BOOK OF ABSTRACTS

19th Central European Quantum Information Processing Workshop

June 3rd–June 6th 2024, Skalica, Slovakia
http://ceqip.eu/2024/

CEQIP 2024

CEQIP 2024 (Central European Quantum Information Procesing workshop) is traditionally focused on current challenges and paradigms of mathematical and computational aspects of emerging quantum technologies. One of the strengths is the traditionally strong social program creating very friendly and creative atmosphere. Besides traditional wine tasting and a cipher game we plan to visit surrounding natural beauties.

Venue

CEQIP 2024 will be held in the Culture House of "free kings town" Skalica situated approximatively 60 km north of Bratislava on the borders with Czechia. The town has a long history dating thousands years in the past, part of it you will discover when coming there.

Invited speakers

- ⋆ Giulio Chiribella (Hong Kong)
- ⋆ Sergey Filippov (Helsinki)
- ⋆ Teiko Heinosaari (Jyväskylä)
- ⋆ Mark Hillery (New York)
- ⋆ Michał Oszmaniec (Warsaw)
- ⋆ Marcin Pawłowski (Gdánsk)

Selection Comittee

- ⋆ Leevi Leppäjärvi (chair)
- ⋆ Djeylan Aktas
- ⋆ Giulio Chiribella
- ⋆ Teiko Heinosaari
- ⋆ Mark Hillery
- ⋆ Michał Oszmaniec
- ⋆ Marcin Pawłowski
- ⋆ Martin Plávala
- ⋆ Daniel Reitzner
- ⋆ Michal Sedlák
- ⋆ Mário Ziman

Organizing Team

- ⋆ Jan Bouda
- ⋆ Radka Hovorková
- ⋆ Leevi Leppäjärvi
- ⋆ Daniel Reitzner
- ⋆ Michal Sedlák
- ⋆ Mário Ziman

The workshop is organized by Research Center for Quantum Information, Institute of Physics, Slovak Academy of Sciences (Bratislava) and Quantum Laboratory, Faculty of Informatics, Masaryk University (Brno).

Program

Monday, 3. 6. 2024

16:00	Registration (with refreshment)
17:00	Evening session
17:00	**Giulio Chiribella** (I)
17:40	**Mark Hillery** (I)
18:20	**Stefan Baeuml** (C)
18:45	End of session
19:00	Welcome dinner (Masaryk winery)

Tuesday, 4. 6. 2024

08:00	Breakfast
09:00	Morning session
09:00	**Teiko Heinosaari** (I)
09:40	**Miguel Navascués** (C)
10:05	**Martin Plávala** (C)
10:30	**Paweł Cieśliński** (C)
10:55	Coffee & Refreshment
11:30	**Michał Oszmaniec** (I)
12:10	**Lin Htoo Zaw** (C)
12:35	**Zoltán Kolarovszki** (C)
13:00	End of session
13:00	Lunch
14:00	Afternoon session
14:00	**Sergei Filippov** (I)
14:40	**Mateus Araújo** (C)
15:05	**Fionnuala Curran** (C)
15:30	**Santiago Llorens** (C)
15:55	End of session
15:55	Coffee & Refreshment
16:00	Poster session
18:30	Cipher game registration
18:30	Dinner (venue)
19:00	Cipher game

Wednesday, 5. 6. 2024

08:00	Breakfast
09:00	Morning session
09:00	**Marcin Pawłowski** (I)
09:40	**Ivor Kresic** (C)
10:05	**Libor Caha** (C)
10:30	Group photo
10:35	Coffee & Refreshment
11:00	**Gerard Anglès Munné** (C)
11:25	**Sang-Jun Park** (C)
11:50	End of session
12:00	Lunch
13:30	Conference boat trip (Skalica - Strážnice - Petrov)
19:00	Conference dinner (Plže, Petrov)

Thursday, 6. 6. 2024

08:00	Breakfast
09:15	Morning session
09:15	**Pierre Botteron** (C)
09:40	**Oskari Kerppo** (C)
10:05	**Giuseppe Viola** (C)
10:30	End of session
10:30	Take Away Refreshment
11:00	Conference bus

(I) Invited talk (35 + 5 min.)
(C) Contributed talk (20 + 5 min.)

Invited talks

1. **Giulio Chiribella:** THE BOUNDARIES OF QUANTUM CAUSALITY

   Quantum theory is in principle compatible with processes that violate causal inequalities, an analogue of Bell inequalities that constrain the correlations observed by a set of parties operating in a definite causal order. Since the introduction of causal inequalities, determining their maximum quantum violation, analogue to Tsirelson's bound for Bell inequalities, has remained an open problem. In this talk I will present a general method for bounding the violation of arbitrary causal inequalities, establishing limits on the correlations achievable by arbitrary local experiments and by arbitrary quantum processes with indefinite causal order. Using this approach, it is possible to show that the maximum violation is generally smaller than the algebraic maximum, and to determine Tsirelson-like bounds for a class of causal inequalities including some of the most paradigmatic examples. Finally, I will discuss a new type of processes that allow for information to flow in an indefinite temporal direction within the parties' laboratories, showing that they allow for the violation of arbitrary causal inequalities to the maximum algebraic value.

2. **Sergey Filippov:** SCALABILITY OF QUANTUM ERROR MITIGATION TECHNIQUES: FROM UTILITY TO ADVANTAGE

   Error mitigation has elevated quantum computing to the scale of hundreds of qubits and tens of layers; however, yet larger scales (deeper circuits) are needed to fully exploit the potential of quantum computing to solve practical problems otherwise intractable. Here we demonstrate three key results that pave the way for the leap from quantum utility to quantum advantage: (1) we present a thorough derivation of random and systematic errors associated to the most advanced error mitigation strategies, including probabilistic error cancellation (PEC), zero noise extrapolation (ZNE) with probabilistic error amplification, and tensor-network error mitigation (TEM); (2) we prove that TEM (i) has the lowest sampling overhead among all three techniques under realistic noise, (ii) is optimal, in the sense that it saturates the universal lower cost bound for error mitigation, and (iii) is therefore the most promising approach to quantum advantage; (3) we propose a concrete notion of practical quantum advantage in terms of the universality of algorithms, stemming from the commercial need for a problem-independent quantum simulation device. We also establish a connection between error mitigation, relying on additional measurements, and error correction, relying on additional qubits, by demonstrating that TEM with a sufficient bond dimension works similarly to an error correcting code of distance 3. We foresee that the interplay and trade-off between the two resources will be the key to a smooth transition between error mitigation and error correction, and hence between near-term and fault-tolerant quantum computers. Meanwhile, we argue that quantum computing with optimal error mitigation, relying on modest classical computer power for tensor network contraction, has the potential to reach larger scales in accurate simulation than classical methods alone.

