Program

and

Book of Abstracts

Workshop of Quantum Simulation and Quantum Walks

17–20 November 2016
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

National Institutes of Natural Sciences
Institute for Molecular Science

	Thu, 17 Nov	Fri, 18 Nov	Sat, 19 Nov	Sun, 20 Nov	
9^{00}	registration	Alberti	Mančal	Werner	9^{00}
	9^{40} opening				
9^{50}	Velázquez	Obuse	Baghbanzadeh	Cedzich	9^{50}
10^{15}		coffee break	coffee break	Cardano	10^{15}
10^{40}	coffee break			coffee break	10^{40}
10^{45}		Mataloni	Ishizaki		
11^{10}	Perinotti			Segawa	11^{10}
11^{35}		Qiang	Petruccione		
12^{00}	Pérez	Wang	Di Franco	Asbóth	12^{00}
12^{25}	lunch break	photo session lunch break	lunch break	Kendon	12^{25}
				closing	12^{50}
15^{00}	Facchini	Hillery	Silberhorn		
	Arnault				
15^{50}	Filip	Reitzner	Xue		
16^{15}	coffee break	Sansoni	coffee break		
16^{40}		posters			
16^{45}	Dunjko		Walmsley		
17^{35}	Rahimi-Keshari		Polyakov		
18^{00}	Urbina		Omar		
18^{25}			19^{30} conf. dinner		

Dear colleagues,

Welcome to the “Workshop of Quantum Simulation and Quantum Walks,” which is the 6th edition of the series. We are glad to have the opportunity to bring together the people working in this exciting field.

You may find the following information useful during the workshop:

- Internet at the Faculty is accessible either through **eduroam** or the local wireless network **wififjfi**.
- The venue is a public building, make sure you never leave your belongings unattended.
- For lunch you can choose from the many restaurants around, we have listed some options on a separate map. Payments are expected in Czech crowns (1€ ≈ 27Kč). While in the center most shops and restaurants accept Euros, they do it at a poor exchange rate, therefore we advise to exchange money[1] or use a payment card.
- The conference dinner will be on Saturday evening. If you plan to take along accompanying persons, make sure during the registration that they are duly signed up.
- Prague has an extensive and reliable public transport, the closest stop by metro is *Staroměstská* and by tram also *Právnická fakulta*. Tickets are sold in advance, and valid for a given duration essentially on all means of public transport. While walking around, please observe that trams have priority even at pedestrian crossings.
- Venue address: Břehová 7, Prague – Old Town/Staré Město
  Contact numbers to local organizers: +420 728950043 (A), +420 777067571 (M)

We wish you a nice time in Prague during the meeting.

Igor Jex (Prague)
Yutaka Shikano (Okazaki)
Aurél Gábris (Prague)
Martin Štefaňák (Prague)
Craig Hamilton (Prague)
Jaroslav Novotný (Prague)
Tamás Kiss (Budapest)

The organizers of WQSQW 2016

[1] When exchanging cash at booths, ask in advance which rate will apply to your transaction!

Thursday, 17 November **Room N° 103**

9:00–9:40	*Registration*
9:40–9:50	*Opening*
	Chair: **Y. Shikano**
9:50–10:40	**Luis Velázquez**: From quantum recurrence to topological phases in quantum walks *(invited)*
10:40–11:10	*Coffee break – Registration*
	Chair: **E. Segawa**
11:10–12:00	**Paolo Perinotti**: Symmetries of quantum walks on Cayley graphs and the Lorentz group *(invited)*
12:00–12:25	**Armando Pérez**: Simulation of neutrino oscillations in vacuum and matter with quantum walks *(contributed)*
12:25–15:00	*Lunch – Registration*
	Chair: **M. Hillery**
15:00–15:25	**Stefano Facchini**: Quantum walking in curved spacetime *(contributed)*
15:25–15:50	**Pablo Arnault**: Quantum walks and gauge fields *(contributed)*
15:50–16:15	**Radim Filip**: Conditional simulation of quantum nonlinear dynamics *(contributed)*
16:15–16:45	*Coffee break*
	Chair: **J. B. Wang**
16:45–17:35	**Vedran Dunjko**: Quantum projective simulation, quantum walks and quantum machine learning *(invited)*
17:35–18:00	**Saleh Rahimi-Keshari**: Efficient classical simulation of quantum-optics experiments *(contributed)*
18:00–18:25	**Juan-Diego Urbina**: The mesoscopic Hong–Ou–Mandel effect and bosonic birthday paradox *(contributed)*

Friday, 18 November

Room N°103

Chair: **P. Mataloni**

9:00–9:50	**Andrea Alberti**: Quantum walks with neutral atoms in polarization-synthesized optical lattices *(invited)*
9:50–10:15	**Hideaki Obuse**: PT symmetric non-unitary quantum walks *(contributed)*
10:15–10:45	*Coffee break*

Chair: **A. Alberti**

10:45–11:35	**Paolo Mataloni**: Integrated waveguide photonics circuits for quantum simulation and beyond *(invited)*
11:35–12:00	**Xiaogang Qiang**: Efficient quantum walk on a quantum processor *(contributed)*
12:00–12:25	**Jingbo Wang**: Efficient quantum circuits for quantum walks *(contributed)*
12:25–12:40	*Photo session*
12:40–15:00	*Lunch break*

Chair: **R. Werner**

15:00–15:50	**Mark Hillery**: Some quantum walks search problems *(invited)*
15:50–16:15	**Daniel Reitzner**: Decoherence in quantum walk searches *(contributed)*
16:15–16:40	**Linda Sansoni**: Driven quantum dynamics *(contributed)*
16:40–19:00	Poster session (*stand numbers refer to page numbers*)

Saturday, 19 November **Room Nº 103**

	Chair: **A. Ishizaki**
9:10–10:00	**Tomáš Mančal**: Quantum excitation energy transport in photosynthetic antennae *(invited)*
10:00–10:25	**Sima Baghbanzadeh**: The role of quantum coherence and geometry in the light-harvesting efficiency of purple bacteria *(contributed)*
10:25–11:00	*Coffee break*
	Chair: **T. Mančal**
11:00–11:50	**Akihito Ishizaki**: Interplays between quantum effects and dynamic fluctuations in photosynthetic light harvesting *(invited)*
11:50–12:15	**Francesco Petruccione**: Open quantum walks *(contributed)*
12:15–12:40	**Carlo Di Franco**: Quantum mechanics and the efficiency of simulating classical complex systems *(contributed)*
12:40–15:00	*Lunch break*
	Chair: **I. Walmsley**
15:00–15:50	**Christine Silberhorn**: Quantum walks in time *(invited)*
15:50–16:15	**Peng Xue**: Experimental implementation of quantum walk on a circle with single photons *(contributed)*
16:15–16:45	*Coffee break*
	Chair: **V. Kendon**
16:45–17:35	**Ian Walmsley**: Photonic quantum networks *(invited)*
17:35–18:00	**Sergey Polyakov**: Full characterization measurement of single-photon states in a primitive boson sampler *(contributed)*
18:00–18:25	**Yasser Omar**: Spatial search by quantum walk is optimal for almost all graphs *(contributed)*
19:30–22:30	*Conference dinner* Departures at 18^{40} and 19^{00} from main entrance

Sunday, 20 November

Room Nº 103

Chair: **L. Velázquez**

9:00–9:50	**Reinhard Werner**: Topological classification of 1D quantum walks with symmetries *(invited)*
9:50–10:15	**Christopher Cedzich**: Bulk-Edge — how about finite systems? *(contributed)*
10:15–10:40	**Filippo Cardano**: Exploring topological phases in quantum walks of twisted light *(contributed)*
10:40–11:10	*Coffee break*

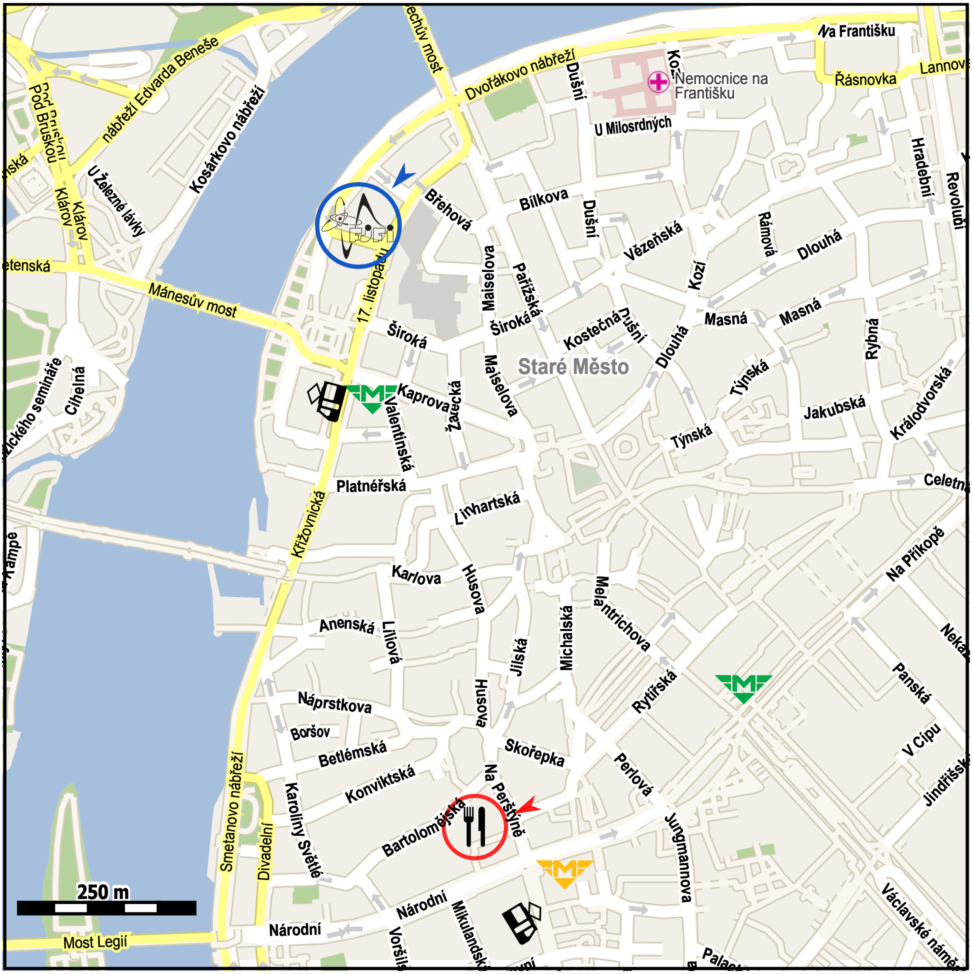
Chair: **Ch. Silberhorn**

11:10–12:00	**Etsuo Segawa**: Sensitivity of a quantum walk to boundary *(invited)*
12:00–12:25	**János Asbóth**: The Hofstadter butterfly takes flight in quantum walks *(contributed)*
12:25–12:50	**Viv Kendon**: Quantum walks in potential wells *(contributed)*
12:50–13:00	*Closing*

Conference dinner on Saturday, 19 November

The dinner will take place in the restaurant and brewery "U Medvídků." It is about 10–20 minutes walk across the historic center of Prague. Groups will be departing from the main entrace at 18:40 and 19:00. Alternatively, it is three stops by tram nos. 2 or 18 from stop *Staroměstská* to stop *Národní třída.*

Address: Na Perštýně 7, 100 01 Prague 1
Starting time: 19:30



You can read more about "U Medvídků" in the info booklet *The Beer Guide to Prague.*

List of contributions

Quantum walks with neutral atoms in polarization-synthesized optical lattices

Andrea Alberti[1]

[1] *Institut für Angewandte Physik, Wegelerstr. 8, 53115 Bonn, Germany**

I will report on quantum walk experiments employing ultracold cesium atoms trapped in polarisation-synthetized optical lattices [1]. Polarisation-synthetized optical lattices are a novel realization of spin-dependent optical lattices, which enable a wide range of quantum walk experiments. Atoms in spin-up and spin-down states are trapped in two distinct optical standing waves, whose position and depth can be individually controlled in time. This allows us to perform arbitrary shift operations of atoms in a fully independent manner for spin-up and spin-down components, on the timescale of microseconds and with a spatial precision of about 1Å.

