应用所科研人员近期研究成果

成果一：

张世华研究员的论文 Tessellating the Latent Space for Non-Adversarial Generative Auto-Encoders 被 IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE 接收发表。

摘要：Non-adversarial generative models such as variational auto-encoder (VAE), Wasserstein auto-encoders with maximum mean discrepancy (WAE-MMD), sliced-Wasserstein auto-encoder (SWAE) are relatively easy to train and have less mode collapse compared to Wasserstein auto-encoder with generative adversarial network (WAE-GAN). However, they are not very accurate in approximating the target distribution in the latent space because they don't have a discriminator to detect the minor difference between real and fake. To this end, we develop a novel non-adversarial framework called Tessellated Wasserstein Auto-encoders (TWAE) to tessellate the support of the target distribution into a given number of regions by the centroidal Voronoi tessellation (CVT) technique and design batches of data according to the tessellation instead of random shuffling for accurate computation of discrepancy. Theoretically, we demonstrate that the error of estimate to the discrepancy decreases when the numbers of samples n and regions m of the tessellation become larger with rates of O((1)/(root n)) and O((1)/(root m)), respectively. Given fixed n and m, a necessary condition for the upper bound of measurement error to be minimized is that the tessellation is the one determined by CVT. TWAE is very flexible to different non-adversarial metrics and can substantially enhance their generative performance in terms of Fr & eacute;chet inception distance (FID) compared to VAE, WAE-MMD, SWAE. Moreover, numerical results indeed demonstrate that TWAE is competitive to the adversarial model WAE-GAN, demonstrating its powerful generative ability.

论文链接：http://dx.doi.org/10.1109/TPAMI.2023.3325282

成果二：

马志明研究员的论文 Deciphering and integrating invariants for neural operator learning with various physical mechanisms 被 NATIONAL SCIENCE REVIEW 接收发表。

摘要：Neural operators have been explored as surrogate models for simulating physical systems to overcome the limitations of traditional partial differential equation (PDE) solvers. However, most existing operator learning methods assume that the data originate from a single physical mechanism, limiting their applicability and performance in more realistic scenarios. To this end, we propose the physical invariant attention neural operator (PIANO) to decipher and integrate the physical invariants for operator learning from the PDE series with various physical mechanisms. PIANO employs self-supervised learning to extract physical knowledge and attention mechanisms to integrate them into dynamic convolutional layers. Compared to existing techniques, PIANO can reduce the relative error by 13.6%-82.2% on PDE forecasting

tasks across varying coefficients, forces or boundary conditions. Additionally, varied downstream tasks reveal that the PI embeddings deciphered by PIANO align well with the underlying invariants in the PDE systems, verifying the physical significance of PIANO. PIANO: a new operator learning framework that deciphers and incorporates invariants from the PDE series via self-supervised learning and attention technique, achieving superior performance in scenarios with various physical mechanisms.
论文链接：http://dx.doi.org/10.1093/nsr/nwad336

成果三：

李楠副研究员的论文 Reversibility-unitality-disturbance tradeoff in quantum channels 被 PHYSICAL REVIEW A 接收发表。
摘要：In this work, we employ the squared Hilbert-Schmidt norm of the Gram matrix for a quantum channel as a reversibility quantifier of this channel, which is shown to be complementary to the entropy of this channel, and derive a complementary relation between the reversibility of a quantum channel and its complementary channel. For a natural unitality measure of a quantum channel, we show that it is equivalent to the entropy of the corresponding complementary channel. By quantifying the disturbance of a quantum channel as the decrease of correlations in a maximally entangled state locally passing through this channel, we eventually establish a reversibility-unitality-disturbance triality relation. To illustrate and compare these quantities, we further evaluate them for some prototypical channels associated with some special quantum information processing tasks and computations, such as the quantum teleportation channel, DQC1 channel, Mach-Zehnder interferometry channel, dephrasure channel and so on, including both unital and nonunital cases.
论文链接：http://dx.doi.org/10.1103/PhysRevA.109.012407

成果四：

李向东研究员的论文 W-entropy and Langevin deformation on Wasserstein space over Riemannian manifolds 被 PROBABILITY THEORY AND RELATED FIELDS 接收发表。
摘要：We prove the Perelman type W-entropy formula for the geodesic flow on the L-2-Wasserstein space over a complete Riemannian manifold equipped with Otto's infinite dimensional Riemannian metric. To better understand the similarity between the W-entropy formula for the geodesic flow on the Wasserstein space and the W-entropy formula for the heat flow of the Witten Laplacian on the underlying manifold, we introduce the Langevin deformation of flows on the Wasserstein space over a Riemannian manifold, which interpolates the gradient flow and the geodesic flow on the Wasserstein space over a Riemannian manifold, and can be regarded as the potential flow of the compressible Euler equation with damping on a Riemannian manifold. We prove the existence, uniqueness and regularity of the Langevin deformation on the Wasserstein space over the Euclidean space and a compact Riemannian manifold, and prove the convergence of the Langevin deformation for c -> 0 and c -> infinity respectively. Moreover, we prove the W-entropy-information formula along the Langevin deformation on the Wasserstein space on Riemannian manifolds. The rigidity

theorems are proved for the W-entropy for the geodesic flow and the Langevin deformation on the Wasserstein space over complete Riemannian manifolds with the CD(0, m)-condition. Our results are new even in the case of Euclidean spaces and complete Riemannian manifolds with non-negative Ricci curvature.
论文链接：http://dx.doi.org/10.1007/s00440-023-01256-y

