INVITED TUTORIALS

GIUSEPPE FALCI
Università di Catania and CNR-IMM MATIS

Dynamics in Cavity Quantum Electrodynamics

PAOLO GIBILISCO
Università di Roma Tor Vergata

An invitation to Quantum Information Geometry

Fisher information is one of the basic tools of statistics, probability and information theory. A quantum satisfying counterpart has been obtained by D. Petz in 1996 using the ideas of Rao and Chentsov who were able to single out Fisher information as the unique Riemannian metric on statistical models contracting under coarse graining. In this talk I'll present the basic results on Quantum Fisher Information: no preceding knowledge of the subject is required. I'll conclude the presentation with an outline of more recent results (based on QFI) on the uncertainty principle and notion of quantum covariance.

CHIARA MACCHIAVELLO
Università di Pavia and INFN Pavia

Multipartite correlations and complementarity

We provide an interpretation of entanglement based on classical correlations between measurement outcomes of complementary properties for composite quantum systems. We start with the bipartite case and discuss in particular what classical correlations in the measurements of these complementary properties tell us about the quantum correlations of the state of the system under consideration. We show that states that have correlations for complementary observables beyond a certain threshold value are entangled.

The reverse is not true, however. We also show that, surprisingly, bipartite separable states with quantum correlations exhibit smaller correlations for complementary observables with respect to classical states.

We use mutual information as a measure of classical correlations, but we conjecture that the first result holds also for other measures (e.g. the Pearson correlation coefficient or the sum of conditional probabilities).

We extend this approach to multipartite systems and introduce new measures of multipartite quantum correlations based on classical correlations of complementary outcomes. We show how these measures, based on the classical mutual information, can be used to detect high-dimensional tripartite entanglement by using only a few local measurements.

PATRIZIA VITALE
Università di Napoli Federico II

Quantum and tomographic metrics from relative entropies

Starting form the relative Tsallis q-entropy as a potential function for the metric, we derive a one-parameter family of quantum metrics for N-level systems and analyze in detail the cases $N = 2,3$. Then we construct explicitly the Fisher-Rao tomographic metric for qubit and qutrit states in different reference frames on the Hilbert space of quantum states. We thus address the problem of reconstructing quantum metrics from tomographic ones, in relation to the uniqueness properties of the latter.

TALKS

MARCO CIANCIARUSO
University of Nottingham UK

Generalized Geometric Quantum Speed Limit

In recent years there has been an intense theoretical and experimental research activity to understand, on one hand, a fundamental concept in quantum mechanics such as time, and to devise, on the other hand, efficient schemes for the implementation of quantum technologies. A basic question that combines and underpins both areas of research is: "How fast can a quantum system evolve in time?" Progress towards answering such a question has led to the establishment of quantum speed limits, intended as lower bounds setting the minimum time that a quantum system takes to undergo a given dynamics between an initial and a target quantum state. Establishing general and tight quantum speed limits is indeed crucial to assess how fast quantum technologies can ultimately be, and can accordingly guide in the design of more efficient protocols operating at or close to the ultimate bounds.
In this work we adopt a unifying and general information geometric framework to construct an infinite family of quantum speed limits valid for any dynamical evolution. We take advantage of the fact that in quantum theory there is not a unique bona fide measure of distinguishability on the state space, but rather an infinite family of so-called contractive Riemannian metrics that are all equally appropriate for this purpose. A different quantum speed limit arises from each of these metrics, in such a way that the tightest bound for a given dynamics is specified by the metric whose geodesic is best tailored to the given dynamical path. By resorting to this intuitive geometric criterion, we derive bounds that are tighter than any previously established one in some relevant instances (e.g., for open system evolutions), and demonstrate the optimality of previously proposed bounds in some other instances (e.g., for closed system evolutions).