3. **Teiko Heinosaari:** POSTPONING THE CHOICE: OPTIMIZING QUANTUM MEASUREMENT STRATEGIES FOR FUTURE INFORMATION GAIN

   The fundamental process of extracting quantum information necessitates the implementation of measurements. In the quantum physical setting, there are infinitely many different measurements and, due to quantum incompatibility, one has to choose only one that is implemented. The choice depends on what kind of information one wants to retrieve. The nontrivial task of selecting an appropriate measurement strategy raises intriguing questions. Firstly, how does the consideration of immediate and future needs influence the selection of measurements? Secondly, if one postpones the choice, does that necessarily imply some drawback? Thirdly, in scenarios where post-measurement information is anticipated, what methods can be devised to optimize the extraction of relevant information? In this talk, I will discuss these questions using concrete examples.

4. **Mark Hillery:** BROADCASTING QUANTUM STATES

   Suppose Alice wants to send a known equatorial quantum state to Bob and Charlie. This could be accomplished by means of teleportation or by remote state preparation, in each case using two singlet states. A procedure that uses less entanglement and classical communication will be presented. It makes use of an entangled state consisting of a qutrit, held by Alice, and two qubits, one held by Bob and the other by Charlie. Alice performs a unitary operation on her qutrit, measures it, and sends the result of her measurement to Bob and Charlie. After they perform any necessary correction operations, the result is that they both possess the qubit state that Alice wished to send. This can be generalized to N receivers, and the entanglement cost is then $\log N$ ebits. It is possible to generalize this procedure to multiple senders. In addition, it is possible for Alice to send a state unknown to her, if the information about the unknown state is contained in a quantum state that is sent to Alice. Two applications of this procedure, one to voting and one to secure transmission will be discussed.

5. **Michał Oszmaniec:** ANCILLA-FREE IMPLEMENTATION OF QUANTUM MEASUREMENTS

   In quantum theory general measurements are described by so-called Positive Operator-Valued Measures (POVMs). In this work we show that in d-dimensional quantum systems an application of depolarizing noise with constant (independent of d) visibility parameter makes any POVM simulable by a randomized implementation of projective measurements that do not require any auxiliary systems to be realized. This result significantly limits the asymptotic advantage that POVMs can offer over projective measurements in various information-processing tasks, including state discrimination, shadow tomography or quantum metrology. We also apply our findings to questions originating from quantum foundations. First, we asymptotically improve the range of parameters for which Werner and isotropic states have local models for generalized measurements (by factors of d and $\log d$ respectively). Second, we give asymptotically tight (in terms of dimension) bounds on critical visibility for which all POVMs are jointly measurable. On the technical side we use recent advances in POVM simulation, the solution to the celebrated Kadison-Singer problem, and a new method of approximate implementation of a class of "nearly projective" POVMs by a convex combination of projective measurements, which we call dimension-deficient Naimark extension theorem.

6. **Marcin Pawłowski:** EXPONENTIALLY DECREASING CRITICAL DETECTION EFFICIENCY FOR ANY BELL INEQUALITY

   Every Bell inequality has a critical detection efficiency η that must be surpassed to avoid the detection loophole. Here, we propose a general method for reducing the critical detection efficiency of any Bell inequality to arbitrary low values. This is accomplished by entangling two particles in N orthogonal subspaces (e.g., N degrees of freedom) and conducting N Bell tests in parallel. This has been tried before with limited success and reasons for this are discussed. We propose a new method based on the introduction of penalized N-product (PNP) Bell inequalities, for which the so-called simultaneous measurement loophole is closed, and the maximum value for local hidden-variable theories is simply the Nth power of the one of the Bell inequality initially considered. We show that, for the PNP Bell inequalities, the critical detection efficiency decays exponentially with N. The strength of our method is illustrated with a detailed study of the PNP Bell inequalities resulting from the Clauser-Horne-Shimony-Holt inequality.

Contributed talks

1. **Gerard Anglès Munné:** SDP BOUNDS FOR QUANTUM CODES

   The fundamental problem in coding theory is to determine the maximum size of an error-correcting code of given distance and block length. Here we approach this question by providing a semi-definite programming hierarchy to determine the existence of quantum codes with given parameters. The hierarchy is complete in the sense that every set of parameters for which no code exists is detected at some level of the hierarchy. We highlight connections to the quantum zero-error communication capacity of quantum graphs.

2. **Mateus Araújo:** QUANTUM KEY DISTRIBUTION RATES FROM NON-SYMMETRIC CONIC OPTIMIZATION

   Computing key rates in QKD numerically is essential to unlock more powerful protocols that use more sophisticated measurement bases or quantum systems of higher dimension. It is a difficult optimization problem that depends on minimizing a convex nonlinear function, the relative entropy. Recently a primal-dual interior-point algorithm was discovered for non-symmetric cones, a category that includes the relative entropy, and was previously out of reach. Here we adapt this algorithm to the problem of computation of key rates, obtaining a very efficient technique for lower bounding them. In comparison to previous techniques it has the advantages of flexibility, ease of use, and above all performance.

3. **Stefan Baeuml:** SECURITY OF CONTINUOUS VARIABLE QKD WITH DISCRETE MODULATION

   Continuous variable quantum key distribution with discrete modulation has the potential to provide quantum physical security using widely available optical elements and existing telecom infrastructure, while allowing for the use of well studied error correction protocols. However, proving finite-size security against coherent attacks poses a challenge. In this work we apply the entropy accumulation theorem, a tool that has previously been used in the setting of discrete variables, to prove finite-size security against coherent attacks for a discrete-modulated QKD protocol involving four coherent states and heterodyne detection, under a realistic photon number cutoff assumption. Our analysis provides non-trivial key rates for $n = 10^{12}$ rounds.

4. **Pierre Botteron:** ALGEBRA OF NONLOCAL BOXES AND THE COLLAPSE OF COMMUNICATION COMPLEXITY

   This work aims to study the distillation of post-quantum correlations and its consequences on communication complexity. We carry out an algebraic study of the structure of wirings connecting nonlocal boxes, thus defining the notion of the "product of boxes", and we show related associativity and commutativity results. This gives rise to the notion of the "orbit of a box", unveiling surprising geometrical properties about the alignment and parallelism of distilled boxes. The power of this new framework is that it allows to prove previously-reported numerical observations concerning the best way to wire consecutive boxes, and to numerically and analytically recover recently-identified noisy PR boxes that collapse communication complexity for different types of noise models.

