

2nd Workshop on Learning Dynamical System

November 25-27, 2026 @ RIKEN AIP & Zoom (hybrid)

Provisional program Updated October 5, 2026

Venue

Open Space

RIKEN Center for Advanced Intelligence Project (RIKEN AIP)

Nihonbashi 1-chome Mitsui Building, 15th floor
1-4-1 Nihonbashi, Chuo-ku, Tokyo 103-0027, Japan

[RIKEN access information](#) [Google Maps](#)

Workshop hours

November 25 · Wednesday	10:00-18:10
November 26 · Thursday	10:00-18:10
November 27 · Friday	10:00-12:20

All times in Japan Standard Time (JST).

About this program

Speaker order and online presentation times remain provisional. Abstracts follow the daily schedules in presentation order.

[Workshop website and latest program](#)

DAY 1 / WORKSHOP PROGRAM

November 25 · Wednesday

All times in Japan Standard Time (JST)

Topology and model reduction

10:00-10:40	Riccardo Muolo RIKEN Dynamics beyond nodes: from topology to synchronization patterns in higher-order networks
10:40-10:50	Break
10:50-11:30	Ying Wang Fudan University Entropy and topological conditional entropy in dynamical systems
11:30-11:40	Break
11:40-12:20	Koichiro Yawata Hitachi, Ltd. Data-driven reduction of rhythmic dynamics through phase autoencoder
12:20-14:00	Lunch

Dynamics of Learning

14:00-14:40	Bingze Lu National Chung Cheng University How numerical integrators shape learned dynamics in neural ODEs
14:40-14:50	Break
14:50-15:30	Xuejin Zhang Jilin University From nonlinear dynamical systems to neural network training: dynamics tracking via polynomials of unitary operators
15:30-15:40	Break
15:40-16:20	Guillaume Braun RIKEN Overfitting of spectral gradient descent: how matrix geometry shapes generalization and implicit bias
16:20-16:40	20 mins break

Numerical methods and applications

16:40-17:20	Axel Turnquist Beijing Institute of Mathematical Sciences and Applications Convergence theory for monotone finite-difference schemes solving prescribed Jacobian equations on unbounded subsets of $\mathbb{R}^n$, with applications to freeform optics and economics
17:20-17:30	Break
17:30-18:10	Rauan Kelesbekov University of Alberta Effects of large-amplitude periodic perturbations on boundary layer separation

DAY 2 / WORKSHOP PROGRAM

November 26 · Thursday

All times in Japan Standard Time (JST)

Dynamical modeling and score learning

10:00-10:40	Jiachen Yao (Online) California Institute of Technology Physics is the best teacher: consistency learning for time-invariant operators of chaotic dynamics
10:40-10:50	Break
10:50-11:30	Yao Li (Online) University of Massachusetts Amherst A probabilistic score estimation using the Bismut-Elworthy-Li formula
11:30-11:40	Break
11:40-12:20	He Ma Fudan University From dynamics learning to dynamics creation: neural transfer learning for complex dynamical systems
12:20-14:00	Lunch

Memory-based modeling of complex systems

14:00-14:40	Qunxi Zhu Fudan University Memory-driven AI modeling of complex systems: methods and applications
14:40-14:50	Break
14:50-15:30	Wanfeng Lu Fudan University From incomplete observations to predictive dynamics: a Koopman-Mori-Zwanzig perspective
15:30-15:50	20 mins break

Distributional dynamics and operator learning

15:50-16:30	Maria Oprea Institute of Science and Technology Austria Learning dynamical systems using measure based metrics
16:30-16:40	Break
16:40-17:20	Yutong Zhang Fudan University Distributional prediction of single-cell dynamics
17:20-17:30	Break
17:30-18:10	Yuanchao Xu Kyoto University Learning Kolmogorov backward operators for spectral analysis and forecasting: a data-driven variational Galerkin framework

DAY 3 / WORKSHOP PROGRAM

November 27 · Friday

All times in Japan Standard Time (JST)

Climate dynamics and data assimilation

10:00-10:40	Claire Valva (Online) California Institute of Technology Analysis and forecasting of the tropical atmosphere with Koopman operators
10:40-10:50	Break
10:50-11:30	Pin-Ying Wu Kyoto University Data-driven sensitivity analysis of atmospheric dynamics using ensembles
11:30-11:40	Break
11:40-12:20	Kota Takeda Nagoya University Ensemble data assimilation in high-dimensional chaotic systems: exploiting low-dimensional structures

Acknowledgement

This workshop is supported by the following JST CREST projects in the research area “Creation of Mathematical Foundation for Prediction and Control.”