FABIO DEELAN CUNDEN
University of Bristol UK

Free fermions and the classical compact groups

We unveil a precise mapping between the ground state of non-interacting free fermions in a box with classical (absorbing, reflecting, and periodic) boundary conditions and the eigenvalue statistics of the classical compact groups. The associated determinantal point processes can be extended in two natural directions: i) we consider the full family of

admissible quantum boundary condition (i.e., self-adjoint extensions) for the Laplacian on a bounded interval, and the corresponding projection correlation kernels; ii) we construct the grand canonical extensions at finite temperature of the projection kernels, interpolating from Poisson to random matrix eigenvalue statistics.
The scaling limits in the bulk and at the edges are studied in a unified framework, and the question of universality is addressed. Whether these finite temperature determinantal processes correspond to the eigenvalue statistics of some matrix models is, a priori, not obvious. We complete the picture by constructing a finite temperature extension of the Haar measure on the classical compact groups. The eigenvalue statistics of the resulting (Poissonized) matrix models correspond exactly to the grand canonical measure of non-interacting free fermions with classical boundary conditions.

MILENA D'ANGELO
Università di Bari

Correlation Plenoptic Imaging

Francesco V. Pepe, Francesco Di Lena, Aldo Mazzilli, Augusto Garucccio, Giuliano Scarcelli, and Milena D'Angelo
Correlation plenoptic imaging pushes imaging to its fundamental limits of both resolution and depth of field, thus enabling dffraction limited imaging with an improved DOF. We present both experimental and theoretical results.

GIUSEPPE FLORIO
Politecnico di Bari

The large dimensional limit of multipartite entanglement

We are interested in the properties of multipartite entanglement of a system composed by n d-level parties (qudits). Focussing our attention on pure states we want to tackle the problem of the maximization of the entanglement for such systems. In particular we effort the problem trying to minimize the purity of the system. It has been shown that not for all systems this function can reach its lower bound, however it can be proved that for all values of n a d can always be found such that the lower bound can be reached. In this paper we examine the high-temperature expansion of the distribution function of the bipartite purity over all balanced bipartition considering its optimization problem as a problem of statistical mechanics. In particular we prove that the series characterizing the expansion converges and we analyze the behavior of each term of the series as d goes to infinite.

GIANCARLO GARNERO
Università di Bari

A quantum particle in a cavity with alternating boundary conditions

We consider the quantum dynamics of a non-relativistic free particle moving in a cavity and we analyze the effect of a rapid switching between two different boundary conditions. We show that this procedure induces, in the limit of infinitely frequent switchings, a new effective dynamics in the cavity related to a novel boundary condition. We explicitly compute the novel boundary condition in terms of the two initial ones. With this procedure we define a dynamical composition law for boundary conditions.

MARCO LAUDATO
TCQP Turku, Finland

Tomographic Reconstruction of Quantum Metrics

In classical Information Geometry one usually uses a potential function to generate a metric tensor and a dual pair of connections on the space of probability distributions [1]. In a previous work [2], we have shown that, by using the quantum Tsallis q-entropy (which includes the Von Neumann one in the limit q --> 1) as a potential function and tomographic methods, it is possible to reconstruct the quantum metrics from the classical one. Specifically, the unique (classical) Fisher-Rao metric defined on the tomographic probabilities associated with a linear tomogram is directly related to one particular (quantum) metric on the space of quantum states in the sense of the Petz classification [3], i.e., to one operator monotone function.
Our claim is that there exists a bijective relation between the choice of the tomographic scheme and the particular operator monotone function identifying a unique quantum metric tensor. As an explicit example, starting from the Von Neumann entropy, we consider a non-linear tomogram provided by a thermal state and we show how such a choice selects a unique operator monotone function. Finally, we show in a general fashion that such a bijective relation exists for any tomographic scheme under the hypothesis of Lipschitzian continuity.
[1] Amari S., Information Geometry and Its Applications, Springer Japan, (2016).
[2] Man'ko V., Marmo G., Ventriglia F., Vitale P., Metric on the Space of Quantum States from Relative Entropy. Tomographic Reconstruction, arXiv:1612.07986v1, (2016).
[3] Petz D., Monotone Metrics of Matrix Spaces, Linear Algebra Appl., 244, 8196, (1996).