Exploiting polarization-synthesized optical lattices, we recently demonstrated a scheme [2] for non-destructive spin-state measurementsthe most gentle way to acquire information about the state of the atom. With an adaptation of this measurement scheme, we also show that a single spin component can be removed from the lattice, leaving the other spin component unaffected (ideal negative measurements). We intend to use spin-selective removal of atoms to realize a lossy discrete-time quantum walks, which we have predicted [3] to give access to the Floquet topological invariants of the corresponding lossless quantum-walk protocol.

The next frontier for our ultracold-atom experiments is the realization of 2D discrete-time quantum walks. The implementation of a novel scheme for spin-dependent transport in the x-y plane with polarization-synthesized optical lattices is currently underway [4]. I will therefore conclude presenting our most recent advances about the construction of the 2D experimental setup [5].

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[1] C. Robens, et al., arXiv:1608.02410 [quant-ph] (2016)
[2] C. Robens, et al., arXiv:1609.06218 [quant-ph] (2016)
[3] J. Asbth, T. Rakovszky, A. Alberti (in preparation)
[4] T. Groh, et al., *Phys. Rev. A* **94**, 013620 (2016).
[5] C. Robens, et al., arXiv:1611.02159 (2016)

Quantum projective simulation, quantum walks and quantum machine learning

Vedran Dunjko[1]

[1] *Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 21a, A-6020 Innsbruck, Austria[*]*

In recent times, we have witnessed an ever increasing interest in the interplay between the fields of artificial intelligence, in particular machine learning, and quantum information. One line of such research considers the potential of quantum improvements in so-called *reinforcement learning* where a learning agent (or: learning algorithm) learns via an interaction with an external environment. In this scenario, quantum improvements have been reported in the context of the physics-motivated Projective Simulation model for artificial intelligence [1, 2], but also in the context of quantized environments [3, 4]. In both cases, the source of quantum improvements can be traced back to a beneficial quantization of a random walk, or, more specifically, a quantized Markov chain. In this talk I will present these recent results, highlighting the function of quantum walks in quantum reinforcement learning models. Furthermore, I will discuss the perspectives of quantum machine learning, and the directions in which progress in quantum walk theory can lead to progress in the nascent field of quantum learning agents.

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[1] Briegel, H. J. and De las Cuevas, G. Projective simulation for artificial intelligence. *Sci. Rep.* **2** (2012).

[2] Paparo, G. D., Dunjko, V., Makmal, A., Martin-Delgado, M. A. and Briegel, H. J. Quantum speedup for active learning agents. *Phys. Rev. X* **4**, 031002 (2014).

[3] Dunjko, V., Taylor, J. M. & Briegel, H. J. Framework for learning agents in quantum environments. *arXiv:1507.08482* (2015).

[4] Dunjko, V., Taylor, J. M. & Briegel, H. J. Quantum-enhanced machine learning. *Phys. Rev. Lett.* **117** 130501 (2016).

Some quantum walk search problems

Mark Hillery[1]
[1]*Department of Physics, Hunter College of CUNY*[*]

One of the main uses of quantum walks is to do searches on graphs. Typically the search is for a distinguished vertex against a uniform background. The background consists of all of the vertices except for the distinguished one, and all of these vertices behave in the same way. We want to look at more general searches. We first look at a situation in which the background is not uniform, that is in which the background vertices can behave in several different ways. We find that in this case the search still works with a quantum speedup, but the probability of success is lower than in the uniform background case. Next we look at the case in which the object to be found is not a distinguished vertex but some kind of a special structure, e.g. an extra edge or a clique. We find some general conditions on when searches of this kind will succeed with a quantum speedup.

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[1] Finding structural anomalies in graphs by means of quantum walks by Edgar Feldman, Mark Hillery, Hai-Woong Lee, Daniel Reitzner, Hongjun Zheng, and Vladimir Bužek, Phys. Rev. A **82**, 040301R (2010).
[2] Searches on star graphs and equivalent oracle problems by J. Lee, Hai-Woong Lee and Mark Hillery, Phys. Rev. A **83**, 022318 (2011).
[3] Finding structural anomalies in star graphs using quantum walks by Seth Cottrell and Mark Hillery, Phys. Rev. Lett. **112**, 030501 (2014).

Interplays between Quantum Effects and Dynamic Fluctuations in Photosynthetic Light Harvesting

Akihito Ishizaki

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Quantum dynamic phenomena are ubiquitous in molecular processes, and yet remain a challenge for experimental and theoretical investigations. On the experimental side, it has become possible to explore molecular processes on a timescale down to a few femtoseconds by means of ultrashort laser pulses. This progress in ultrafast laser spectroscopy has opened up real-time observation of dynamic processes in complex chemical and biological systems, and has provided a strong impetus to theoretical studies of condensed phase quantum dynamics or real-time quantum dissipative dynamics.

Investigation on the primary steps of photosynthesis is an example of such efforts. With minor possible exceptions near hydrothermal vents, this process provides the energy source for essentially all living things on Earth. Photosynthetic conversion of the energy of sunlight into its chemical form suitable for cellular processes involves a variety of physicochemical mechanisms. The conversion starts with the absorption of a photon of sunlight by one of the light-harvesting pigments, followed by transfer of electronic excitation energy to the reaction center. At low light intensities, the quantum efficiency of the conversion is near unity; that is, each of the absorbed photons almost certainly reaches the reaction center and drives the electron transfer reactions. A longstanding question in photosynthetic research has been the following: *How do light-harvesting systems deliver such high efficiency in the presence of disordered and fluctuating dissipative environments?* The precise molecular mechanisms are not yet fully elucidated from the standpoint of physical sciences.

In this presentation, we provide an overview of recent experimental and theoretical investigations of photosynthetic energy/charge transfer, specifically addressing interplays between quantum mechanical effects and dynamic fluctuations of pigments electronic states induced by their surrounding proteins.

Quantum Excitation Energy Transport in Photosynthetic Antennae

Tomaš Mančal[1]

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Photosynthetic antennae are natural energy transferring molecular systems exhibiting high quantum efficiency of exciton energy transport in space and across spectral domains. Due to their biophysical importance they are studied in great detail by spectroscopic methods with high temporal and spectral resolutions [1]. Decades worth of accumulated experimental literature and the accompanying theoretical framework describing details of the energy transfer processes have been relatively recently put into question by innovative experimental techniques [2]. In this contribution I want to review briefly the general properties of photosynthetic energy transfer together with the basic theoretical techniques to describe it. I will discuss to what extent and if at all a paradigm change in the theoretical description of photosynthetic systems is needed. The question of quantum nature of photosynthetic energy transfer will be addressed by comparison to classical models of the same phenomenon [3].

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[1] H. van Amerongen, L. Valkunas and R. van Grondelle, *Photosynthetic excitons*, World Scientific, Singapore, 2000
[2] G. S. Engel et al., *Nature*, **446**, 782 (2007)
[3] T. Mančal, *J. Phys. Chem. B*, **117**, 11282 (2013)

Integrated waveguide photonics circuits for quantum simulation and beyond

Paolo Mataloni

Physics Department
Sapienza University of Rome

Quantum simulators are getting to the level of real devices, constituted by a quantum system which can be controlled in its preparation, evolution and measurement and whose dynamics can implement that of the target quantum system we want to simulate. In this context, photonics quantum technologies are expected to play an instrumental role in the realization of controlled quantum systems capable, in their evolution, to simulate a given complex system.

I will present some of the main results obtained in this field by using integrated waveguide optical circuits, that represent the hardware of a quantum simulator. These systems are constituted by interferometer arrays of beam splitters and phase shifters fabricated on single integrated platforms and have the potential of speeding- up the evolution from lab systems to the next generation of quantum optical devices for real-world applications. Using the mobility of photons we are able to create arbitrary interconnections within these systems and to mimic the main features of quantum phenomena of increasing complexity.

Symmetries of quantum walks on Cayley graphs and the Lorentz group

Paolo Perinotti

Università degli Studi di Pavia,
Dipartimento di Fisica, QUIT Group,
and INFN Gruppo IV, Sezione di Pavia,
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We describe the emergence of different geometries from the structure of local, homogeneous and isotropic quantum walks on an abstract Hilbert space. We show how homogeneity gives rise to a translation group structure through the construction of a Cayley graph. In the case where the translation group is the 3-dimensional free Abelian group, one can prove that the simplest quantum walk satisfying all the symmetry constraints can be described by Weyl's equations. After reformulating the relativity principle in terms of the walk dynamics we show that the symmetry group of the walk contains a non-linear representation of the Lorentz group, that in a suitable approximation corresponds to the usual linear representation.

Sensitivity of a quantum walk to boundary

Etsuo Segawa[1] and Hideaki Obuse[2,*]

[1] *Graduate School of Information Sciences, Tohoku University*

[2] *Faculty of Engineering, Applied Physics, Hokkaido University*

We treat the quantum walk model on the two dimensional lattice with the cutting edge along the $x = 0$ line introduced by Asboth and Edge [1]. We provide more detailed analytical result of this model; in particular, we investigate in the contribution of the edge state to the stochastic behavior of the quantum walk.

Due to the translation invariant with respect to the vertical direction of this model, the time evolution Γ on $\ell^2(\mathbb{Z}_+ \times \mathbb{Z})$ is decomposed into $\{\hat{\Gamma}_k\}_{k\in[0,2\pi)}$. First we show $\hat{\Gamma}_k$ is isomorphic to the CMV matrix whose Verblunsky parameter is $(\eta(k), 0, \eta(k), 0, \dots)$ with some complex value $\eta(k)$. Secondly, using the previous studies on the spectral analysis on the CMV matrix related to quantum walks, CGMV method [2, 3], we obtain the dispersion relation explicitly. Finally, we examine how the quantum walk feels the boundary. To this end, we focus on the edge state through the limit distribution of the quantum walk. We show that up to the parameter determining this quantum walk model, the response to the boundary is classified into (i) localization, (ii) (continuously) linear spreading, (iii) ballistic spreading. The limit measure is not a probability distribution since its integration over its domain is strictly smaller than 1. The "missing value" derives from the contribution of the bulk state.