JST CREST**Innovation in Interdisciplinary Mathematical Research via Single-Cell Data Science**

Principal investigator: Yusuke Imoto (Kyoto University)

Grant number: JPMJCR24Q1

JST CREST**Nonlinear, dissipative, and random dynamics based on deterministic governing equations**

Principal investigator: Aiko Yakeno (Tohoku University)

Grant number: JPMJCR24Q6

DAY 1 / ABSTRACTS

November 25 · Wednesday

10:00-10:40 JST Riccardo Muolo

RIKEN

Dynamics beyond nodes: from topology to synchronization patterns in higher-order networks

In recent years, increasing attention has been given to dynamical processes taking place on higher-order networks, where interactions are not limited to links, but may involve also higher-dimensional simplices [1]. While classical network models assume that state variables live on nodes and interact through links, many real systems - including brain, climate, and transportation systems - cannot be fully described within this node-centric perspective [2]. In this talk, I will introduce the framework of higher-order networks and the concept of topological signals, namely, dynamical variables defined on simplices of higher dimensions. I will briefly present the basic tools required for this setting, including elementary notions of discrete calculus, discrete topology and geometric algebra, which serve as the mathematical foundation for modeling dynamical processes beyond the node-based paradigm.

Next, I will discuss models of oscillatory dynamics extended to this framework. First, I will present the topological Kuramoto model [3], in which phases are not restricted to nodes but may also be associated with links, and where the coupling arises from the combinatorial structure of the simplicial complex. Then, I will introduce the discrete Hodge Laplacian and the Dirac-Bianconi operator [4], the former generalizing diffusive interactions to the higher-order setting, while the latter provides cross-talk between signals defined on simplices of different dimensions. Finally, I will introduce the notion of Dirac-Bianconi driven oscillators, where the dynamics of node- and link-signals coexist, interact and may give rise to collective oscillatory behaviors [5].

References

- [1] Bianconi G., Higher-Order Networks: An Introduction to Simplicial Complexes. Elements in the Structure and Dynamics of Complex Networks, Cambridge University Press, 2021.
- [2] Millán A.P., Sun H., Giambagli L., Muolo R., Carletti T., Torres J.J., Radicchi F., Kurths J., Bianconi G., Topology shapes dynamics of higher-order networks. Nat. Phys., 21: 353-361, 2025.
- [3] Millán A.P., Torres J.J., Bianconi G., Explosive Higher-Order Kuramoto Dynamics on Simplicial Complexes. Phys. Rev. Lett., 124(21): 218301, 2020.
- [4] Bianconi G., The topological Dirac equation of networks and simplicial complexes. J. Phys. Complex., 2(3): 035022, 2021.
- [5] Muolo R., León I., Kato Y., Nakao H., Synchronization of Dirac-Bianconi driven oscillators. J. Phys. A: Math. Theor. 59 095201, 2026.

10:50-11:30 JST Ying Wang

Fudan University

Entropy and topological conditional entropy in dynamical systems

This talk presents two perspective advances in entropy theory for dynamical systems. First, we discuss further characterizations for weak expansiveness of actions by amenable groups. More precisely, we characterise topological conditional entropy in terms of either topological entropy of subsets or ideas of Bowen's dimensional entropy of subsets (joint with Dou Dou, Guohua Zhang). Second, we study topological and measure-theoretical entropies of a nonautonomous dynamical system via the ideas of local entropy theory. We prove local and global variational inequalities, which relates to the topological entropy of a nonautonomous dynamical system to its measure-theoretical entropy (joint with Kexiang Yang, Guohua Zhang).

11:40-12:20 JST Koichiro Yawata

Hitachi, Ltd.