5. **Libor Caha:** A COLOSSAL ADVANTAGE: 3D-LOCAL NOISY SHALLOW QUANTUM CIRCUITS DEFEAT UNBOUNDED FAN-IN CLASSICAL CIRCUITS

   We present a computational problem with the following properties: (i) It can be solved with near certainty by a noisy constant-depth 3D quantum circuit. (ii) It is average-case-hard for constant-depth Boolean circuits with unbounded fan-in AND gates, i.e., AC^0-circuits, of size smaller than a certain subexponential. Such an advantage against unbounded fan-in classical circuits was previously only known in the noise-free case or without locality constraints. By overcoming these limitations, we propose the strongest unconditional, fault-tolerant quantum advantage to date. Such subexponential lower bounds have traditionally been referred to as exponential. We use the term colossal since our fault-tolerant 3D architecture resembles a certain Roman monument.

6. **Paweł Cieśliński:** ON THE POLYGAMOUS NATURE OF QUANTUM NONLOCALITY

   Quantum mechanics imposes limits on the statistics of certain observables. Here, we focus on the trade-offs for the simultaneous violation of multiple Bell inequalities. In the simplest case of three observers, it has been shown that violating one Bell inequality precludes the violation of any other, a property called monogamy of Bell violations. We show that the Bell monogamy does not hold universally and the only monogamous situation is that of the three observers. We present a systematic methodology for identifying quantum states and tight Bell inequalities that do not obey the monogamy principle for more than three observers. The identified polygamous inequalities are experimentally violated by the measurement of Bell-type correlations using six-photon Dicke states.

7. **Fionnuala Curran:** MAXIMAL INTRINSIC RANDOMNESS OF A QUANTUM STATE

   One of the most counterintuitive aspects of quantum theory is its claim that there is 'intrinsic' randomness in the physical world. Arising from the phenomenon of superposition, this intrinsic, or private, randomness has no classical counterpart. Mixed quantum states also possess an apparent, classical form of randomness, however, as the 'actual' state of the system in each round of measurement may be unknown to an experimentalist, but known to a nefarious eavesdropper. We ask, then, how much intrinsic randomness can be extracted from a quantum state? We answer this question using three common quantifiers of randomness, the conditional min-, von Neumann and max-entropies, finding necessary and sufficient conditions for the projective measurements that achieve the bound in each case.

8. **Oskari Kerppo:** MAXIMAL ELEMENTS OF QUANTUM COMMUNICATION

   A prepare-and-measure scenario is naturally described by a communication matrix which collects all conditional outcome probabilities of the scenario into a row-stochastic matrix. The set of all possible communication matrices is partially ordered via the ultraweak matrix majorization relation. By considering maximal elements in this preorder for a subset of matrices implementable in a given theory, it becomes possible to identify communication matrices of maximum utility. The identity matrix of an appropriate size is the greatest element in classical theories, while the maximal elements in quantum theory have remained unknown. We completely characterize the maximal elements and show that incompatible communication matrices exist in quantum theory.

9. **Zoltán Kolarovszki:** PIQUASSO: A PHOTONIC QUANTUM COMPUTER SIMULATION SOFTWARE PLATFORM

   We introduce the Piquasso quantum programming framework, a full-stack open-source software platform for the simulation and programming of photonic quantum computers. Piquasso can be programmed via a high-level Python programming interface enabling users to perform efficient quantum computing with discrete and continuous variables. Via optional high-performance C++ backends, Piquasso provides state-of-the-art performance in the simulation of photonic quantum computers. The Piquasso framework is supported by an intuitive web-based graphical user interface where the users can design quantum circuits, run computations, and visualize the results.

10. **Ivor Kresic:** GENERATING INTERATOMIC ENTANGLEMENT VIA PHOTON-MEDIATED SELF-ORGANIZATION IN A CONDENSATE

    We devise a novel methodology by which the runaway process at the onset of cavity self-organization in a condensate can be used to efficiently and scalably generate quantum correlated pairs (Dicke-squeezing) in continuously translationally symmetric Hamiltonians. We numerically study this effect in two example systems, using self-organization via (a) diffraction-mediated coupling and (b) ring cavity superradiance, to achieve entanglement in the atomic momentum. We theoretically devise and numerically demonstrate a protocol by which such self-organized states can be utilized in quantum enhanced SU(1,1) matter wave interferometry for precise determination of photon recoil frequency.

11. **Santiago Llorens:** QUANTUM MULTI-ANOMALY DETECTION

    A source assumed to prepare a specified reference state sometimes prepares an anomalous one. We address the task of identifying the anomalies in a series of n states with k anomalies. We analyze minimum error and zero-error protocols and compute the success probability when both reference and anomalous states are known to the observer. We use results from association schemes theory, in particular, the Johnson association scheme. We also study the regime of large n and show that the success probability is non-vanishing. Finally, we address the case in which the observer is blind to both reference and anomalous states, presenting a universal protocol for which we prove that in the asymptotic limit, the success probability corresponds to the average of the known state scenario.

12. **Miguel Navascues:** FIRST-ORDER OPTIMALITY CONDITIONS FOR NON-COMMUTATIVE OPTIMIZATION PROBLEMS

    We consider the problem of optimizing the state average of a polynomial of non-commuting variables, over all operator representations satisfying a list of polynomial constraints. Such non-commutative polynomial optimization (NPO) problems are routinely solved through hierarchies of semidefinite programming (SDP) relaxations. We heuristically derive, via a Lagrangian formulation of the problem, first-order optimality conditions, which can be enforced by adding new positive semidefinite constraints to the already existing SDP hierarchies. We provide sufficient conditions for these optimality conditions to hold and use the new constraints to compute local properties of ground states of many-body spin systems and the maximum quantum violation of Bell inequalities.

13. **Sang-Jun Park:** RANDOM COVARIANT QUANTUM CHANNELS

    In this work, we introduce natural probability distributions for covariant quantum channels. Specifically, this is achieved through the application of "twirling operations" on random quantum channels without symmetry, derived from the Stinespring representation. We explore various types of group symmetries, including hyperoctahedral covariance and diagonal orthogonal covariance (DOC), and analyze their properties related to quantum entanglement. In particular, we discuss the threshold phenomenon for PPT and entanglement breaking properties, comparing thresholds among different classes of random covariant channels. Finally, we contribute to the PPT-squared conjecture by showing that the composition between two random DOC channels is generically entanglement breaking.