GIUSEPPE MAGNIFICO
Università di Bologna

Quantum Simulation of (1+1)D QED

Simulating quantum physics is still today a very challenging problem due to the very large size of the Hilbert spaces that typically grows exponentially with the degrees of freedom. This property imposes significant limitations in calculating the ground states of quantum many-body Hamiltonians and determing the time evolution. In recent years, a new simulation method, called quantum simulation, have become increasingly popular in order to circumvent these difficulties. The basic idea is very simple: to use some fully controllable quantum system, called quantum simulator, to emulate and to analyze the original problem. We will explore these ideas, focusing on the simulation of Schwinger model for (1+1)D quantum electrodynamics. In doing so, we use numerical techniques, such as DMRG, which exploit entanglement properties of strongly correlated systems.

Luigi Malagò
RIST, Romania

An introduction to Information Geometry from the perspective of Riemannian Optimization

In the first part of the talk we review the Information Geometry of statistical manifolds, with a focus on the exponential family. We introduce the notions of Riemannian gradient and exponential map, which are required for the design of first-order optimization methods, such as gradient descent. The second part the presentation is devoted to second-order geometry. Parallel transport allows to move tangent vectors along a curve, in such a way that they remain parallel with respect to the connection; covariant derivative leads to the definition of the Riemannian Hessian, used in second-order optimization methods, such as the Newton method. We conclude the presentation with some examples from the Gaussian distribution.

Stefano Marcantoni
Università di Trieste

Thermodynamics of a bipartite quantum system

The generalization of the laws of thermodynamics for strongly interacting quantum systems is an open issue. Concerning the first law, the definitions of heat and work are still debated because one has to evaluate the contribution of the interaction Hamiltonian. Moreover, the internal entropy production rate of a system is always non-negative if its dynamics is described by a time-dependent Lindblad generator, but usually this is not the case when the environment is finite and strongly interacting.
It is possible to tackle this issue considering a generic bipartite quantum system, initially prepared in a product state, and studying the exchange of energy and entropy between the interacting subsystems [1]. By properly defining heat, work and entropy production at the microscopic level, one can write a generalized version of the first and second law of thermodynamics that highlights the role of correlations and interaction.
Some interesting features of this formulation can be illustrated by a simple example, namely a qubit undergoing dephasing due to the coupling with a bath of harmonic oscillators. This model is important because it is analytically solvable and many physical quantities are computed exactly, without the usual weak-coupling approximation.
[1] S. Alipour, F. Benatti, M. Afsary, F. Bakhshinezhad, S. Marcantoni, and A. T. Rezakhani, Sci. Rep. 6, 35568, (2016).

Dimitri Marinelli
RIST, Romania

Information Geometry and Deep Learning: A Physicist's Perspective

I will review basic approaches of information geometry to the study of deep learning with a particular focus on the landscape and the optimization issues.
Can non-Euclidean geometry be the tool to understand the learning process as it was for Physics a century ago?

FABIO MARIA MELE
Università di Napoli Federico II

Quantum Metric and Entanglement on Spin Networks

Motivated by the idea that, in the background-independent framework of a Quantum Theory of Gravity, entanglement is expected to play a key role in the reconstruction of spacetime geometry [1], we investigate the possibility of using the formalism of Geometric Quantum Mechanics (GQM) [2] to give a tensorial characterization of entanglement on spin network states.
Our analysis focuses on the simple case of a single link graph (Wilson line state) for which we define a dictionary to construct a Riemannian metric tensor and a symplectic structure on the space of states. The manifold of (pure) quantum states is then stratified in terms of orbits of equally entangled states and the block-coefficient matrices of the corresponding pulled-back tensors fully encode the information about separability and entanglement [2,3]. In particular, the off-diagonal blocks define an entanglement monotone interpreted as a distance with respect to the separable state. As such, it provides a measure of graph connectivity.
Moreover, in the maximally entangled case, the entanglement monotone is proportional to a power of the area of the surface dual to the link. This suggests a connection between the GQM formalism and the (simplicial) geometric properties of spin network states through entanglement.
[1] E. R. Livine and D. R. Terno. Reconstructing quantum geometry from quantum information: Area renormalisation, coarse-graining and entanglement on spin networks. (2006), gr- qc/0603008.
[2] P. Aniello, J. Clemente-Gallardo, G. Marmo, G. F. Volkert, Classical Tensors and Quantum Entanglement I: Pure States, Int. J. Geom. Meth. Mod. Phys., 7:485, (2010).
[3] P. Aniello, J. Clemente-Gallardo, G. Marmo, and G. F. Volkert. From Geometric Quantum Mechanics to Quantum Information. (2011), 1101.0625.