Each situation of the dispersion relation for cases (i) (ii) (iii) is that the quasi-energy of the edge state is constant, non-zero second derivative, and linear, respectively. In particular, in case (ii), the limit measure is provided by a parametric expression using the quasi-energy of the edge-state which gives a deformed Konno's distribution.

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[1] Janos K. Asboth and Jonathan M. Edge, Phys. Rev. A 91, (2015) 022324.

[2] M. J. Cantero, F. A. Grünbaum, L. Moral and L. Velázquez, Communications on Pure and Applied Mathematics 63 (2010) 464-507.

[3] N. Konno and E. Segawa, Quantum Inf. Comput. 11 (2011) 485–495.

Quantum Walks in Time

Christine Silberhorn[1]

[1] *Integrated Quantum Optics, Department of Physics, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany**

Photonic quantum walk systems provide an attractive platform for the implementation of quantum simulations of various types of phenomena. However their experimental realization requires setups with high complexity, in particular in terms of scalability, this means the number of modes, and sufficient control of all system parameters.

We employ time multiplexing with pulsed light in specific fibre loop geometries to demonstrate different types photonic quantum walks. By using the polarisation as internal degree of freedom we can implement arbitrary coin states, while the realization of the step operator in the temporal domain provides superior coherence properties for the scalability and the homogenity of the walk. By introducing optical modulators we can precisely control the dynamics of the photonic walks.We demonstrate a fully coherent photonic quantum walks over many steps on different graph structures[1].

Among the targets for simulations are transport phenomena in disordered systems. To demonstrate the capabilities of our apparatus in this context we have realized six steps of a percolation quantum walk on a three-site graph and have investigated non-Markowian open system dynamics [3].

Concepts such as topological insulators have sparked interest in the investigation of topological material properties. Here, we present the direct measurement of topological invariants in a discrete-time quantum walk experiment[2].

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[1] T. Nitsche, F. Elster, J. Novotny, A. Gabris, I. Jex, S. Barkhofen, C. Silberhorn *New J. Phys.*, **18**, 063017 (2016)

[2] S. Barkhofen, T. Nitsche, F. Elster, L. Lorz, A. Gabris, I. Jex, C. Silberhorn *arXive:1606.00299*, (2016)

[3] F. Elster, S. Barkhofen, T. Nitsche, J. Novotny, A. Gabris, I. Jex, C. Silberhorn *Scientific Reports*, **5**, 13495 (2015)

From Quantum Recurrence to Topological Phases in Quantum Walks

J. Bourgain,[1] C. Cedzich,[2] T. Geib,[2] F. A. Grünbaum,[3] C. Stahl,[2] L. Velázquez,[4,*] A. H. Werner,[5] R. F. Werner,[2] and J. Wilkening[3]

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[5] *Department of Mathematical Sciences, University of Copenhagen, Denmark*

Two approaches to recurrence in quantum walks have been recently proposed, which differ in the presence or absence of monitoring at each step. In the monitoring case, a key role is played by the first return generating function, which turns out to be a so-called Schur function. This links this topic to a large body of mathematical literature and is the origin of a rich interplay which allowed for a spectral characterization of quantum recurrence, but also provided new insights into unsolved mathematical problems.

A more recent discovery connects the first return generating functions to the study of symmetry protected topological phases in quantum walks. Such generating functions codify the relevant information of the evolution operator for identifying topological indices. This reduces the calculation of such indices to finite-dimensional problems, allowing for a complete classification of topological phases for arbitrary non-translation invariant coined walks and generalizations.

This talk will be a review of the above results, including the geometric and topological meaning (Berry phases, winding numbers) that the first return generating functions give to certain recurrence properties, and the striking behaviour of such generating functions under certain splittings of quantum walks.

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Photonic Quantum Networks

Ian A. Walmsley

University of Oxford, Department of Physics, UK

Building complex quantum systems has the potential to reveal new phenomena that cannot be studied using classical simulation. Photonics has proven to be an effective means to engineer quantum systems of this kind, and for the investigation of such effects. The challenge is to build a quantum state of sufficient complexity, both in the number of photons and the number of modes. Hybrid light-matter quantum networks [1], in which the channels use light as a communication medium and the nodes use matter for processing operations, have emerged as a particularly important class of architectures for constructing and utilizing such states. A quantum network, consisting of simple nodes with some quantum dynamics, interconnected by coherent channels, inherits the features of robustness and scalability from its classical network counterparts, but it also exhibits functionality that goes beyond what is possible with conventional technologies [2].

Here I will describe experiments exploiting the quantum interference of three single photons on a reconfigurable integrated photonic chip. We develop multiple on-chip, low-loss sources of single photons and introduce a low-loss silica-on-silicon waveguide architecture that enables us to show the first genuine quantum interference of three single photons on an integrated platform [3]. We make use of this three-photon interference for the first proof-of-principle demonstration of a new intermediate model of quantum computation called boson sampling, and we perform an on-chip demonstration of the quantum teleportation protocol where all key parts – entanglement preparation, Bell-state analysis and quantum state tomography – are performed on a reconfigurable photonic chip [4–6].

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[1] H. J. Kimble, *Nature* **453.7198** 1023-1030 (2008)
[2] I. A. Walmsley, *Science*, 348, 525 (2015)
[3] J. B. Spring et al, *arXiv:1603.06984*
[4] B. J. Metcalf et al., *Nat. Phot.* **8** (2014)
[5] W. Clements et al, *arXiv:1603.08788*
[6] P. C. Humphreys et al., *New J. Phys*, **17**, 103044 (2015)

Topological classification of 1D quantum walks with symmetries

C. Cedzich,[1] T. Geib,[1] F. A. Grünbaum,[2] C. Stahl,[1]
L. Velázquez,[3] A. H. Werner,[4] and R. F. Werner[1]
[1] *Institut für Theoretische Physik, Leibniz Universität Hannover, Germany*
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There is a large heuristic literature on topological insulators, that is, on the classification of Hamiltonian quantum lattice systems, which obey certain discrete symmetries. Some of these ideas have been transferred to the setting of quantum walks, and it has been observed that additional invariants may appear in this case [1], leading to a richer classification. In this talk we will give a rigorous and complete classification in the one-dimensional case [2]. That is, we assign to every walk three indices. The basic statement is then that these index triples coincide for two walks if and only if one can be deformed into the other by a norm-continuous path of walks, each of which satisfies the symmetries, a gap condition and a locality condition.

The basic idea of the classification and the determination of the index groups for each symmetry type are elementary and do not require advanced tools like K-theory. Non-gentle local perturbations, i.e., ones that cannot be continuously contracted to the identity, are identified as the essential new feature of the walk case. The talk will focus on the setting and a sketch of the main steps, leaving some further details to the presentations of other coauthors.

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[1] *Bulk-boundary correspondence for chiral symmetric quantum walks.* J. K. Asbóth and H. Obuse. Phys. Rev. B 88: 121406, 2013.

[2] *A topological classification of one-dimensional symmetric quantum walks.* C. Cedzich, T. Geib, F. A. Grünbaum, C. Stahl, L. Velázquez, A. H. Werner and R. F. Werner. In preparation.

The Hofstadter Butterfly takes flight in Quantum Walks

Janos K. Asboth[1] and Andrea Alberti[2]

[1] *Wigner Research Centre for Physics, Budapest*
[2] *Institut für Angewandte Physik, Universität Bonn*

When we apply a magnetic field to a quantum walk on a lattice [1], the spectrum of quasienergies develops a fractal structure of minigaps: the quantum walk version of the Hofstadter butterfly [2]. We find that in many quantum walks, the Hofstadter butterfly winds in quasienergy (Fig. 1), i.e., "takes flight" – a feat impossible for time-independent Hamiltonians. We show when and why this occurs, and how this can be used to calculate the Rudner invariant of quantum walks [3].

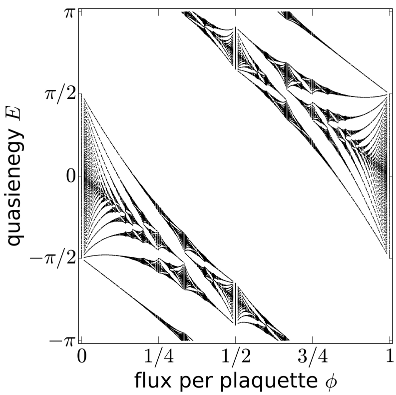

FIG. 1: The Hofstadter butterfly, i.e., spectrum as a function of magnetic field, of the two-dimensional split-step quantum walk.

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The role of quantum coherence and geometry in the light-harvesting efficiency of purple bacteria

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Photosynthetic organisms harvest light using antenna complexes containing many (bacterio)chlorophyll molecules. Despite the wide diversity of the light-harvesting complexes and very noisy environments around them, the energy collected by these complexes is transmitted with generally high efficiency, through the excitonic energy transfer (EET), to the reaction centre where it starts the first chemical reactions of photosynthesis. Accordingly, understanding EET mechanisms and the design principle of these antennae can help to make more efficient artificial light-harvesting complexes.

Here, by taking into account the coherent excitonic delocalization within the light-harvesting complexes of purple bacteria, we investigate the role of rotational symmetry of these complexes on the efficiency of EET, by modelling hypothetical antennae whose symmetry is broken [1]. Our results demonstrate that breaking the symmetry of these complexes will attenuate the performance of energy transfer, due to the destruction of the coherent process of supertransfer. Specifically, in natural light conditions as the LH1 pigments orientations are randomly changed, the performance of the natural geometry is 5.5 standard deviations better than the mean of thousands of reorientations. The magnitude of this improvement is one of the largest photosynthetic efficiency enhancement we are aware of that has been attributed to a coherent effect.

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Exploring topological phases in quantum walks of twisted light

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We present the realization of a photonic quantum walk based on the Orbital Angular Momentum of light [1], showing topological phases that characterize periodically modulated 1D systems (Floquet topological insulators). We found that information about the system topology can be extracted from the statistical moments associated with photons OAM spectrum; while varying a control parameter that determines the value of the invariants, these show marked differences in distinct phases and exhibit abrupt variations at the transition points [2]. Moreover specific combinations of such moments are quantized as the topological invariants [3], hence can be used to detect topological phases. We confirm experimentally these results in our photonic platform, and report the measurement of complete topological invariants characterizing this class of systems [3, 4]. Importantly, we demonstrate that the method we propose is widely applicable in a variety of 1D topological systems.

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Bulk-Edge - how about finite systems?

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In this talk we study symmetry protected topological phases for one-dimensional quantum walks on finite lattices [1]. In particular, we investigate the implications of the infinite theory [2] for finite subsystems. The subsystems are obtained by cutting out a finite number of sites from an infinite lattice and considering arbitrary unitary restrictions of the infinite quantum walk which belong to the same symmetry type. We obtain a variant of bulk-boundary correspondence where due to the finiteness of the system the symmetry protected eigenvalues lie not on the symmetry invariant points of the spectrum anymore. However, they can be found in an exponentially small neighbourhood of the symmetry invariant points. The relevant exponent can be determined from the decay of the formal solutions of the eigenvalue equation via transfer matrices in the bulk phases.