14. **Martin Plávala:** ALL INCOMPATIBLE MEASUREMENTS ON QUBITS LEAD TO MULTIPARTICLE BELL NONLOCALITY

    Bell nonlocality is a fundamental phenomenon of quantum physics as well as an essential resource for various tasks in quantum information processing. It is known that measurement incompatibility is necessary for the observation of nonlocality, but the question of which incompatible measurements are useful, remained open. Here we prove that any set of incompatible measurements on qubits leads to a violation of some Bell inequality. Since there exists incompatible measurements on qubits which do not lead to Bell nonlocality for two particles, our results demonstrate a fundamental difference between two-particle and multi-particle nonlocality, pointing at the superactivation of measurement incompatibility as a resource.

15. **Giuseppe Viola:** QUANTUM STRATEGIES FOR RENDEZVOUS AND DOMINATION TASKS ON GRAPHS WITH MOBILE AGENTS

    This work explores the application of quantum non-locality, a renowned and unique phenomenon acknowledged as a valuable resource. Focusing on a novel application, we demonstrate its quantum advantage for mobile agents engaged in specific distributed tasks without communication. The research addresses the significant challenge of rendezvous on graphs and introduces a new distributed task for mobile agents grounded in the graph domination problem. Through an investigation across various graph scenarios, we showcase the quantum advantage. Additionally, we scrutinize deterministic strategies, highlighting their comparatively lower efficiency compared to quantum strategies. The paper concludes with a numerical analysis, providing further insights into our findings.

16. **Lin Htoo Zaw:** CERTIFYING NON-GAUSSIAN ENTANGLEMENT WITH CONDITIONAL DISPLACEMENT GATES

    In weakly-dispersive cQED devices, conditional displacement (CD) gates are used to probe the characteristic function of cavity states, while Wigner function measurements are difficult and quadrature measurements are unavailable. As such, past demonstrations of entanglement in such architectures have resorted to state tomography. I recently proposed a non-Gaussian entanglement witness that uses only CD gates and qubit readouts. The witness arises from Bochner's theorem and a surprising connection between two negativities: that of the reduced Wigner function, and that of the partial transpose. It requires as few as four points of the characteristic function, and simultaneously lower bounds the Wigner negativity volume and a measure conjectured to be the partial transpose negativity.

Posters

1. **Ieline Ahmed::** SIMULATION OF QUANTUM KEY DISTRIBUTION

   As the classical methods of encryption are threatened by the development of quantum computers with a higher number of qubits, people have started looking for alternative methods of encryption involving quantum mechanics. In this project, we have studied the first quantum key distribution protocol, BB84, followed by the application of the classical error correction code, Hamming. We have carried out simulations in Python and checked if these results are in conformity with the analytical results given by Shor and Preskill in 2000.

2. **Ardra Ajitha Vijayan:** STUDY OF GENUINE ACTIVATION OF NON LOCALITY

   The structure of quantum theory assures the discrimination of any possible orthogonal set of states. However, the scenario becomes highly nontrivial in the limited measurement setting and leads to different classes of impossibilities, viz., indistinguishability, unmarkability, irreducibility, etc. These phenomena, often referred to as other nonlocal aspects of quantum theory, have the utmost importance in the domain of data hiding, secret sharing, etc. It, therefore, becomes a pertinent question to distill/activate such behaviors from a set, apparently devoid of these nonlocal features and free from local redundancy. Here, we explore all such stronger versions of nonlocality and affirmatively answer to activate each of them.

3. **Djeylan Aktas, Younes Benamara, Gilberto Borges, Peter Rapčan, Saeid Salari:** THE SKQCI NATIONAL QKD INFRASTRUCTURE, A QUANTUM COMMUNICATION TESTBED

   Quantum Key Distribution(QKD) promises an unconditional security based on the laws ofquantum physics that eavesdroppers cannot retrieve key information without introducing detectable errors. This allows for two remote parties to share sequences of private random bits which are primitives to implement secure communication protocols that do not rely on the assumption of a bounded computing power for the attacker. As of late, recent works have demonstrated that entanglement-based QKD serves as one of the most suitable candidate for creating fully connected topologies, which greatly reduces the overhead cost of adding a new user. In this work, we plan for the deployement of the backbone infrastructure of the national Slovak quantum network. We report the design of a broadband of entangled pair generator using the spontaneous parametric down conversion process in a Sagnac interferometer configuration that displays polarisation entanglement with a near perfect visibility of $\sim$99%.

4. **Jan Lennart Bönsel:** PROPOSED METHOD TO PRODUCE LARGE MULTIPARTITE NONLOCALITY AND TO BENCHMARK QUANTUM COMPUTERS

   We address the problem of producing n-partite Bell nonlocality with a large number of qubits n. The main limiting factors are: (i) The interaction topology might not allow arbitrary two-qubit gates. (ii) Noise limits the violation, and (iii) the number of measurements grows exponentially with n. We point out that graph states that are compatible with the two-qubit connectivity can be efficiently prepared, overcoming (i). For graph states, there exist Bell inequalities whose resistance to white noise increases exponentially with n. This limits the impact of (ii). We introduce a method to address (iii). As a result, we show how to produce n-partite Bell nonlocality with large n. This allows benchmarking nonclassical correlations, and we simulate our method for an IBM quantum computer.

5. **Gábor Drótos:** CERTIFYING A COMPLEX QUBIT HILBERT SPACE IN A PREPARE-AND-MEASURE SCENARIO: HOW SELF-TESTING HELPS

   We construct linear witnesses for performing self-tests in possibly minimal setups within a prepare-and-measure scenario for qubit messages. In a setup involving four (three) preparations and three (two) projective measurements in addition to the target, we exemplify how to self-test any four- (three-) outcome extremal positive operator-valued measure. We also achieve self-testing of any number of pure state preparations with the help of three projective measurements at most. Beyond self-testing, we use the same witness to certify that a set of four preparations spans a complex qubit Hilbert space by violating the maximum witness value attainable by real qubit preparations. We implement such a certification exercise on two publicly available quantum processors.

6. **Jorge Escandón-Monardes:** TRANSCRIBING QUANTUM CHANNELS INTO QUANTUM STATES

   We introduce a circuit that takes an arbitrary quantum channel on a d-dimensional system and outputs its process matrix, a.k.a. χ-matrix. Our circuit consists of one target qudit and two control qudits. Interestingly, at the end of the circuit the χ-matrix gets encoded in the control register, while the target qudit recovers its arbitrary initial state, regardless of the quantum channel applied on it. We briefly discuss some features of the circuit and its eventual application in quantum process tomography and other computational tasks.