Data-driven reduction of rhythmic dynamics through phase autoencoder

Rhythmic phenomena in complex systems can often be described by low-dimensional variables such as phase and amplitude. Phase autoencoders provide a data-driven framework for learning such reduced representations directly from time-series data, without requiring an explicit mathematical model.

In this talk, I will introduce several studies on phase autoencoders for limit-cycle oscillators and discuss their use for estimating phase-related quantities and analyzing rhythmic dynamics. I will also discuss current challenges and future directions toward more general data-driven reduction of rhythmic systems.

14:00-14:40 JST Bingze Lu

National Chung Cheng University

How numerical integrators shape learned dynamics in neural ODEs

This talk will explain how the choice of numerical integrator affects the training of neural ODEs for discovering unknown dynamical systems from data. Although neural ODEs can accurately fit observed trajectories, the learned systems may exhibit opposite behavior to the underlying dynamics. Such discrepancies are often attributed to insufficient data or limited numerical accuracy. Our study reveals how the stability region of the chosen integrator constrains the spectrum of the learned system. In particular, because the stability region of backward Euler extends into the right half of the complex plane, training with this integrator can produce a dynamical system with eigenvalues having positive real parts. Consequently, the learned continuous dynamics may exhibit spurious expansion even when the numerical trajectories reproduce the observed contraction.

14:50-15:30 JST Xuejin Zhang

Jilin University

From nonlinear dynamical systems to neural network training: dynamics tracking via polynomials of unitary operators

Nonlinear dynamical systems and neural network training can both be viewed as continuous evolutions of states in an underlying phase space. However, representing and tracking such nonlinear processes using linear operators, particularly unitary operators compatible with quantum computation, raises fundamental challenges concerning global linearization, spectral tractability, and trajectory reconstruction. In this talk, we introduce a unified framework based on Koopman operator theory. First, nonlinear state evolution is lifted to linear operator evolution in a Hilbert space. By coupling the Koopman and Perron-Frobenius operators, we construct a self-adjoint representation that simultaneously describes the evolution of observables and state distributions. Next, a heat-kernel embedding is employed to compactify the dynamics in a reproducing kernel Hilbert space with a discrete spectral structure, enabling the construction of a compact self-adjoint generator and its associated unitary evolution operator. The target evolution operator is then approximated by Riesz-Cesàro polynomials of this fundamental unitary operator, which can be implemented through linear-combination-of-unitaries techniques. Convergence of the approximation is established in the operator norm. Finally, a Wasserstein-based variational recovery map is introduced to decode the evolved distribution into pointwise trajectories in the original phase space. This framework provides a systematic route for tracking general nonlinear dynamics using polynomials of unitary operators and offers a theoretical foundation for modeling neural network optimization as a dynamical system, with potential applications to quantum representations and prediction of training trajectories.

15:40-16:20 JST Guillaume Braun

RIKEN

Overfitting of spectral gradient descent: how matrix geometry shapes generalization and implicit bias

We study the generalization of spectral gradient descent (SpecGD) in overparameterized matrix classification with corrupted labels. Each input combines a shared low-rank signal with a rank-one sample-specific perturbation, referred to as a shortcut, that enables memorization but does not generalize. We contrast collapsed shortcuts, which share a singular direction, with dispersed shortcuts, which occupy distinct singular directions. Changing only this geometry can reverse the relative generalization of GD and SpecGD: collapsed shortcuts can favor SpecGD, while dispersed shortcuts can favor GD. In the dispersed regime, exact shortcut orthogonality eliminates the signal from the late-stage SpecGD direction, while vanishing random correlations collectively generate a small but generalization-relevant signal through a second-order effect. To identify the direction selected by SpecGD, which the spectral max-margin problem alone does not determine, we combine a refined analysis of its dual with the exponentiated-gradient dynamics of normalized loss weights. Finally, we show that a single SpecGD step can already interpolate and generalize well, while continued training converges to a direction with substantially worse generalization.