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Quantum walks and gauge fields

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Discrete Time Quantum Walks (DTQWs) were originally considered by Feynmann as possible discretizations of the Dirac dynamics in $(1+1)$ dimensions. It has been realized during the past five years that DTQWs can actually describe Dirac fermions in higher dimensions and coupled to arbitrary gauge fields, including gravity. I will review all results connecting DTQWs to gauge fields and focus the last part of the presentation on the recent construction of discrete curvature (field-strength) tensors, which paves the way to full-fledged gauge theories based on DTQWs.

Quantum walking in curved spacetime

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Some Quantum Walks admit a continuum limit, leading to familiar PDEs (e.g. the Dirac equation). We show how prior grouping and encoding allows for more general continuum limit equations. In particular, we show that Grouped QWs lead to an entire class of PDEs encompassing the massive Dirac equation in (3+1) curved spacetime. This means that the metric field can be represented by a field of local unitaries over a lattice.

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Contributed talks

Quantum mechanics and the efficiency of simulating classical complex systems

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The development of tools allowing us to infer models from observed data, and thus to simulate possible future outputs, has a central role in several fields. Many fundamental questions in nature and society can be addressed only by isolating indicators of future behavior in highly complex systems. However, even the most efficient constructions often require information about the past that is uncorrelated with future predictions. In terms of energetic costs, this brings a waste of resources in the computer simulations based on such models. Even if the systems to simulate are completely classical, it has been proved that quantum information can reduce this waste beyond classical limits [1].

During the talk I will sketch this scenario, that could lead to interesting questions also for the scientific community working on quantum walks, and present some of the aforementioned results. In particular, I will describe a possible implementation of a quantum model that breaks this classical bound. Such experiment can be realized by exploiting tools and schemes already used for the implementation of quantum walks in linear-optics setups [2].

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Conditional simulation of quantum nonlinear dynamics

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We propose and analyse feasible methods for conditional simulation of quantum nonlinear dynamics. The methods use either linear optics, homodyne detection and single quanta states of the oscillator or nonlinear interaction of the oscillator with fully controlled two level systems. Both applicability and stability of proposed methods will be discussed on specific examples of cubic nonlinear interaction and optomechanical interaction. We finally suggest the most experimentally feasible arrangement with trapped ions suitable for stable conditional simulation. It can be used to study in detail short-time unitary quantum dynamics of many experimentally unexplored nonlinear processes.

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Quantum walks in potential wells

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Inspired by the use of classical random walks to model the behaviour of the scalar matter field during the inflationary period of the early universe, we study discrete-time, coined quantum walks in one-dimensional potential wells. We parameterised a quadratic potential $V(x) = m^2x^2/2$ with a tuneable mass parameter m, using a position-dependent biased coin operator H with bias determined by θ

$$H = \begin{pmatrix} \sin\theta & \cos\theta \\ \cos\theta & -\sin\theta \end{pmatrix} \quad \text{where} \quad \theta = \frac{1}{2}\arctan\left(\frac{m^2}{x}\right)$$

is determined by the derivative (slope) of the potential at x. Choosing different functions for $V(x)$ allows us to treat cubic, quartic, exponential and anything in between, see figure 1.

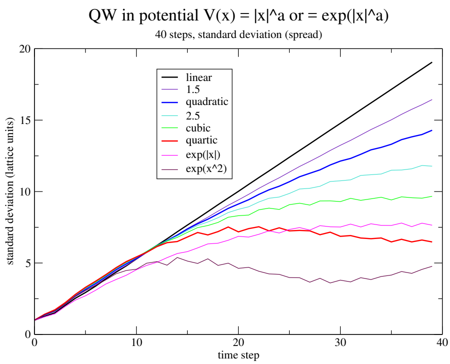

FIG. 1: quantum walks in potentials for various scalings

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$\mathcal{PT}$ symmetric non-unitary quantum walks

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Recently, a non-unitary one-dimensional quantum walk associated with gain and loss is implemented in the fiber loops experiment[1]. The experiment shows that the quasienergy of the non-unitary time-evolution operator in the homogeneous system is kept to be real. This provides convincing evidence that the non-unitary quantum walk possesses a special symmetry, so called $\mathcal{PT}$ symmetry (combined parity and time-reversal symmetry). However, the definition of $\mathcal{PT}$ symmetry for the time-evolution operator has not yet been fully understood, and this prevents further developments of non-unitary quantum walks.

We explain how to identify the $\mathcal{PT}$ symmetry operator and then verify $\mathcal{PT}$ symmetry of the time-evolution operator of the one-dimensional non-unitary quantum walk even when parameters depend on the position[2]. Taking this result into account, we study Floquet topological phases of the $\mathcal{PT}$ symmetric non-unitary quantum walk in the one dimension[3]. We numerically observe that, by introducing position dependent coin operators into the system by keeping $\mathcal{PT}$ symmetry of the time-evolution operator, localized states with zero and π quasienergies appear near the interface where the topological number varies from a value to the other one, as expected from the bulk-edge correspondence. This provides a way to observe highly intense probabilities of localized states originating to Floquet topological phases in actual experimental setups. Furthermore, we show that the quasienergy of non-unitary quantum walks becomes real even when the coin operator randomly varies over the position, which apparently breaks $\mathcal{PT}$ symmetry[4]. This provides evidence that phenomena peculiar to $\mathcal{PT}$ symmetry can be observed in a broader class of non-unitary quantum walks.

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Spatial search by quantum walk is optimal for almost all graphs

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The problem of finding a marked node in a graph can be solved by the spatial search algorithm based on continuous-time quantum walks (CTQW). However, this algorithm is known to run in optimal time only for a handful of graphs. In this work, we prove that for Erdös-Rényi random graphs, i.e. graphs of n vertices where each edge exists with probability p, search by CTQW is *almost surely* optimal as long as $p \geq \log^{3/2}(n)/n$. Consequently, we show that quantum spatial search is in fact optimal for *almost all* graphs, meaning that the fraction of graphs of n vertices for which this optimality holds tends to one in the asymptotic limit. We obtain this result by proving that search is optimal on graphs where the ratio between the second largest and the largest eigenvalue is bounded by a constant smaller than 1. Finally, we show that we can extend our results on search to establish high fidelity quantum communication between two arbitrary nodes of a random network of interacting qubits, namely to perform quantum state transfer, as well as entanglement generation. Our work shows that quantum information tasks typically designed for structured systems retain performance in very disordered structures.

Simulation of neutrino oscillations in vacuum and matter with quantum walks

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We analyze the simulation of Dirac neutrino oscillations using quantum walks, both in vacuum and in matter [1]. We show that this simulation, in the continuum limit, reproduces a set of coupled Dirac equations that describe neutrino flavor oscillations, and we make use of this to establish a connection with neutrino phenomenology, thus allowing one to fix the parameters of the simulation for a given neutrino experiment. We also analyze how matter effects for neutrino propagation can be simulated in the quantum walk. In this way, important features, such as the MSW effect, can be incorporated. Thus, the simulation of neutrino oscillations with the help of quantum walks might be useful to illustrate these effects in extreme conditions, such as the solar interior or supernovae.

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Contributed talks

Open Quantum Walks

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Open quantum walks were introduced as quantum walks exclusively driven by the interaction with the external environment and defined as discrete completely positive maps on graphs [**?**]. Over the last few years, dynamical properties and limit distributions of Open Quantum Walks (OQWs) have been intensely studied. However, only recently the connection between the rich dynamical behavior of OQWs and the corresponding microscopic system-environment models has been established. The microscopic derivation of an OQW as a reduced system dynamics on arbitrary graphs allow explaining the dependence of the dynamical behavior of the OQW on the temperature and coupling to the environment.

OQWs provide a natural formalism for the description of the dynamics of weakly coupled modular systems. One of the typical examples of such situation is a transport of excitations between large light-harvesting macromolecular complexes weakly coupled to each other. Starting from the microscopic model (systems plus bath) here we will present the application of the OQWs for the description of the excitation transport in an LH2 inspired system.

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Full Characterization Measurement of Single-Photon States in a Primitive Boson Sampler

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Single-photon sources are characterized by the normalized second-order correlation function and indistinguishability. The second-order auto-correlation function characterizes the photon statistics and is related to measurements by Hanbury Brown and Twiss (HBT), denoted $g^{(2)}_{\mathrm{HBT}}$. The second-order interference of the two input fields can be measured via a similar correlation function, referred to as Hong, Ou, and Mandel (HOM) interferometry. The significance of this measurement is that it determines indistinguishability C of the interfering non-entangled input states. Typically, any realistic measurement of C requires at least one supplemental measurement to determine $g^{(2)}_{\mathrm{HBT}}$.

Here, by using random quantum walks, we show a method to simultaneously access the single photon purity and indistinguishably. The two replicas of the state under measurement are sent to a first beamsplitter. Each of the outputs of the first beamsplitter is subsequently sent onto their own beamsplitter. The statistics of light that exits this photonic circuit is defined by both $g^{(2)}_{\mathrm{HBT}}$ and C. In characterizing Fisher information, we prove that our method provides more knowledge about the input state than a conventional method using the same quantum resource. To demonstrate the new method, we characterized light from a single quantum dot. We compare this new approach with a traditional HBT measurement. We also compare the HOM visibilities, one calculated from the data obtained with our method and the other directly obtained through a traditional experiment. The measurements compare well.

To conclude, we theoretically introduce and experimentally demonstrate a new measurement method to simultaneously characterize a state of light by taking advantage of boson sampling.

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Efficient Quantum Walk on a Quantum Processor

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The random walk formalism is used across a wide range of applications, from modelling share prices to predicting population genetics. Likewise quantum walks have shown much potential as a framework for developing new quantum algorithms. Here we present explicit efficient quantum circuits for implementing continuous-time quantum walks (CTQWs) on the circulant class of graphs. These quantum circuits provide the time-evolution states of CTQWs on circulant graphs exponentially faster than best previously known methods. These circuits also allow us to sample from the output probability distributions of CTQWs on circulant graphs efficiently. We provide evidence from computational complexity theory that solving the same sampling problem for arbitrary circulant quantum circuits is intractable for a classical computer, assuming a highly plausible conjecture that the infinite tower of complexity classes known as the polynomial hierarchy does not collapse. This builds a new link between CTQWs and computational complexity theory and it indicates a family of tasks which could ultimately demonstrate quantum supremacy over classical computers. As a proof of principle we experimentally implemented the proposed quantum circuit on an example four-vertex circulant graph using a two-qubit photonics quantum processor to sample the probability distributions and perform state tomography on the output states of CTQWs.

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Efficient classical simulation of quantum-optics experiments

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It is generally believed that quantum computers can perform certain tasks faster than their classical counterparts. Identifying the resource that potentially enables this speedup is of particular interest in quantum information science. Attempts to identify the elusive quantum feature are generally back-door attacks, studying not what is essential for speedup, but rather what is lacking in quantum circuits that can be efficiently simulated classically. In this talk, by using the well-developed theory of phase-space quasiprobability distributions (PQDs), we introduce two sufficient conditions for efficient classical simulation of generic quantum-optics experiments: M bosonic modes prepared in an arbitrary state undergo an M-mode quantum process; one generates samples by making a measurement on the M output modes [1]. In particular, the question is whether sampling from the output probability distribution can be efficiently simulated on a classical computer. Our conditions show that negativity in PQDs is an essential resource for a generic quantum-optics experiment not to be efficiently simulatable.