DAVIDE PASTORELLO
Università di Trento

A geometric viewpoint on quantum control

In this talk I propose a new geometric approach to study the controllability of quantum systems in terms of symplectic and Riemannian structures on projective Hilbert spaces, exploiting some tools of classical control theory. In particular the notion of accessibility algebra for classical non-linear systems in affine form can be adapted to study quantum controllability within geometric Hamiltonian formulation of quantum mechanics. Moreover operator controllability of a quantum system will be completely characterized in terms of Killing vector fields on the complex projective space w.r.t. Fubini-Study metric.

FRANCESCO PEPE
Centro Fermi Roma and INFN Bari

Bound states and entanglement generation in waveguide quantum electrodynamics

We investigate the behavior of a pair of two-level (artificial) atoms embedded in a linear waveguide, in a quasi-one-dimensional configuration. While an isolated atom would unavoidably decay to its ground state, in our configuation we find that, under proper conditions, the system can spontaneously relax towards an entangled bound state, with the two atoms sharing one excitation. Exploting the resolvent formalism, we analyze the properties of such bound states, which occur for resonant values of the interatomic distance, and discuss their relevance with respect to entanglement generation. The stability of such states close to the resonance is studied, as well as the properties of non-resonant bound states, whose energy is below the threshold for photon propagation.
Authors: P. Facchi, M. S. Kim, S. Pascazio, F. V. Pepe, D. Pomarico, T. Tufarelli

ANGELO RUSSOMANNO
SNS Pisa and ICTP Trieste

Multipartite entanglement after a quantum quench

(Silvia Pappalardi, Angelo Russomanno, Alessandro Silva, Rosario Fazio)
In this talk I will present a recent work of ours in which we study the multipartite entanglement of a quantum many-body system undergoing a quantum quench. We quantify multipartite entanglement through the quantum Fisher information (QFI) density and we are able to express it after a quench in terms of a generalized response function. For pure state initial conditions and in the thermodynamic limit, we can express the QFI as the fluctuations of an observable computed in the so-called diagonal ensemble. We apply the formalism to the dynamics of a quantum Ising chain after a quench in the transverse field. In this model the asymptotic state is, in almost all cases, more than two-partite entangled. Moreover, starting from the ferromagnetic phase, we find a divergence of multipartite entanglement for small quenches closely connected to a corresponding divergence of the correlation length.

LUIGI SEVESO
Università di Milano

Quantum metrology beyond the quantum Cramér-Rao theorem

In quantum parameter estimation theory, it is usually assumed that the parameter labels the family of statistical models among which one has to differentiate, however it does not influence the measurement scheme aimed at extracting information on the parameter itself. In this talk, we argue that on the contrary there are sensible measurement schemes which carry intrinsic information on the value of the parameter. In such cases, it may happen that the Fisher information is not bounded by the quantum Fisher information, i.e. a violation of the quantum Cramer-Rao theorem. We discuss examples where this does happen, and attempt to provide an alternative approach to find the genuine bound to precision of quantum measurements in such a generalized setting.
[1] "Quantum metrology beyond the quantum Cramér-Rao theorem", L. Seveso, M. A. C. Rossi, M. G. A. Paris, Phys. Rev. A 95, 012111