16:40-17:20 JST Axel Turnquist

Beijing Institute of Mathematical Sciences and Applications

Convergence theory for monotone finite-difference schemes solving prescribed Jacobian equations on unbounded subsets of $\mathbb{R}^n$, with applications to freeform optics and economics

Consider two probability measures μ and ν , with supports on subsets of $\mathbb{R}^n$ and with density functions f and g , respectively. Now consider a pushforward map T that locally transports mass from μ to ν . If T is smooth enough, it satisfies the Jacobian equation $f(x) = g(T(x)) \det DT(x)$, which follows from the standard change of variables formula.

In many interesting applications, a pushforward mapping T can be found with specific structure that is a result of T solving an optimization problem. A classical example is the case where $T(x) = \nabla u(x)$, where u is a convex function. This gradient mapping arises in the optimal transport problem with a quadratic cost function. In this case, the Jacobian equation becomes the Monge-Ampère equation: $f(x) = g(\nabla u(x)) \det(D^2 u(x))$, coupled with the associated nonlocal second boundary condition $T(\text{spt}(\mu)) = \text{spt}(\nu)$.

The greatest generalization which preserves the essential structure of the above problem arises in some freeform optics problem and problems of stable matching in economics. In this case, the pushforward map can be written as $T(x) = F(x, u(x), \nabla u(x))$, where u is a G -exponential function, referring to a generating function G . The potential function u solves a PDE known as the prescribed Jacobian equation (PJE): $\det(D^2 u(x) + A(x, u(x), \nabla u(x))) = \psi(x, u(x), \nabla u(x))$, subject to the condition $T(\text{spt}(\mu)) = \text{spt}(\nu)$. Many optimal transport problems are subcases of this general formulation.

We consider solving PJE's with monotone finite-difference methods. These methods have shown promise in solving fully nonlinear elliptic PDEs due to the relative simplicity of proving the convergence of the resulting discrete solutions to locally Lipschitz viscosity solutions of such PDEs. In order to solve such PDEs on unbounded subsets of $\mathbb{R}^n$, we perform a cutoff of the problem at a finite radius $R > 0$. First, we present some results on explicit convergence rates of choosing a cutoff radius $R > 0$ in the quadratic cost optimal transport case. We then present results on the convergence of discretizations of such problems.

17:30-18:10 JST Rauan Kelesbekov

University of Alberta

Effects of large-amplitude periodic perturbations on boundary layer separation

It is known experimentally that finite-amplitude periodic excitations of a boundary layer may lead to a delay of separation or even to the reattachment of initially separated flow. The transition from separated states to reattached ones is described by a curve in the perturbation frequency-amplitude parametric space. In this work we study a minimal model - a boundary layer on a flat plate subjected to large excitation amplitudes - to identify these transition curves and to understand the underlying physical mechanisms. Two settings are considered: when a finite-amplitude traveling-wave perturbations enter the boundary layer (a) at the leading edge and (b) through the free-stream flow. A discrete stream function method, explicitly enforcing mass conservation, was applied to incompressible Navier-Stokes system of equations on a staggered grid with second-order spatial and time numerical approximations. Simulations show, in particular, that perturbations in setting (a) lead to separation at lower amplitudes compared to setting (b). We also offer a theoretical explanation for the observed behavior.

DAY 2 / ABSTRACTS

November 26 · Thursday

10:00-10:40 JST Online Jiachen Yao

California Institute of Technology

Physics is the best teacher: consistency learning for time-invariant operators of chaotic dynamics

Accelerating the prediction of long-term behavior in chaotic systems is crucial in scientific computing. However, existing methods rely on numerical solvers or autoregressive models that advance one small step at a time, which makes long horizons expensive. We instead view this problem as learning the system's time-invariant evolution operator, which jumps the state across a large time span in a single evaluation. To this end, we derive the consistency equations a time-invariant operator must satisfy, with differential and compositional objectives in physical time. These equations also connect the learned operator to the physics-prescribed instantaneous dynamics, enabling direct physics embedding in consistency learning. Across five chaotic systems, we find that physics-distilled consistency makes both short-term trajectories and long-term statistics more accurate. The learned operator survives temporal extrapolation and requires one-tenth as many evaluations as autoregressive rollout, offering an efficient route to long-term simulation of chaotic dynamics.