These conditions provide useful practical tools for investigating the effects of imperfections in implementations of boson sampling [2]. Considering simple models for various sources of errors, we find necessary and sufficient conditions for the relevant PQDs to be nonnegative, and thus for such experiments to be efficiently simulated classically using our methods. Our analysis suggests that mode mismatching is the chief challenge for implementations of boson sampling of interesting size.

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Decoherence in Quantum Walk Searches

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Decoherence in quantum(-walk) searches and in their predecessor, Grover search in particular has been studied in several different settings [1–4]. The noise models used, were, however non-localized, affecting either the oracle, or whole state space. In this paper we study Grover search under the influence of localized partially dephasing noise. For example in quantum walk searches on physical graphs, part of a graph can be affected by the noise.

In these settings we find, that in the case when the size of the affected subspace is rather small, the quadratic speedup can be retained, while for uncorrelated noise on large subspaces, the algorithm in its actual form does not help any more. We present here first order approximations obtained by a technique of invariant subspaces adapted to mixed states.

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Driven quantum dynamics

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Quantum dynamics of many-particle systems is attracting more and more attention. In this regard the main issue, from the experimental point of view, is the generation of many walkers. For example photonic implementations suffers from losses and low signals, which make it a hard task. A way to tackle this challenge is to generate particles directly inside the network instead of preparing the input state outside. This is what we call a *driven system*.
Here we present driven dynamics based on the generation of particles within the network. This approach can be explored in the framework of quantum walks [1] and search algorithms [2]. The introduction of the generation inside the network strongly affects the evolution of the walkers giving rise to new effective linear evolutions that depend on the generation parameters. A driven dynamics can also be exploited for boson sampling protocols [3]. When using heralded single-photon sources based on parametric down-conversion, this approach offers enhancement in the input state generation rate over scattershot boson sampling [4], reaching the scaling limit for such sources [5]. More significantly, this approach offers a dramatic increase in the signal-to-noise ratio with respect to higher-order photon generation from such probabilistic sources, which removes the need for photon number resolution during the heralding process as the size of the system increases.

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The mesoscopic birthday paradox

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Two fundamental phenomena due to quantum indistinguishability in the many-body scattering of identical particles, the Hong-Ou-Mandel (HOM) effect and the Bosonic Birthady Paradox (BBP), are here lifted into the mesoscopic regime where the influence of irregular confinement during the scattering process results on the universality of interference effects appearing on top of the classical background.

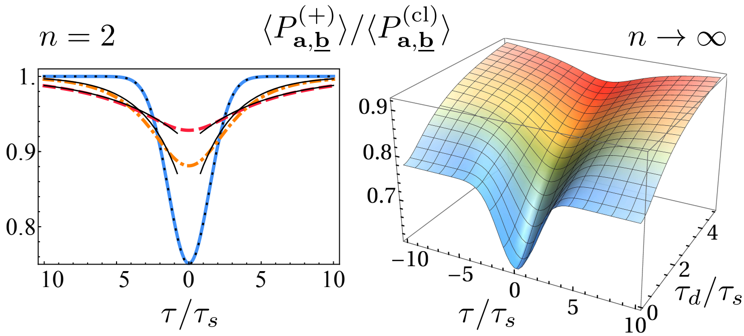

FIG. 1: Suppression of the averaged quantum probability $\langle P^{(+)}\rangle$ with respect to the classical one to see a process where n bosons injected in channels $\mathbf{a}$ leave in different channels $\underline{\mathbf{b}}$ of a cavity. Left: due to chaotic scattering, the usual HOM profile disappears if the delay time τ of the incoming wavepackets of width τ_s gets comparable with the cavity's dweel time τ_d. Right: for two macroscopically occupied incoming wavepackets $n \to \infty$ this suppresion is the BBP, and undergoes a quantum-classical transition as shown in [1].

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Efficient quantum circuits for quantum walks

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Quantum walks have shown much potential as a general framework for developing a new generation of quantum algorithms. These algorithms depend on interference between the multiple paths that are simultaneously traversed by a quantum walker, as well as internal interactions and intrinsic entanglements if more than one quantum walkers are involved. As such, quantum walk has become a subject of intense theoretical and experimental studies. An increasingly pressing challenge is to demonstrate quantum supremacy of such algorithms over classical computation, which requires an efficient physical implementation of the prescribed quantum walks.

In this presentation, we will describe the construction of efficient circuits for implementing quantum walks in both discrete and continuous time on a wide range of undirected and directed graphs. This includes coin-based quantum walks, Szegedy quantum walks, PT-symmetric quantum walks, chiral quantum walks, as well as quantum walks via an open system. We will discuss the design principles for the development of efficient quantum circuits for quantum walks of different types, providing some intuition to how such implementations are derived.

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Experimental implementation of quantum walk on a circle with single photons

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We experimentally implement a quantum walk on a circle in position space. Using a novel arrangement of linear optical elements our experiment realizes clockwise- and counter-clockwise cycling walks for the first time. We show examples of quantum walk on a circle with 3, 4, and 5 nodes respectively. A periodic evolution in a quantum walk on a 3-node circle or 4-node circle is observed and the walker+coin state revives every 8 steps. Whereas for a quantum walk on a 5-node circle, a periodical revival is observed for every 24 steps. Coherent information encoded in the coin state shows the periodic collapse and revival due to the interaction between the coin and walker. The technology to realize clockwise- and counter-clockwise-cycling walks can be expanded to simulate a quantum walk on a circle with arbitrary number nodes.

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Contributed talks

Suitable bases for quantum walks with Wigner coins

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There is an increasing interest in studying quantum walks recently. It is given by the potential application of quantum walks models in many fields regarding physics, information technology and chemistry. Quantum walks started as a theoretical concept describing processes in nature. Subsequently the experimental realizations using trapped atoms and later cold ions and photons were conducted.

We investigate a limit distribution, it is approximative probability distribution for large number of steps, for certain quantum walks. The work is motivated by paper by Miyazaki et al.[1], where authors introduced quantum walk models on a line where the coin is Wigner rotation matrix. Wigner walks are very interesting, since they exhibit trapping feature around the origin for odd dimensions of the coin space.

In [1], the authors derived general formulas for calculation of the limit distribution and showed the exact results for several dimensions with respect to the standard coin space basis. We showed [2] that the total limit distribution can be greatly simplified by a different choice of the basis, which we call optimal. Moreover, the optimal basis also reveals some interesting features that are otherwise hidden. We calculate also the trapping probability at the vicinity of the origin and provide an insight into the construction of the optimal basis for other types of quantum walks.

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Joint measurements and hidden variables models for entangled mixed states

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Entanglement is essential to demonstrate a violation of local realism. One could thus believe that all bipartite entangled states should violate some Bell inequality, for suitable measurements. While this is true for bipartite pure states, it is false for mixed states. This was shown by Werner, who found a class of mixed state that are entangled and yet can still be described using a local hidden variable model [1].

One way of generating a mixed state is to pass a pure state through a quantum channel. One could also regard the hypothetical quantum channel as part of any subsequent measurement procedure. For any measurement we wanted to make, placing a quantum channel in front of the detector defines a new noisy version of this measurement. Hence measurements on a mixed state are equivalent to making different noisy measurements on some pure state. Essentially, one can find an equivalent setup involving a pure state by transferring the noise within the mixed state onto the measurement process.

Using this approach, we prove that a local hidden variable model exists for qubit Werner states if one is able to jointly measure certain noisy measurements. Conversely, we prove that when a suitable hidden variable model exists for qubit Werner states, this implies that the corresponding noisy measurements can be jointly measured. Finally, we extend the results to show that when Alice and Bob make general measurements on any entangled mixed state, a local hidden variable model can be constructed if one can jointly measure a different set of generalized measurements.

The results thus complement existing work that shows that a correspondence between quantum steering an joint measurability [2].

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Decision / function problems based on boson sampling

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The problem of boson sampling amounts to determining the probability distribution for the output of a linear optical network where each input port has either vacuum or a single photon input. Somewhat surprisingly, this problem is difficult, in the sense that there is no known algorithm that scales efficiently with the size of network and number of input modes. In fact, the problem has been shown to be equivalent to that of evaluating the permanent of a matrix.

While it is difficult to classically simulate boson sampling, one could, in principle, determine the answer by performing a quantum optics experiment. An experimental realization of boson sampling in a large network is thus a demonstration that quantum systems can efficiently simulate systems that would be classically intractable. Boson sampling could thus provide strong evidence is support of a so called quantum advantage. We argue, however, that boson sampling might also be useful for decision problems, which occur within cryptography [1]. Central to our work is a method of 'binning' the results, which we claim does not significantly reduce the complexity of classically simulating such boson sampling problems. This claim is based on numerical evidence.

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Posters

Exploring topological phases in a quantum walk exploiting Orbital Angular Momentum of light

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Topological phases of matter have recieved widespread interest from fields like quantum computing, spintronics and metrology [5]. These phases are characterized by global topological order which manifests in phenomena like robust edge states. Quantum walks have proven to be ideal platforms to investigate the fundamental features of topological phases [4]. Here we present a photonic quantum walk which shows general features of one dimensional periodically driven systems with chiral symmetry [3]. In this platform the space of light's Orbital Angular Momentum implements a one dimensional lattice [1][2]. By using spin-orbit coupling effects the position of the photon on this lattice is changed in a way which depends on its polarization. We analize, theoretically and experimentally, the topological feathures of this quantum walk.

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Spread and Entanglement in a One-Dimensional Self-Avoiding Quantum Walk

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Self-avoiding quantum walks aim to avoid stepping back onto previously visited sites, therefore has the potential of spreading faster than ordinary quantum walks. They are applied to problems such as protein folding and percolation. Tuneable self-avoidance is possible by recording the memory of the walker's previous locations and applying a coin operator as a function of memory [1]. This results in an accelerated growth of the spanned Hilbert space. We apply matrix product states formalism [2–4]. to investigate the spread or the walk and the entanglement properties between memory, position and coin spaces.

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Posters

Measuring topological invariants in disordered discrete time quantum walks

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Experimental determination of the invariants associated to the topological phases of materials is a crucial ingredient for applications. In our recent experiment we have demonstrated the measurement of the topological invariants of discrete time quantum walks in one dimension. The setup is the implementation of a proposal [1] based on a scattering arrangement.

We have determined topological invariants for uniform split step quantum walks of various parameters. We have also applied the scheme to disordered quantum walks, indicating in one case the stability and in the other case the occurrence of a phase transition depending on the nature and strength of the applied disorder [2].

The implementation was carried out on the optical time-multiplexing feedback loop with a dynamical control of the quantum coin operator. This feature served as the essential ingredient to perform the required accurate spatial and temporal control of the discrete time quantum walk dynamics [3].

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Topological classification of symmetric walks: steps into the second dimension

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The successful classification of symmetric quantum walks in one lattice dimension [1, 2] naturally calls for generalizations to higher dimensions. The simplest case is given by quantum walks which are translationally invariant in directions parallel to a possible phase boundary. Indeed, this can be treated as a one-dimensional system depending on a parameter, the quasi-momentum in the lateral direction(s). I will describe the results that can be obtained in this way from the classification [2].