成果五：

朱湘禅研究员的论文 Global Existence and Non-Uniqueness for 3D Navier-Stokes Equations with Space-Time White Noise 被 ARCHIVE FOR RATIONAL MECHANICS AND ANALYSIS 接收发表。

摘 要 ： We establish that global-in-time existence and non-uniqueness of probabilistically strong solutions to the three dimensional Navier-Stokes system driven by space-time white noise. In this setting, solutions are expected to have space regularity of at most -1/2 - ? for any ? > 0. Consequently, the convective term is ill-defined analytically and probabilistic renormalization is required. Up until now, only local well-posedness has been known. With the help of paracontrolled calculus we decompose the system in a way which makes it amenable to convex integration. By a careful analysis of the regularity of each term, we develop an iterative procedure which yields global non-unique probabilistically strong paracontrolled solutions. Our result applies to any divergence free initial condition in L-2 ? B-8,8(-1+?) (,) ? > 0, and also implies non-uniqueness in law.
论文链接：http://dx.doi.org/10.1007/s00205-023-01872-x

成果六：

骆顺龙研究员的论文 Coherence in multipath interference via quantum Fisher information 被 PHYSICAL REVIEW A 接收发表。

摘要：Wave-particle duality, as complementarity displayed in interferometry, has been investigated extensively from both theoretical and experimental perspectives. In this work, we quantify coherence in multipath interference via quantum Fisher information and illuminate its basic properties. We prove that any rational quantifier of coherence satisfying monotonicity under incoherent operations is nonincreasing in the presence of path detectors. This quantitatively implies that increase on the path information will lead to the loss of coherence or interference (wave feature), which is consistent with wave-particle duality. Furthermore, we provide an operational illustration of wave feature as quantum Fisher information of phase shift parameters encoded in each interference path. By dividing the variance of a quantum state relative to a von Neumann measurement into quantum uncertainty and classical uncertainty, we establish a coherence-predictability-correlations triality relation, with coherence (wave feature) quantified by quantum Fisher information, predictability quantified by purity of a classical probability distribution, and correlations quantified by classical uncertainty relative to the von Neumann measurement determined by the interference paths. Finally, we make a comparison between this triality relation and the wave-particle-mixedness triality relation in the literature.
论文链接：http://dx.doi.org/10.1103/PhysRevA.108.062416

成果七：

骆顺龙研究员的论文 Average coherence and entropy 被 PHYSICAL REVIEW A 接收发表。

摘要：Quantum coherence is one of the characteristic features of quantum mechanics and underpins many quantum mysteries. To eliminate the influence of the reference basis on the coherence of a quantum state and uncover its intrinsic properties, it is common to study coherence by averaging over different reference bases. Using the metric-adjusted skew information, we explore three natural approaches to average coherence of a state: average over all orthonormal bases, average over all elements of an operator orthonormal base, and average over a complete family of mutually unbiased bases. We establish the equivalence among these three types of average coherence and interpret the unified average coherence as the coherence of a quantum state relative to a depolarizing channel. Additionally, we employ the unified average coherence to introduce a notion of quantum f entropy (where f is an operator monotone function associated with the metric-adjusted skew information) and demonstrate that quantum f entropy possesses properties analogous to the ubiquitous von Neumann entropy. Furthermore, we illuminate some connections between quantum f entropy and quasientropy, and compare f entropy with von Neumann entropy, Renyi entropy, and Tsallis entropy for some typical states.

论文链接：http://dx.doi.org/10.1103/PhysRevA.108.052406

成果八：

张波研究员的论文 Deep unfolding as iterative regularization for imaging inverse problems 被 INVERSE PROBLEMS 接收发表。

摘要：Deep unfolding methods have gained significant popularity in the field of inverse problems as they have driven the design of deep neural networks (DNNs) using iterative algorithms. In contrast to general DNNs, unfolding methods offer improved interpretability and performance. However, their theoretical stability or regularity in solving inverse problems remains subject to certain limitations. To address this, we reevaluate unfolded DNNs and observe that their algorithmically-driven cascading structure exhibits a closer resemblance to iterative regularization. Recognizing this, we propose a modified training approach and configure termination criteria for unfolded DNNs, thereby establishing the unfolding method as an iterative regularization technique. Specifically, our method involves the joint learning of a convex penalty function using an input-convex neural network to quantify distance to a real data manifold. Then, we train a DNN unfolded from the proximal gradient descent algorithm, incorporating this learned penalty. Additionally, we introduce a new termination criterion for the unfolded DNN. Under the assumption that the real data manifold intersects the solutions of the inverse problem with a unique real solution, even when measurements contain perturbations, we provide a theoretical proof of the stable convergence of the unfolded DNN to this solution. Furthermore, we demonstrate with an example of magnetic resonance imaging reconstruction that the proposed method outperforms original unfolding methods and traditional regularization methods in terms

of reconstruction quality, stability, and convergence speed.
论文链接：http://dx.doi.org/10.1088/1361-6420/ad1a3c