10:50-11:30 JST Online Yao Li

University of Massachusetts Amherst

A probabilistic score estimation using the Bismut-Elworthy-Li formula

In this talk I will introduce a new approach of obtaining point-wise score estimates of generic stochastic differential equations (SDEs) using Malliavin calculus. This approach provides effective supervision for many existing score learning methods, which significantly improves the performance of score training for SDEs without explicit solutions. I will explain how the algorithm work, how to choose a suitable nonlinear SDE, how to choose collocation points, and demonstrate several examples of sample regeneration.

11:40-12:20 JST He Ma

Fudan University

From dynamics learning to dynamics creation: neural transfer learning for complex dynamical systems

Complex dynamical systems exhibit rich behaviors that are often difficult to reconstruct, predict, and control. In this talk, I will introduce Neural Dynamical Transfer Learning (NDTL), a framework for creating new dynamical systems by transferring and combining dynamical features from existing ones. The method learns representations of vector fields and enables the fusion of properties such as attractor geometry, Lyapunov exponents, and power spectra. Examples from chaotic, ecological, and epidemiological systems illustrate how NDTL can move beyond learning existing dynamics toward the creation of systems with desired dynamical characteristics.

14:00-14:40 JST Qunxi Zhu

Fudan University

Memory-driven AI modeling of complex systems: methods and applications

How can AI be endowed with memory so that it can better understand and simulate complex systems in the real world? This is the central question addressed in this talk. Beginning with the broader context of complex systems research, the talk will briefly review mainstream methodological frameworks and their current applications. It will then focus on the memory-driven paradigm, systematically presenting our latest advances in this direction and demonstrating, from theoretical, methodological, and application perspectives, its effectiveness in enhancing the modeling and identification of complex systems. Finally, the talk will discuss potential pathways and future trends at the intersection of artificial intelligence and complex systems.

14:50-15:30 JST Wanfeng Lu

Fudan University

From incomplete observations to predictive dynamics: a Koopman-Mori-Zwanzig perspective

Learning predictive dynamics from incomplete observations is central to the study of complex systems across physics and biology. We focus on two representative scenarios in this talk: sparse, irregular observations of spatiotemporal fields, as encountered in turbulence and weather systems; and temporally sparse, unpaired distribution snapshots from single-cell RNA sequencing (scRNA-seq). Our approach builds on Koopman theory, which offers a unified perspective for understanding nonlinear dynamics through the linear evolution of observables. Learning suitable observables of system states or spatiotemporal fields provides compact representations of the underlying dynamics. A weak formulation of the continuity equation in Wasserstein space further extends traditional operator estimation to unpaired distribution snapshots, enabling dynamical learning even when individual trajectories are unavailable. Nonetheless, the resulting finite-dimensional representation need not be dynamically closed, so linear evolution alone may miss essential influences of unresolved degrees of freedom. The Mori-Zwanzig formalism connects this lack of closure to memory effects, motivating corrections that compensate for the limitations of the finite-dimensional linear approximation. Together, Koopman representation learning and memory closure provide a shared theoretical foundation for describing both the principal dynamical structure and the influence of hidden variables. Through spatiotemporal forecasting and the modeling of single-cell population dynamics, we illustrate how this perspective supports interpretable dynamical representations, improves prediction beyond the observed time horizon, and enables learning directly from distribution snapshots.

15:50-16:30 JST Maria Oprea

Institute of Science and Technology Austria

Learning dynamical systems using measure based metrics

Learning chaotic dynamics from data is notoriously difficult, particularly when observations are sampled slowly, trajectories cannot be tracked over time, or measurements are corrupted by noise. Measure-based techniques, which compare distributions of states rather than individual trajectories, have shown notably greater robustness to noise, but the evidence for their advantage has so far been largely numerical. In this work, we study the learning problem using the maximum mean discrepancy (MMD) as a metric between distributions. By working with a quadratic approximation of the MMD, we give a theoretical analysis of how noise affects the reconstructed dynamics, and we use it to explain why measure-based algorithms outperform pointwise approaches when data are noisy. We also present preliminary computational results based on the quadratic approximation of the MMD.