7. **Seyed Arash Ghoreishi:** GEOMETRIC BLOCH VECTOR SOLUTION TO MINIMUM-ERROR DISCRIMINATIONS OF MIXED QUBIT STATES

   We investigate minimum-error discrimination for mixed qubit states using a geometric approach. By analyzing positive operator-valued measure solutions and introducing Lagrange operator Γ, we develop a four-step structured instruction to find Γ for N mixed qubit states. Our method covers optimal solutions for two, three, and four mixed qubit states, including a novel result for four qubit states. We introduce geometric-based POVM classes and non-decomposable subsets for constructing optimal solutions, enabling us to find all possible answers for the general problem of minimum-error discrimination for N mixed qubit states with arbitrary a priori probabilities.

8. **Aabhas Gulati:** SEPARABILITY OF CYCLIC PHASE PERMUTATION INVARIANT STATES

   In this paper, we study a class of states that are invariant under local signed cyclic permutations, which we call local CYCLIC phase permutation invariant states (or LCPPI). These classes of states show the phenomenon of PPT entanglement, and are also amenable to more geometric analysis. We prove that the states in this linear subspace can be parameterised with a tuple of 3 vectors, (a, b, c) such that $a_1 = b_1 = c_1$, thus have a linear scaling of parameters with the dimension d. We are able to completely characterize the separable states and PPT states in small dims. In case of LCPPI states, we provide various entanglement criterion based on zero patterns of a, making connections with finding maximal cliques in graphs. This allows us to construct various new examples of PPT entangled states.

9. **Marwan Haddara:** PARTIALLY DETERMINISTIC POLYTOPES: PROPERTIES AND APPLICATIONS

   Recent works in quantum foundations have uncovered new device-independent correlation sets of interest. In this work we define these objects, termed partially deterministic polytopes, in full generality and explore their basic geometrical features with respect to the relevant parameters. The well known no-signaling and Bell-local sets can be recovered as special cases, while in other cases, the correlation sets lie strictly between them. We introduce a family of novel experimental protocols which add to the known Wigner's friend-type scenarios as examples of situations where seemingly reasonable physical assumptions lead to constraints that are equivalent to the existence of a partially deterministic model. We also discuss other situations where classes of partial deterministic polytopes arise, essentially uncovering a unifying mathematical outlook on seemingly different forms of nonclassicality.

10. **Noah Pascal Köstner:** PROJECTIONS WITH FINITE PRODUCT EXPANSION IN C*-TENSORPRODUCTS

    We'd like to better understand the constant c that was introduced into the hierarchy described in [Ligthart, Gachechiladze and Gross, Commun. Math. Phys., 401 (3) 2023]. So we consider the following setting: Let A, B be two C*-subalgebras of a some C*-algebra C. Assume that A, B are commuting and generate C as a C*-algebra. Now consider a projection $P \in C$ with the special property that it has a "finite product expansion" in the sense that $P = \sum_{i=1}^{r} a_i b_i$, $a_i \in A$, $b_i \in B$ for some natural number r. I will discuss this and a related question (where $r = \infty$) on my poster.

11. **Robin Krebs:** HIGH SCHMIDT NUMBER CONCENTRATION IN QUANTUM BOUND ENTANGLED STATES

    A deep understanding of quantum entanglement is vital for advancing quantum technologies. The strength of entanglement can be quantified by counting the entangled degrees of freedom, a quantity called Schmidt number (SN). A particular challenge is to identify the SN in undistillable quantum states which remain positive under partial transpose (PPT). Finding PPT states with high SN has become a mathematical challenge, for which we introduce efficient analytical tools for the class of generalized grid states. Our methods improve the best known bounds for PPT states with high SN. Most notably, we construct a SN three PPT state in five dimensional systems and states with a SN of $(d+1)/2$ for odd d-dimensional systems, representing the best-known scaling of the SN in a local dimension.

12. **Leevi Leppäjärvi:** ON THE SIMULATION OF QUANTUM MULTIMETERS

    In the quest for robust and universal quantum devices, the notion of simulation plays a crucial role, both from a theoretical and from an applied perspective. In this work, we go beyond the simulation of quantum channels and quantum measurements, studying what it means to simulate a collection of measurements, which we call a multimeter. To this end, we first explicitly characterize the completely positive transformations between multimeters. However, not all of these transformations correspond to valid simulations, as evidenced by the existence of maps that always prepare the same multimeter regardless of the input, which we call trash-and-prepare. We give a new definition of multimeter simulations as transformations that are triviality-preserving, i.e., when given a multimeter consisting of trivial measurements they can only produce another trivial multimeter. In the absence of a quantum ancilla, we then characterize the transformations that are triviality-preserving and the transformations that are trash-and-prepare. Finally, we use these characterizations to compare our new definition of multimeter simulation to three existing ones: classical simulations, compression of multimeters, and compatibility-preserving simulations.

13. **M. Hamed Mohammady:** THERMODYNAMIC CONSTRAINTS ON THE QUANTUM MEASUREMENT PROCESS

    While quantum theory dictates that the act of measurement must perturb at least some property of the measured system, it does allow for measurements that are minimally invasive: so called ideal measurements. But as shown recently, ideal measurements of projection valued measures are incompatible with the laws of thermodynamics. We show that for the more general class of "unsharp" positive operator valued measures, then the laws of thermodynamics may be made compatible with an approximate or unsharp version of ideal measurements.

14. **Jan Nöller:** DEVICE-INDEPENDENT CERTIFICATION OF QUANTUM GATES UNDER THE DIMENSION ASSUMPTION

    Certification of quantum computing components can be crucial for quantum hardware improvements and the calibration of quantum algorithms. In this work, we propose an efficient method for certifying single-qubit quantum computation in a black-box scenario under the dimension assumption. The method is based on testing deterministic input-output correlations for predetermined gate sequences. We show that a single-qubit universal gate set can be certified, and analyze in detail certification of the S gate, for which the sample complexity grows inversely linear with respect to the average gate infidelity. Our approach takes a first step in bridging the gap between strong notions of certification from self-testing and practically highly relevant approaches from quantum system characterization.

15. **Ties-Albrecht Ohst:** Revealing hidden physical nonclassicality with nonnegative polynomials

    Understanding quantum phenomena which go beyond classical concepts is a focus of modern quantum physics. Here, we show how the theory of nonnegative polynomials emerging around Hilbert's 17th problem, can be used to optimally exploit data capturing the nonclassical nature of light. Specifically, we show that nonnegative polynomials can reveal nonclassicality in data even when it is hidden from standard detection methods up to now. Moreover, the abstract language of nonnegative polynomials also leads to a unified mathematical approach to nonclassicality for light and spin systems, allowing us to map methods for one to the other. Conversely, the physical problems arising also inspire several mathematical insights into characterisation of nonnegative polynomials.