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Selective dynamical decoupling for quantum state transfer

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Faithful placement of a quantum state at a prescribed time to a given position on a discrete quantum network is one of the elementary tasks of quantum information processing [1, 2]. Several schemes for perfect state transfer are known. Vast majority of physical systems suffer from imperfections, discrete quantum networks being no exception.

Recently the method of dynamical decoupling has been proposed for suppression of decoherence in two-state quantum systems by Viola and Lloyd. We propose to use this method for imperfect quantum networks known as bent linear qubit chains.

We found several analytic solutions to the basic equation of the selective dynamical decoupling. The equation itself is a result of perturbation theory. We examined the properties of different solutions, their advantages and disadvantages over each other.

The decoupling schemes scale the time necessary for state transfer to take place. Compared to unperturbed network, the systems with the correction algorithm applied take longer to facilitate state transfer.

Based on our numerical simulations of several realistic scenarios, these schemes are able to suppress the unwanted interactions and stabilize the state transfer protocols efficiently.

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Measurement-induced chaos in an iterated Tavis-Cummings scheme

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We propose a cavity QED scheme based on the Tavis-Cummings model to realize a conditional, nonlinear dynamics exhibiting complex chaos in an ensemble of two-level atoms. The atoms interact pairwise with the coherent cavity field, which is subjected to homodyne measurement after the interaction. One member of the pair of atoms is then measured and if it is found in its ground state the other member of the pair is kept, otherwise discarded. The quantum state of the resulting ensemble of atoms is related to the state of the original ensemble via a nonlinear transformation. By iterating this process with the help of an optical conveyor belt, for example, one arrives at complex deterministic chaos, where the evolution of pure quantum states is sensitive to the initial conditions [1].

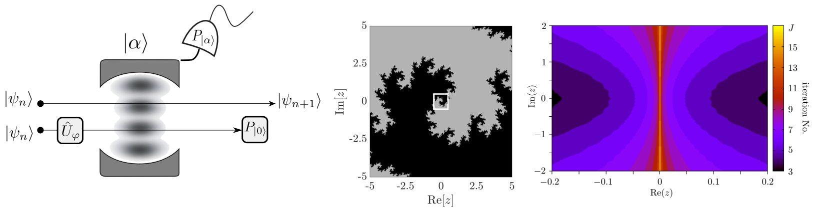

FIG. 1: (left) Sketch of a single step of the scheme. (middle) After iterating the nonlinear map points converge to two fixed points. (right) Number of iterations needed for initially close states to become orthogonal.

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Quantum walks in a magnetic field

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Inspired by the results of the "electric" quantum walks [1], such as revivals, ballistic expansion and Anderson localization, depending on the rationality of the electric field, it is an obvious question whether these conclusions have analogues for magnetic quantum walks [2, 3].

I will present a simulation package for quantum walks in a magnetic field on a 2D lattice, including tools to analyze propagation and spectral properties. Typical results for homogeneous as well as inhomogeneous fields will be discussed.

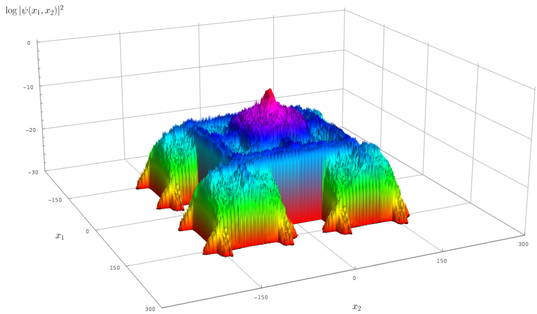

FIG. 1: Logarithmic plot of the spatial probability distribution of a magnetic walk after $t = 400$ time steps. Here, the magnetic field is $\Phi/2\pi = 1/101$ and the initial state is randomly distributed on an sphere centered at the origin with radius 7.

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Gaussian BosonSampling with arbitrary photon numbers

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In recent times, the BosonSampling problem [1] has emerged for scientists as a test bed to explore the computational properties of quantum particles without the need for a universal quantum computer. While the proof-of-principle experiments with few photons have been successfully implemented [2–7], the challenge is to improve the scalability in the realisation. Developing new protocols (i.e. [8, 9]) that retain the complexity of BosonSampling but reduce the experimental effort is a key area of research. To this aim, we present a Gaussian BosonSampling problem with arbitrary photon numbers that relates the sampling probability of a general Gaussian state to the Hafnian of a linear network. We construct a generalised sampling problem analogously to [1] and show an improvement of measurement statistics for the experimental implementation.

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Global Behavior of Finite Quantum Walks

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One dimensional quantum walks in the presence of absorbing boundaries have been studied along a number of directions. In particular, it has been shown in [1] and more thoroughly proved in [2] that absorbing boundaries also reflect quantum information. Such results are limited in scope in that they are only concerned with local absorption probabilities. In this presentation we will prove that the global conditional probability distribution of the one-dimensional finite quantum walk with absorbing boundaries approaches a simple unique limit in the form of a standard trigonometric function. For one-dimensional quantum walks on the circle with no absorbing boundaries, all eigenvectors of the finite quantum walk operator have eigenvalues with modulus 1, so that no stable probability distribution is reached. On smaller timescales, the conditional probability distributions of finite quantum walks phase between modal distributions. Extensions of these results to two-dimensional finite quantum walks with absorbing boundaries are studied computationally using QWSIM software [3].

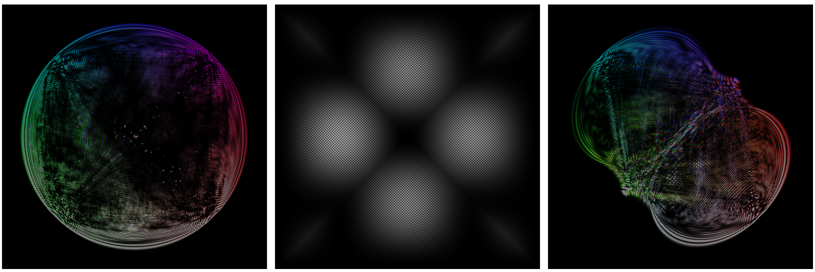

FIG. 1: Two-dimensional finite quantum walks.

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Quantum non-Gaussianity from a large ensemble of single photon emitters

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Quantum attributes of light has been so far related to in-compability with mixtures of coherent states [1]. The progress in quantum optics indicates that this feature do not suffice to witness exotic behavior of light anymore. On the other hand quantum non-Gaussianity is starting to appear as a promising property reflecting interesting states of light suitable for quantum protocols [2]. We introduce hierarchy of criteria of quantum non-Gaussianity and predicts this attribute can be observed even on states of light with high mean number of photons, which undergo realistic imperfections [3]. This contrasts negativity of Wigner function, that is unreachable in experimental platforms with losses below fifty percent.

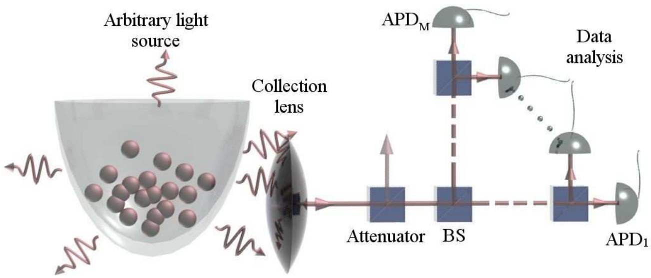

FIG. 1: Set-up for testing quantum non-Gaussianity of light radiated from an ensemble of single photon emitters.

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The Computational Complexity of Multiboson Correlation Interference

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We demonstrate that a computational power beyond any classical capabilities can be achieved in bosonic linear interferometers even with nonidentical photons [1]. This approach overcomes the challenge of generating identical bosons, which so far have been essential in quantum information processing, including the well-known problem of boson sampling [2].

In contrast to the original formulation of boson sampling, we investigate MultiBoson Correlation Sampling, where time-resolved sampling measurements at the interferometer output are performed [3, 4]. Interestingly, even with photons of completely different colors this problem is at least as computationally hard as the original boson sampling problem with identical photons [1].

These results demonstrate the quantum computational supremacy inherent in the fundamental nature of quantum interference [3].

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Quantum walks that interact with graphs

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Using quantum walks as a tool to generate entangled quantum states is not a new idea. However, the literature mostly focuses on entangling the degrees of freedom intrinsic to the quantum walk system, for example, entangling the walker's position degree of freedom and the coin [1], or two motional states of a given walker [2]. In the work on which this talk is based [3], we consider using a quantum walk as a tool for generating entanglement in an external lattice of qubits, by allowing for an interaction between the walker and the qubits on the lattice at each time step.

More explicitly, we consider a discrete time quantum walk which evolves on a graph with a qubit on each of its vertices. At each time step, a controlled-Z operation is performed, with the walker's coin state as control, and the qubit on the walker's current position vertex as the target. By extensive computer simulation, we show that this *interacting quantum walk* is effective in generating multipartite entanglement between the vertex qubits, as well as between the vertex qubits and the walker. We also show that for certain graph structures, the interaction with the quantum walk causes the vertex qubits to be in a cluster state after a short number of time steps. Such states are known to be a resource for measurement based quantum computation [4], suggesting a new application for quantum walks in this context.

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Robust quantum state engineering through coherent localization in biased-coin quantum walks

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We address the performance of a coin-biased quantum walk as a generator for non-classical position states of the walker. We exploit a phenomenon of *coherent localisation* in the position space — resulting from the choice of small values of the coin parameter and assisted by post-selection — to engineer large-size coherent superpositions of distinguishable position states of the walker. The protocol that we design appears to be remarkably robust against both the actual value taken by the coin parameter and strong dephasing-like noise acting on the spatial degree of freedom. We finally illustrate a possible linear-optics implementation of our proposal, suitable for both bulk and integrated-optics platforms.

Analysis of Chaotic Behaviour in Entanglement Purification

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Quantum entanglement is an essential resource for quantum information, computation, and cryptography. The entanglement is fragile and dissipates when the state is transmitted through the environment whence some repairing mechanisms are needed. These processes - purification protocols - use measurement to modify the state in order to restore or improve the entanglement.

One of the recently studied protocols [1, 2] shows exponential sensitiveness to input states, i.e. chaotic behaviour emerges in quantum world in an interesting way. We present an analysis of this particular protocol behaviour considering action of the protocol on special sets of two-qubit states. Special attention is paid to sets of mixed states containing Bell state as an attractor. Theory of iterated complex functions is employed together with numerical analysis to obtain insight into the dynamics of the purification. Besides finding attractors, the structure of the studied sets and their relevance to global dynamics is discussed.

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P o s t e r s

Unifying framework for coined quantum walks with different shift operators

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The definition of a quantum walk consists of two main parts: the Hilbert space describing an actual state of a quantum walker and a generator specifying the time evolution. In order to define quantum walk for any graph with various rules of walker's shifting, we modify both of these.

The discrete time evolution of a quantum walker typically consists of two unitary operators: the coin operator C mixing walker's internal states and the shift operator S which performs walker's shift among vertices. For simple graphs, like line graphs or square lattices, the choice of S is quite natural and thus only variations of the coin operator are usually investigated. Nevertheless, there are always multiple alternatives for the shift operator S and this ambiguity is much more visible and important in more complex graphs. For example, there are multiple choices of the shift operator for a honeycomb lattice leading to dramatically different time evolutions. For systematic analysis of resulting walker's evolution a unifying framework naturally incorporating various shift operators is desired.