16:40-17:20 JST Yutong Zhang

Fudan University

Distributional prediction of single-cell dynamics

Modeling how perturbations reshape cellular dynamics remains challenging because single-cell observations are unpaired across time, while perturbation effects are entangled with background cellular variation. Although multi-conditional flow matching models achieve strong interpolation across observed time points and conditions, their ability to extrapolate to unseen perturbations and generate reliable counterfactual trajectories remains limited. We address this problem through causal disentanglement, decomposing cellular states into a condition-invariant background representation and a condition-responsive representation that captures perturbation-specific effects. Building on this disentangled latent space, we aim to explicitly learn how experimental conditions modify the underlying dynamical vector field. By transferring dynamical structure learned from observed conditions and inferring condition-specific vector fields for held-out perturbations, the framework is designed to improve extrapolation to unseen conditions and enable more principled counterfactual generation.

17:30-18:10 JST Yuanchao Xu

Kyoto University

Learning Kolmogorov backward operators for spectral analysis and forecasting: a data-driven variational Galerkin framework

For a time-homogeneous Markov process, the fixed-lag solution operator $(T_\tau f)(x) = \mathbb{E}[f(X_{t+\tau}) \mid X_t = x]$ of the Kolmogorov backward equation evolves observables linearly and deterministically, even when the state dynamics is stochastic. We estimate this operator from time-lagged data without knowing the governing equation and compress it by Galerkin projection onto a finite-dimensional observable space that is fixed in advance or selected variationally. The reduced matrix is used for spectral analysis and finite-horizon forecasting. We trace how operator-approximation, space-selection, and finite-sampling errors enter the computed eigenvalues, invariant subspaces, and forecasts. Near an isolated spectral cluster, the invariance defect of a subspace controls its distance from the target invariant subspace, and the forecast bounds are uniform in the horizon for stable reduced models. When the operator estimate is specifically induced by a Fourier neural operator (FNO) approximation of a deterministic time- τ mapping, we propagate the state-map error through the Galerkin construction. Numerical experiments illustrate spectral approximation and forecasting, including long-rollout stability and a comparison with extended dynamic mode decomposition (EDMD) using fewer observed transition pairs than basis functions.

DAY 3 / ABSTRACTS

November 27 · Friday

10:00-10:40 JST Online Claire Valva

California Institute of Technology

Analysis and forecasting of the tropical atmosphere with Koopman operators

Data driven approximations of Koopman and transfer operators can be used to perform feature extraction in nonlinear systems, where we can identify quasi-oscillatory spatial modes that evolve coherently with characteristic frequencies through an eigendecomposition. These can be useful tools for understanding and forecasting the climate system, particularly its oscillatory components. I will discuss implementations of this technique in the tropical atmosphere - analyzing the Quasi-Biennial and the Madden-Julian Oscillations - where we are able to use these methods to quantify the strength of nonlinear interactions with the seasonal cycle and for improved extended-range weather prediction, respectively.

10:50-11:30 JST Pin-Ying Wu

Kyoto University

Data-driven sensitivity analysis of atmospheric dynamics using ensembles

Atmospheric flows are chaotic dynamical systems with strong sensitivity to small changes in their initial states. Identifying the elements to which future atmospheric evolution is most sensitive is important for weather prediction and for understanding atmospheric dynamics. This study explores data-driven sensitivity analysis using ensembles of numerical simulations. Several conventional ensemble-based sensitivity methods are first compared within a unified framework, followed by nonlinear sensitivity analysis using a Gaussian process emulator trained on ensemble data. Using the Lorenz 96 model as a test bed, we examine how linear and nonlinear approaches identify sensitive directions and assess their potential for future applications to atmospheric dynamics.

11:40-12:20 JST Kota Takeda

Nagoya University

Ensemble data assimilation in high-dimensional chaotic systems: exploiting low-dimensional structures

Data assimilation is a framework that combines mathematical models with observational data, originally developed in numerical weather prediction. We present its mathematical foundations, and then focus on ensemble-based algorithms that exploit the essential low-dimensional structures of high-dimensional chaotic systems arising in atmospheric modeling. Recent advances are highlighted, and future directions are discussed.