16. **Lucas Porto:** A toolkit for analysing Bell nonlocality and EPR-Steering for two-qubit states

    Entanglement, EPR-steering and Bell nonlocality are different forms of nonlocal correlations which may be manifested by quantum states. While entanglement of two-qubit states is easily characterized by partial transposition, deciding whether a given two-qubit state can manifest Bell nonlocality or EPR-steering is a much harder task. In this work, we present powerful and simple-to-use computational methods to ensure the existence of LHV and LHS models, or to ensure that the given state violates a Bell inequality or an EPR-steering inequality. Our methods improve and combine previously known methods for studying LHS and LHV models for two-qubit states considering two-outcome measurements. As an application, we estimate the relative volume of two-qubit states which admit such local models.

17. **Samgeeth Puliyil:** Thermodynamic Signatures of Genuinely Multipartite Entanglemen

    In this work, we propose thermodynamic quantities that can quantify the genuineness of entanglement in multipartite quantum systems. Instead of entropy, these quantities are defined in terms of energy—particularly the difference between global and local extractable works (ergotropies) that can be stored in quantum batteries. Along with scrutinizing the properties of these measures, we compare them with the other existing genuine measures and argue that they can serve the purpose in a better sense. The generality of our approach allows us to define suitable functions of ergotropies capturing the signature of k-nonseparability that characterizes qualitatively different manifestations of entanglement in multipartite systems.

18. **Martin J. Renner:** Compatibility of generalized noisy qubit measurements

    It is a crucial feature of quantum mechanics that not all measurements are compatible with each other. However, if measurements suffer from noise they may lose their incompatibility. Here, we consider the effect of white noise and determine the critical visibility such that all qubit measurements, i.e. all positive operator-valued measures (POVMs), become compatible, i.e. jointly measurable. In addition, we apply our methods to quantum steering and Bell nonlocality. We obtain a tight local hidden state model for two-qubit Werner states of visibility $1/2$. This determines the exact steering bound for two-qubit Werner states and also provides a local hidden variable model that improves on previously known ones.

19. **Ricardo Rivera:** A BQP_1-complete QSAT problem

    Based on a previous attempt by [Meiburg, 2021], we successfully engineer a quantum SAT problem that is complete for BQP_1. This is the first known natural problem for this class. The key idea relies on the circuit-to-Hamiltonian transformation. While this transformation is more commonly used to show negative results about estimating the ground state energy of local Hamiltonians with a quantum computer, here we do the contrary. We show that when the constraints of a QSAT problem are given by similar Hamiltonians, there is a quantum algorithm that computes the answer with certainty. Furthermore, this construction can also be modified slightly to yield similar QSAT problems that are complete for other quantum and classical complexity classes.

20. **Davide Rolino:** Classical theories with measurement disturbance

    We prove that the property of No-Information Without Disturbance (NIWD), the fact that extracting information from a system irreversibly alters its state, is not per se a signature of non-classicality. The counterexamples are given by two classical theories: Minimal Classical Theory (MCT) and Minimal Strongly Causal Bilocal Classical Theory (MSBCT). Furthermore, we generalize the results obtained for MCT and MSBCT to two broader classes of theories: Minimal Operational Probabilistic Theories and Minimal Strongly Causal Operational Probabilistic Theories. The study of these classes of theories could improve our understanding of the properties that allow a generic physical theory to admit secure cryptographic protocols, and further characterize their computational properties.

21. **Saadat Salman Shariff:** Circuit Complexity in $\mathcal{Z}_2$ EEFT

    Motivated by recent studies of circuit complexity in weakly interacting scalar field theory, we explore the computation of circuit complexity in $\mathcal{Z}_2$ Even Effective Field Theories ($\mathcal{Z}_2$ EEFTs). We consider a massive free field theory with higher-order Wilsonian operators such as ϕ^4, ϕ^6, and ϕ^8. To facilitate our computation, we regularize the theory by putting it on a lattice.

First, we consider a simple case of two oscillators and later generalize the results to N oscillators. This study was carried out for nearly Gaussian states. In our computation, the reference state is an approximately Gaussian unentangled state, and the corresponding target state, calculated from our theory, is an approximately Gaussian entangled state. We compute the complexity using the geometric approach developed by Nielsen, parameterizing the path-ordered unitary transformation and minimizing the geodesic in the space of unitaries. The contribution of higher-order operators to the circuit complexity in our theory is discussed. We also explore the dependency of complexity on other parameters in our theory for various cases.

22. **Natália Salomé Móller:** INDEFINITE TEMPORAL ORDER ON A SUPERPOSITION OF SPHERICAL SHELLS

    The field of indefinite order in quantum theory was born from an attempt to construct a generalized quantum theory with indefinite order. The quantum switch (QS) is the simplest task of this kind: the order of operations applied on a target system is entangled with the state of a control system. In the gravitational QS, this order is entangled with the state of a quantum spacetime. In [Quantum 8 1248 (2024)] we propose a freely falling agent that crosses the interior region of massive spherical shells in a superposition of different radii and becomes entangled with the spacetime geometry. Just as in Einstein's elevator, the agent is not able to acquire information of the external geometry. Our protocol implements the GQS in a universal sense, avoiding decoherence for any operation.

23. **Soham Sau:** SEQUENTIAL IMPLEMENTATION OF QUANTUM INSTRUMENTS

    The formalism of quantum instruments is useful when one needs to tell the post-measurement state along with the measurement statistics of an experiment. The work presented is a study of the sequential implementation of quantum instruments. We define a special sequence of instruments called adaptive sequences. By an adaptive sequence, we mean that every instrument will be dependent upon the classical outcome of the preceding instrument in the sequence. We provide constructive proof that an instrument can be realized as an adaptive sequence of any finite number of instruments. We provide constructive proof that an instrument can be realized as an adaptive sequence of any finite number of instruments. Sequential implementation of POVMs can be considered a special case of our work.