The power of this method can be demonstrated on analysis of quantum walks with dynamical bond percolation. It is an open system dynamics with nontrivial and typically rich asymptotic behaviour [1]. We investigate percolated quantum walks on finite honeycomb lattices and show that the choice of the shift operator has a major influence on the asymptotic regime. For example, it determines presence or absence of trapped states.

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Gibbs-like asymptotic states of quantum markov chains

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Quantum markov chains, i.e. iterated sequences of quantum operations, represent a convenient way of time-evolution description of a general open quantum system. Nowadays, quantum markov chains show a great potential in many areas of quantum theory reaching from its very fundamentals to practical applications, i.e. random quantum walks.

Recently, the asymptotic dynamics of a wide class of quantum markov chains on finite dimensional Hilbert space was studied. For this class, it was shown that the asymptotic dynamics is governed by so-called attractor space, which can be derived by solving a set of algebraic equations called attractor equations.

Here we give the relations between the elements of the attractor space (i.e. attractors) and the integrals of motion corresponding to such a quantum markov chain. Next, we show that the asymptotic states of such quantum markov chain can be rewritten in a form, which resembles a well known concept of a generalized Gibbs state. This so-called Gibbs-like states follow a principle, which can be regarded as a generalization of maximal entropy principle.

Quantum walks using superconducting circuit via coherent controlization

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Coherent controlization is a process by which priori unspecified operation on subsystems is coherently conditioned on the state of a control qubit. This process forms an essential part of the constriction of the probability unitaries, which are the building blocks of a flexible quantum walk operator with priori unspecified terms. The practical realization of coherent controlization requires an auxiliary system in addition to the control and target qubits. However, the details of the implementation depend on the nature of the ancilla system and the type of qubit used. Here we show a method that allows coherent controlization in a register of superconducting transmon qubits coupled to an auxiliary microwave cavity [1]. The proposed method is based on the conditioning of the one-qubit rotations on the vacuum state of the cavity, as shown in Fig. 1 for two qubits, and is scalable to larger number of qubits via a nested construction.

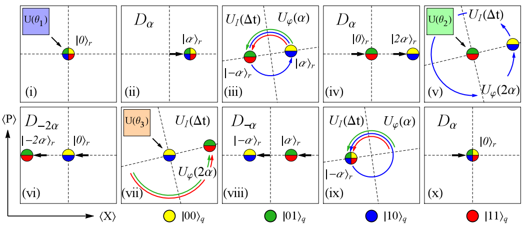

FIG. 1: Two-qubit probability unitary implementation with priory unspecified rotations based on manipulations with the cavity state.

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Controlling and tracking quantum mobile agents

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We aim at utilizing combinatorial game theory for creating methods of controlling and analysing the behaviour of quantum agents in networks. To achieve this we develop and analyse quantum models for two combinatorial games – Magnus-Derek game and Cop-Robbers game.

Using Magnus-Derek game [1, 2] we develop a quantum walk model for exploring a quantum network with a distracted sense of direction. The model enables us to study the optimization strategies and counter-strategies in the situation when one aims at exploring the network. We analyse the behaviour of quantum mobile agents operating with non-adaptive and adaptive strategies which can be employed in this scenario. We introduce the notion of node visiting suitable for analysing quantum superpositions of states by distinguishing between visiting and attaining a position.

On the other hand using Cop-Robbers game [3] we study the scenario of network exploration with the dynamic information about the target location. We focus on one-cop version of the game. We consider the simulation of the classical model in the quantum scenario and we introduce winning conditions appropriate for handling the quantum strategies.

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Fighting dispersion in continuous time quantum walks on graphs

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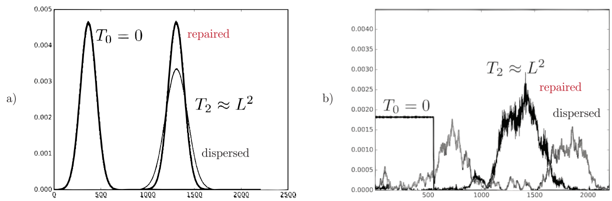
Continuous-time quantum walks (CTQW) on graphs are a basic tool for quantum algorithms [1]. Childs et al. have shown that they are also universal for quantum computing, in a space efficient with multiple wavepackets in a dual-rail encoding with a nonlinear interaction [2]. There, one needs to be careful about the tradeoff between the packet width (momentum precision) and the required computational time/space. The first reason is that individual small subgraphs that the packets scatter on only approximate the desired perfect reflection/transmission, when the momentum is not exactly the desired p_0. Second, moving the packets on long lines between components of the graph introduces dispersion errors.

We introduce a new method for fighting dispersion, resulting in shorter required packets/longer coherence times. The tool is a small anti-dispersion gadget graph, canceling the effects of dispersion on a line to a few orders in $\delta = p - p_0$. The effects of the gadget on Gaussian and rectangular wavepackets for momentum $\pi/4$ are illustrated in the Figure. The packets have width $L \approx 500$. We compare the *dispersed* evolution for time L^2 on a plain cycle of length $5L$, and the *repaired* evolution on a cycle that includes our antidispersion gadgets.



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Adjacent vertices can be hard to find by quantum walks

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Quantum walks are quantum counterparts of classical random walks. They have been useful for designing quantum algorithms that outperform their classical versions for a variety of search problems. Most of the papers, however, consider a search space containing a single marked element only.

We show that if the search space contains more than one marked element, their placement may drastically affect the performance of the search. More specifically, we study search by quantum walks on general graphs and show a wide class of configurations of marked vertices, for which search by quantum walk needs $\Omega(N)$ steps, that is, it has no speed-up over the classical exhaustive search. We refer such configurations of marked vertices as *exceptional configurations*.

We show that any pair of adjacent marked vertices having the same degree d forms an exceptional configuration, for which the probability of finding a marked vertex is limited by const $\cdot\, d/N$. This covers any pair of adjacent vertices in regular graphs — d-dimensional lattices, hypercube, etc. — as well as some pairs of adjacent vertices for non-regular graphs.

Next, we analyze three near-by marked vertex case, i.e. marked triangle, and prove that any three mutually connected marked vertices form an exceptional configuration. After that, we extend the analysis and show that any k-clique of marked vertices forms an exceptional configuration. Additionally, we formulate general conditions for a configuration of marked vertices to be exceptional.

Our results greatly extend the class of known exceptional configurations; until now the only known such configuration was the "diagonal construction" by [AR08].

[AR08] A. Ambainis, A. Rivosh. Quantum walks with multiple or moving marked locations. *Proceedings of SOFSEM'08*, 485-496, 2008.

Experimentally probing measurement-induced transition between two regimes of recurrence

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The measurement process plays a crucial role in quantum mechanics as it interrupts the unitary evolution of a state. The consequences are apparent when investigating the return probability (Polya-number) of a particle in a Hadamard walk on the line [1–4]: Depending on whether the evolution is restarted or continued after the measurement, two different regimes of recurrence can be observed. We investigate both cases experimentally for the first time by introducing sinks in a time-multiplexed quantum walk setup using a fast-switching electro-optic modulator (EOM). Monitoring the evolution of the walker over twenty steps reveals the fundamental differences of the two cases as predicted by theory: In case the experiment is restarted after a measurement, the Polya-number will gradually approach unity. In contrast, continuing the experiment after a measurement yields an asymptotic value of the Polya-number of $2/\pi$, which will be reached in good approximation after only four steps and then remain almost constant for the following steps.

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Quantum walks in synthetic gauge fields with 3D integrated photonics

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There is great interest in designing photonic devices capable of disorder-resistant transport and information processing. In this work we propose to exploit 3D integrated photonic circuits in order to realize 2D discrete-time quantum walks in a background synthetic gauge field. The gauge fields are generated by introducing the appropriate phase shifts between waveguides. Polarization-independent phase shifts lead to an Abelian or magnetic field, a case we describe in detail. We find that, in the disordered case, the magnetic field enhances transport due to the presence of topologically protected chiral edge states which do not localize. Polarization-dependent phase shifts lead to effective non-Abelian gauge fields, which could be adopted to realize Rashba-like quantum walks with spin-orbit coupling. Our work introduces a flexible platform for the experimental study of multi-particle quantum walks in the presence of synthetic gauge fields, which paves the way towards topologically robust transport of many-body states of photons.

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Atom-light interaction for quantum simulation of a nonlinear potential

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We propose a way of implementing a class of nonlinear operations by sequential application of conditional gates based on atom-light interactions such as Jaynes-Cummings and Rabi interactions and projective measurements. We demonstrate performance of the approach on the example of the cubic nonlinearity by several different ways in which the full nonlinear operation can be decomposed into sequences of the individual gates and we compare their performance. It is shown that an high strength nonlinear gate such as cubic gate can be built asymptotically at optimal success probability. This scheme brings many advantages over the previously proposed all-optical methods and can be applied in several available experimental platforms, such as cavity quantum electrodynamics, trapped ions, and others.

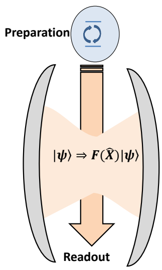

FIG. 1: A cartoon scheme for achieving a unit optical operator.

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Validating multiphoton interference on three-dimensional laser-written quantum circuits

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Photonic quantum walks represent a promising platform for both fundamental research and more practical tasks in quantum simulation and quantum information, thanks to the inherent advantages of using photons as information carriers and to the high-level fabrication technologies. At the core of the advantages of this quantum framework lies the plethora of phenomena arising from multiphoton interference in linear optical interferometers. It is thus indispensable to be able to efficiently and reliably assess this genuine interference, in order to validate the operation of these new quantum devices. Distinctive quantum features have been predicted indeed for photonic states injected into Sylvester and Fourier interferometers, where specific measurable quantities allow to estimate the goodness of a single-photon source. Moreover, such quantities can be efficiently measured on interferometers of larger dimensions, as required in regimes where classical simulations can no longer validate the operation of a quantum device in a reasonable time. Here we develop a scalable approach for the implementation of Sylvester and quantum Fourier transformations on integrated photonic circuits, exploiting three-dimensional architectures enabled by the femtosecond laser writing fabrication technique. The experimental results demonstrate genuine multiphoton interference along the quantum walks, offering a powerful and general tool for the diagnostic of any single-photon source.

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Topological invariants and quantized displacement in quantum walks with decay

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In this talk we discuss a family of discrete time quantum walks in one dimension where the walker can exit the system at the end of each step. We find that if the quantum walk operator possesses chiral symmetry the expectation value of the displacement of the walker before it leaves the system is quantized to integer values given by a topological invariant of the walk - independent of, e.g., the exit probability. This is analogous to the behaviour of continuous time lattice systems with decaying sites studied by Rudner and Levitov.[1] We show analytic proof and numerical evidence of this topological quantization for a number of different quantum walk protocols and discuss its robustness against decoherence and disorder.

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[1] M. S. Rudner, L. S. Levitov, *Phys. Rev. Lett.*, **102**, (2009)

Posters

On possible algorithmic applications of exceptional configurations in quantum walks

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We recently discovered several exceptional configurations of marked locations in quantum walks that resulted in a significally different behaviour of quantum walk compared with what is expected in typical case (e.g. [NRQ15] and [NRE15]).

