of the GBG model in real instances include the tuning of network size for best response to external influence and finite-size scaling to assess critical behaviour under random link failures.

Structure, processes and dynamics of networks with higher order interactions

Stefano Boccaletti
CNR Institute of Complex Systems, Florence

All the beauty, richness and harmony in the emergent dynamics of a complex system largely depend on the specific way in which its elementary components interact.

The last twenty years have seen the birth and development of the multidisciplinary field of Network Science, wherein a variety of distributed systems in physics, biology, social sciences and engineering have been modelled as networks of coupled units, in the attempt to unveil the mechanisms underneath their observed functionality.

But there is a fundamental limit in such a representation: networks capture only pairwise interactions, whereas the function of many real-world systems not only involves dyadic connections, but rather is the outcome of collective actions at the level of groups of nodes. For instance, in ecological systems, three or more species may compete for food or territory, and similar multi-component interactions appear in functional and structural brain networks, protein interaction networks, semantic networks, multi-Authors scientific collaborations, offline and online social networks, gene regulatory networks and spreading of consensus or contagious diseases due to multiple, simultaneous, contacts. Such multi-component interactions can only be grasped through either hypergraphs or simplicial complexes, which indeed have recently found a huge number of applications in social and biological contexts, as well as in engineering and brain science. These structures are indeed becoming increasingly relevant, thanks to the enhanced resolution of data sets and the recent advances in data analysis techniques, which (concurrently and definitely) have shown that they play a pivotal role in the complex organization and functioning of real-world distributed systems.

In my talk, I will describe a series of relevant problems which arise when one goes beyond the limit of pairwise interactions in a networked system. In particular, I will try to focus on some structural issues of these new objects, such as the need of properly redefining centrality and rankings of nodes, as well as on a series of new emerging phenomenologies that appear in processes and dynamics taking place on top of such new objects.