24. **Michal Sedlák:** STORAGE AND RETRIEVAL OF TWO UNITARY CHANNELS

    Ability to precisely capture the functioning of a state transformation is vital not only for quantum engineering. Single use of an entangled probe system can make a footprint with arbitrary precision, but the retrieval of the action of the stored transformation will either suffer from errors or will happen only with limited success probability. Thus, limits of storage and retrieval for N uses of one out of two unitary transformations are a quite fundamental task. We completely solve the problem for both maximum fidelity and perfect probabilistic approach for qubits. We present results of an optical experiment for the latter approach. The storage and retrieval quality have been assessed using quantum tomography of states and processes and the results are discussed in relation to non-optimal measure-and-prepare strategy to illustrate advantages of our protocol. The retrieval part of the experiment can be also interpreted as a realization of probabilistic quantum processor operating at an optimal trade-off between overlap of program states, distinctness of the desired unitary transformations and the achievable success probability. Finally, the optimal perfect probabilistic results are generalized to d dimensional case.

25. **Fereshte Shahbeigi:** NONLOCALITY OF CHANNELS UNDER DECOHERENCE

    Bell nonlocality, a fundamental aspect of quantum theory, asserts that correlations in quantum states cannot always be explained by hidden variables assuming local realism. While being extensively studied in the context of quantum states, the study of nonlocality for quantum channels has only recently garnered attention. In this work, we explore the meaning of nonlocality for channels and address the following questions: how to identify nonlocal properties of bipartite channels and how do these properties change under decoherence? To answer the first question, we present a game analogous to the Buscemi semiquantum game [F. Buscemi, PRL 108, 200401 (2012)], which can identify any channel outside the set of Local Operations with Shared Randomness (LOSR). Furthermore, we show that generic dephasing noise can increase the nonlocal properties of states and channels. Through different tasks, we demonstrate that the gap between LOSR and localizable channels is at least 50% in units of the fidelity as an objective function. We find that if a channel remains nonlocal under full decoherence, it can be advantageous for certain tasks even without noise. We also discuss how a classical channel can exhibit nonlocality and find that simulating a classical channel with quantum resources can expand the set of classical transformations that Alice and Bob can perform in distant labs without direct communication.

26. **Sazim Sheikh:** HIGHER-ORDER INCOMPATIBILITY IMPROVES DISTINGUISHABILITY OF CAUSAL QUANTUM NETWORKS

    We show that the incompatible 'higher-order testing procedures' perform better in discriminating the causal quantum networks than its compatible counterpart. To demonstrate our claim, we consider a quantum comb discrimination task in which the receiver gets a black-box that implements a quantum comb and her task is to determine which comb it implements. We show that the receiver does better at winning the game when she has access to incompatible testers over compatible ones. Our analysis generalizes the earlier finding that the incompatibility of measurement is a bona fide resource in the quantum state discrimination games.

27. **Abdelmalek Taoutioui:** CERTIFYING ASYMMETRIC CONFIGURATION OF THREE QUBIT STATES IN THE PREPARE-AND-MEASURE SCENARIO

We consider a prepare-and-measure scenario, where Alice prepares a qubit state with an untrusted device chosen from a set of three states and sends it to Bob, who probes the state with an uncharacterized measurement device. We prove that an asymmetric configuration of the Bloch vectors associated with the qubit trine states can be certified by constructing a linear functional W on the observed measurement probabilities based on biased $2 \to 1$ quantum random access codes. To achieve this, we computed a bound on this witness W that holds for any mirror symmetric configuration of the Bloch vectors of the prepared trine states and an overall witness bound which self-tests a specific set of target states. The difference between these two values defines our asymmetry measure of the target states.

28. **Leonardo Vaglini:** INFORMATION CONTENT OF A SOURCE IN POST-QUANTUM THEORIES

    In classical Shannon theory the information content of a source is defined in terms of the minimal compression rate (bits per symbol) needed to store the output of the source in a perfectly recoverable way. Here we extend the definition of information content to operational probabilistic theories, we discuss relevant properties such as the subadditivity and invariance under reversible operations and we investigate to what extent the information content can be understood as a measure of purity for states. Finally, by means of a counterexample, we disprove the conjecture that, in general, one of the extensions of entropy already proposed in the literature can be used to compute the information content.

29. **Mário Ziman:** MINIMUM-ERROR DISCRIMINATION OF THERMAL STATES

    We study several variations of the question of minimum-error discrimination of thermal states. Besides of providing the optimal values for the probability of error, we also characterize the optimal measurements. For the case of a fixed Hamiltonian, we show that for a general discrimination problem the optimal measurement is the measurement in the energy basis of the Hamiltonian. We identify a critical temperature, determining whether the given temperature is best distinguishable from thermal state of very high or very low temperatures. Further, we investigate the decision problem of whether the thermal state is above or below some threshold value of the temperature. Also, in this case, the minimum-error measurement is the measurement in the energy basis. This is no longer the case once the thermal states to be discriminated have different Hamiltonians. We analyze a specific situation when the temperature is fixed but the Hamiltonians are different. For the considered case, we show the optimal measurement is independent of the fixed temperature and also of the strength of the interaction.

Invited talks

1. **Giulio Chiribella:** The boundaries of quantum causality
2. **Sergey Filippov:** Scalability of quantum error mitigation techniques: from utility to advantage
3. **Teiko Heinosaari:** Postponing the choice: optimizing quantum measurement strategies for future information gain
4. **Mark Hillery:** Broadcasting quantum states
5. **Michał Oszmaniec:** Ancilla-free implementation of quantum measurements
6. **Marcin Pawłowski:** Exponentially decreasing critical detection efficiency for any Bell inequality

Contributed talks

1. **Gerard Anglès Munné:** SDP bounds for quantum codes
2. **Mateus Araújo:** Quantum key distribution rates from non-symmetric conic optimization
3. **Stefan Baeuml:** Security of continuous variable QKD with discrete modulation
4. **Pierre Botteron:** Algebra of Nonlocal Boxes and the Collapse of Communication Complexity
5. **Libor Caha:** A colossal advantage: 3D-local noisy shallow quantum circuits defeat unbounded fan-in classical circuits
6. **Paweł Cieśliński:** On the Polygamous Nature of Quantum Nonlocality
7. **Fionnuala Curran:** Maximal intrinsic randomness of a quantum state
8. **Oskari Kerppo:** Maximal Elements of Quantum Communication
9. **Zoltán Kolarovszki:** Piquasso: A Photonic Quantum Computer Simulation Software Platform
10. **Ivor Kresic:** Generating interatomic entanglement via photon-mediated self-organization in a condensate
11. **Santiago Llorens:** Quantum multi-anomaly detection
12. **Miguel Navascues:** First-order optimality conditions for non-commutative optimization problems
13. **Sang-Jun Park:** Random Covariant Quantum Channels
14. **Martin Plávala:** All incompatible measurements on qubits lead to multiparticle Bell nonlocality
15. **Giuseppe Viola:** Quantum Strategies for Rendezvous and Domination Tasks on Graphs with Mobile Agents
16. **Lin Htoo Zaw:** Certifying Non-Gaussian Entanglement With Conditional Displacement Gates