In this poster we present an ongoing research on possible algorithmic applications of these effects. In most cases, we do not obtain a better algorithmic complexity that beats best known results, but we demonstrate a different approach for constructing quantum algorithms with the use of quantum walks

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P o s t e r s

Dirac emulation of a particle-antiparticle polarizer on a tight binding chain

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Working with a tight-binding periodic chain of potentials we emulate a $1+1$ dimensional Dirac-like equation. In it we design a polarizer interaction which separates positive and negative energy components without the use of external fields. The effect is engineered using hopping amplitudes and on-site potentials. A description of the polarizer potential relying on a generalized Foldy-Wouthuysen transformation beyond Dirac points is given. Our results are verified numerically by means of wave-packet evolution, including an analysis of Zitterbewegung on the chain. We analyze the robustness of the potential by reducing its size and number of couplings with the intention of finding a compact-support version which can be made experimentally feasible.

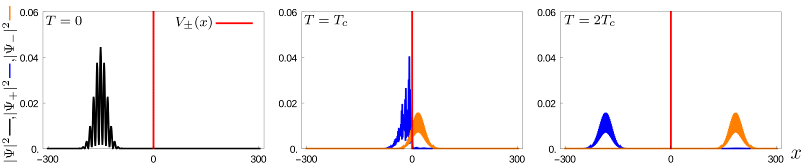

FIG. 1: Evolution of a wave packet going through the polarizer. The dynamics are presented in three steps; the first image corresponds to times before the collision. The second image shows the interference caused by the collision and finally, the third image shows how both components have been spatially separated and now travel in opposite directions.

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Simulation of channels and dynamical maps

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The evolution of an open quantum system[1] can be described by a dynamical map $\Phi(t)$, where for all times $\Phi(t)$ is a quantum channel. Such a dynamical map is usually described in terms of a master equation. Alternatively we can stroboscopically simulate these dynamical maps via collision models. There the system under consideration, ρ, repeatedly collides via unitary interaction with its environment ε. Under stroboscopic simulation[2] of dynamical map $\Phi(t)$ we understand that $\Phi(n\Delta)[\rho] = \Phi_n[\rho]$, where Φ_n is a channel produced by the collision model after n collisions. We analyze strengths and weaknesses

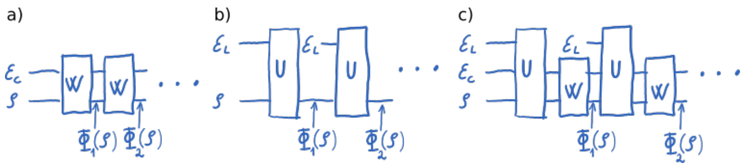

FIG. 1: Three different collision models

of three different collision models (see fig. 1), depending on the type of environment. *Collision model for coherent evolution:* System always interacts with the same environment, initially in state ε_C, see fig 1 a). This model naturaly stroboscopically simulates dynamical maps $\Phi(t)[\rho] = \mathrm{Tr}_{\mathrm{env}}[e^{iHt}(\varepsilon_c \otimes \rho)e^{-iHt}]$. *Collision model for Markovian evolution:* System always interacts with a fresh copy of environmental state ε_L, see fig. 1 b). This model naturaly stroboscopically simulates Markovian dynamical maps $\Phi_t[\rho] = e^{Lt}$. *Combined collision model:* This model combines the features of both models above.

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Hyper quantum walks

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The quantum walk model can be described as a composition of two operators that take block operator form with respect to two different decompositions of the computational basis into sets of basis states. The main restriction in the model is that the decomposition corresponding to the edges of the graph always consists of sets with two basis states. We aim at loosening this restriction in order to develop a generalized quantum walk model suitable for hypergraphs.

Definition 1 *A* hypergraph H *is a pair* (V, E)*, where* V *is a set of vertices and* E *is a set of edges. In this case we have* $E \subseteq 2^V$*.*

Definition 2 *We define a quantum walk on a hyper-graph* (V, E) *as a composition of two unitary operators:* U^V *and* U^E *on a space* $\mathcal{X} = \mathrm{span}(\{|v, e\rangle : e \in E \wedge v \in e\})$ *where*

$$U^V = \sum_{v \in V} C_v, U^E = \sum_{e \in E} S_e, \tag{1}$$

where $C_v \in L(\mathrm{span}(\{|v, e\rangle\}_{v \in e}))$ *and* $C_e \in L(\mathrm{span}(\{|v, e\rangle\}_{v \in e}))$*.*

Using above definitions we show that standard quantum walks models are special cases of the hyper quantum walk. In particular,

Fact 1 *Staggered quantum walks [1] are hyper quantum walks.*

Also the fact that both operators U^V, U^E are defined exactly the same way allows us to harness the symmetry

Fact 2 *In hyper quantum walks framework one can successfully search on a* $2/3-$*dimensional grid using the same coin and edge operators.*

Additionally, generalized edges can model walks on directed graphs.

Fact 3 *In hyper quantum walks framework one can define unitary walks on directed graphs (with directed closed loops).*

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Neighborhood Dependent Quantum Walks

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Discrete time Quantum Walks (QW) with particle and site history dependence show promise in lattice search. We generalize a simple site history model [1], with a memory qubit at each site steering particle direction, to allow dependence on history of the neighborhing qubits. This provides an avenue to richer walk strategies. Many previous history dependent QW, including the model in [1], were shown in [2] to be single-particle sectors of Quantum Lattice Gas Automata (QLGA). Neighborhood dependent QW, however, can only be realized as singleparticle sectors of more general Quantum Cellular Automata (QCA). These, therefore, have a range of dynamically more complex behaviors. We demonstrate some of their interesting walk regimes through simulations.

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Posters

Dynamical and thermodynamical control of open quantum Brownian motion

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Open quantum Brownian motion was introduced as a new type of quantum Brownian motion for Brownian particles with internal quantum degrees of freedom. Recently, an example of the microscopic derivation of open quantum Brownian motion has been presented [1]. The microscopic derivation allows relating the dynamical properties of open Quantum Brownian motion and the thermodynamical properties of the environment. In the present work, we study the possibility of control of the external degrees of freedom of the "walker" (position) by manipulating the internal one, e.g. spin, polarization, occupation numbers. To this end we consider a free quantum Brownian walker with N-dimensional internal degrees of freedom interacting with a decoherent environment. In this case, the connection between dynamics of the "walker" and thermodynamical parameters of the system is established.

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Perfect state transfer by means of discrete-time quantum walk search algorithms on highly symmetric graphs

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Perfect state transfer between two marked vertices of a graph by means of a discrete-time quantum walk is analyzed. We consider the quantum walk search algorithm with two marked vertices, sender and receiver. It is shown by explicit calculation that, for the coined quantum walks on a star graph and a complete graph with self-loops, perfect state transfer between the sender and receiver vertex is achieved for an arbitrary number of vertices N in $O(\sqrt{N})$ steps of the walk. Finally, we show that Szegedy's walk with queries on a complete graph allows for state transfer with unit fidelity in the limit of large N.

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Posters

Translation-invariant quantum walks with symmetries

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[2] *Department of Mathematics, University of California, Berkeley, USA*
[3] *Departamento de Matemática Aplicada & IUMA, Universidad de Zaragoza, Spain*
[4] *Department of Mathematical Sciences, University of Copenhagen, Denmark*

The classification of quantum walks with discrete symmetries [1, 2] leads to the prediction of perturbatively stable eigenstates localized at the boundary of two different bulk-systems. Usually the bulk systems are taken to be translationally invariant, so it is necessary to develop efficient ways for evaluating the indices [1] for translationally invariant walks.

I will describe the index formulas for all symmetry types of the "ten-fold way", which are given in terms of the band structure of the walk over the Brillouin zone. The band structure is not required to be differentiable, merely continuous. However, in the differentiable case there are formulas equal to or reminiscent of Berry phases.

It is also shown that these invariants are complete, i.e., that two walks with the same index can be deformed into each other in the class of translationally invariant symmetric walks.

[1] *Bulk-Edge Correspondence of one-dimensional Quantum Walks.* C. Cedzich, F. A. Grünbaum, C. Stahl, L. Velázquez, A. H. Werner and R. F. Werner. Journal of Physics A: Mathematical and Theoretical 49(21): 21LT01, 2016. arXiv:1502.02592.

[2] *A topological classification of one-dimensional symmetric quantum walks.* C. Cedzich, T. Geib, F. A. Grünbaum, C. Stahl, L. Velázquez, A. H. Werner and R. F. Werner. In preparation.

Optimal discrimination of pure states in the single-qubit regime

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Quantum state discrimination between single qubits is a central and fundamental problem in the field of quantum information; it has relevance in quantum key distribution and quantum metrology [1], and it also provides insights into problems in the multiple-qubit regime [2].

We consider the problem of minimum-error quantum state discrimination for single-qubit pure states. We find a way to use the Helstrom conditions constructively, thereby solving the problem analytically for any number of arbitrary signal states with arbitrary prior probabilities. This method also reveals that when the number of signal states is smaller than five, the solution given - and hence the optimal measurement strategy - is unique, with a caveat.

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Coherent transport over an explosive percolation lattice

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We investigate coherent transport over a finite square lattice in which the growth of bond percolation clusters are subjected to an Achlioptas type selection process [1, 2], i.e., whether a bond will be placed or not depends on the sizes of clusters it may potentially connect. Different than the standard percolation where the growth of discrete clusters are completely random, clusters in this case grow in correlation with one another. We utilize continuous-time quantum walks and continuous-time random walks for modeling coherent and incoherent transport processes, respectively, in case of absorptions [3, 4]. We show that certain values of correlation strength, if chosen in a way to suppress the growth of the largest cluster which actually results in an explosive growth later on, may lead to more efficient transports than in the case of standard percolation, satisfied that certain fraction of total possible bonds are present in the lattice [5]. In this case transport efficiency obeys a power law in the vicinity of bond fraction where effective transport begins. It turns out that the higher correlation strengths may also reduce the efficiency as well. We also compare our results with those of the incoherent transport and examine the spreading of eigenstates of corresponding structures. We demonstrate that structural differences of discrete clusters due to different correlations result in different localization properties.

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Chiral Quantum Walks

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Chiral quantum walks are models of continuous-time quantum walks which explicitly break time-reversal symmetry. In this poster, we show how breaking time-reversal symmetry of the unitary dynamics of such walks can enable directional control, enhancement, and suppression of quantum transport [1]. Examples ranging from exciton transport to complex networks are presented. We also report on an experimental implementation of a simple chiral quantum walk [2].

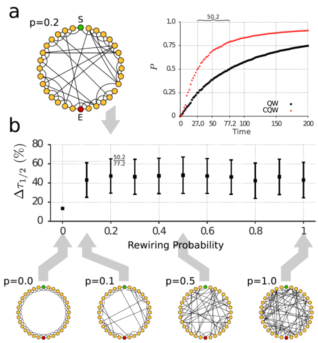

FIG. 1: Transport enhancement of the chiral quantum walk with respect to its non-chiral counterpart in randomly generated Watts-Strogatz networks: in (a) we depict the transport probability for rewiring probability $p = 0.2$, (b) shows the enhancement of half arrival time for different values of p.

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