Posters

1. **Ieline Ahmed::** Simulation of Quantum Key Distribution
2. **Ardra Ajitha Vijayan:** Study of genuine activation of non locality
3. **Djeylan Aktas, Younes Benamara, Gilberto Borges, Peter Rapčan, Saeid Salari:** The skQCI national QKD infrastructure, a quantum communication testbed
4. **Jan Lennart Bönsel:** Proposed method to produce large multipartite nonlocality and to benchmark quantum computers
5. **Gábor Drótos:** Certifying a complex qubit Hilbert space in a prepare-and-measure scenario: how self-testing helps
6. **Jorge Escandón-Monardes:** Transcribing quantum channels into quantum states
7. **Seyed Arash Ghoreishi:** Geometric Bloch Vector Solution to Minimum-Error Discriminations of Mixed Qubit States
8. **Aabhas Gulati:** Separability of cyclic phase permutation invariant states
9. **Marwan Haddara:** Partially deterministic polytopes: properties and applications
10. **Noah Pascal Köstner:** Projections with finite product expansion in C*-tensorproducts
11. **Robin Krebs:** High Schmidt number concentration in quantum bound entangled states
12. **Leevi Leppäjärvi:** On the simulation of quantum multimeters
13. **M. Hamed Mohammady:** Thermodynamic constraints on the quantum measurement process
14. **Jan Nöller:** Device-independent certification of quantum gates under the dimension assumption
15. **Ties-Albrecht Ohst:** Revealing hidden physical nonclassicality with nonnegative polynomials
16. **Lucas Porto:** A toolkit for analysing Bell nonlocality and EPR-Steering for two-qubit states
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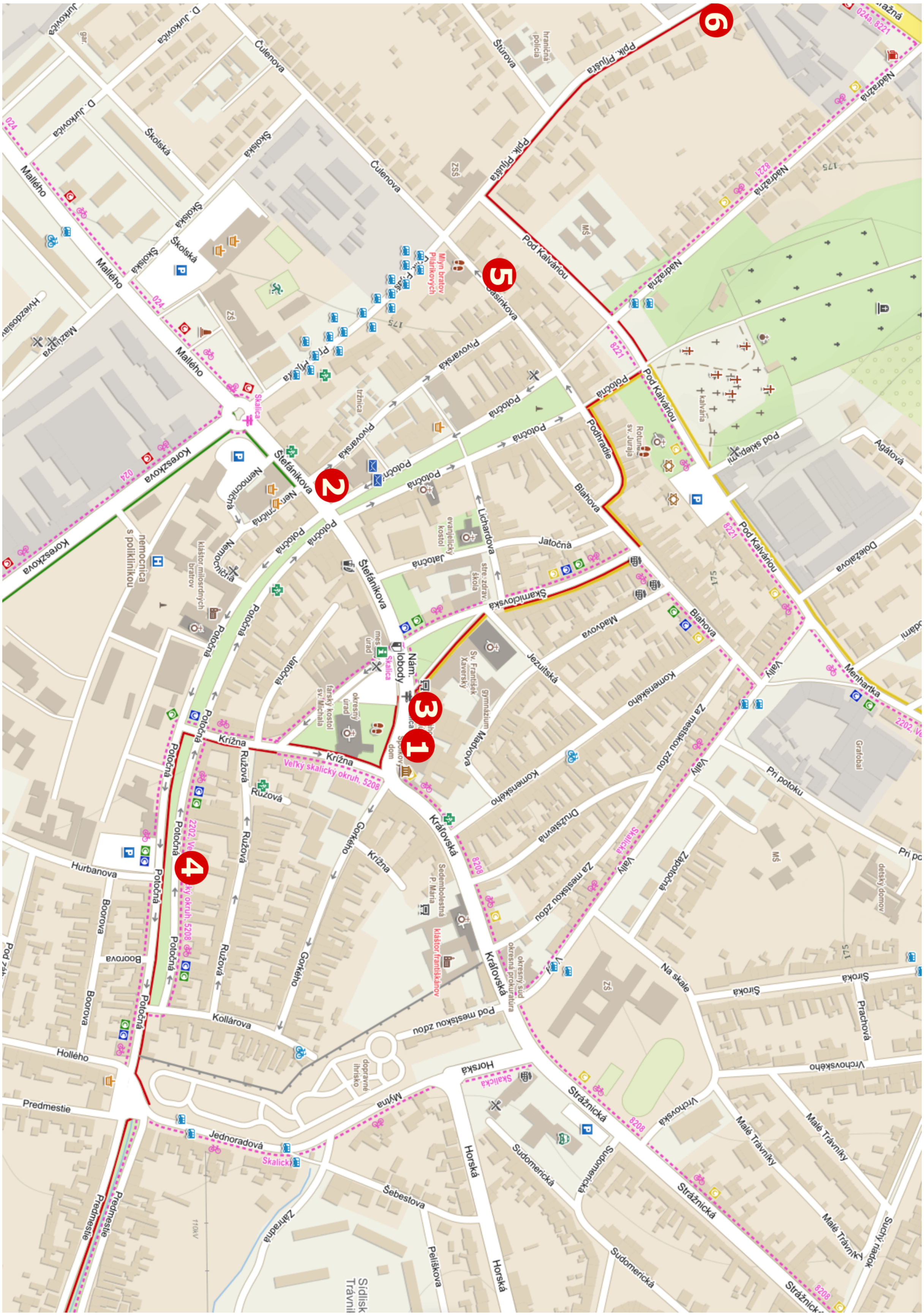
22. **Natália Salomé Móller:** Indefinite temporal order on a superposition of spherical shells
23. **Soham Sau:** Sequential implementation of Quantum Instruments
24. **Michal Sedlák:** Storage and retrieval of two unitary channels
25. **Fereshte Shahbeigi:** Nonlocality of channels under decoherence
26. **Sazim Sheikh:** Higher-order incompatibility improves distinguishability of causal quantum networks
27. **Abdelmalek Taoutioui:** Certifying asymmetric configuration of three qubit states in the prepare-and-measure scenario
28. **Leonardo Vaglini:** Information content of a source in post-quantum theories
29. **Mário Ziman:** Minimum-error discrimination of thermal states



Points of interest:

(1) Skalica culture center (conference venue)
(2) St. Michael Hotel
(3) Hotel Tatran
(4) Guest-house Potočná
(5) Masaryk winery
(6) Guest-house Skalica