Centre for Quantum Information and Communication

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Mémoires de Fin d'Etudes pour l'année académique 2018-19

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Thème général : Sciences de l'Information Quantique

Etudiants concernés : Ir. Physique ou Ms. Science Physique
Ir. Informatique ou Ms. Science Informatique

Pré-requis : Tous les sujets nécessitent des connaissances de base de mécanique quantique, de théorie des probabilités et d'algèbre linéaire.

Note : Certains sujets sont plus proches de la physique quantique (optique quantique, communication et crytpographie quantique), d'autres de l'informatique quantique (algorithmes quantiques, complexité quantique) ou bien encore des fondements de la physique quantique.

Langue : Français ou anglais en fonction de la personne qui supervise le mémoire (par souci d'uniformité, tous les sujets sont présentés en anglais ci-dessous)

1) Continuous majorization relations in quantum phase space
Supervisor : Nicolas Cerf

The theory of majorization provides a way of comparing probability distributions in terms of disorder. Whenever A majorizes B, it means that A is more ordered than B (consequently, iA has a lower entropy than B). Majorization has also recently turned out to have many applications in quantum information theory, for example in relation with quantum entanglement. This thesis will investigate a much less explored continuous-variable counterpart of majorization theory and its role for comparing Wigner distributions in quantum phase space (x,p). We have good reasons to anticipate that it is a powerful tool in order to address a conjectured entropic uncertainty relations for position and momentum variables (the vacuum state continuously majorizes all other states with a positive Wigner function).

2) Multi-photon quantum interferences in multimode linear optics circuits
Supervisor : Nicolas Cerf

There has recently been a regained interest in multi-photon multimode quantum interferences because better understanding them may be a key for implementing future quantum technologies with photonic integrated devices. The celebrated Hong-Ou-Mandel effect is the paradigm of such an interferometric suppression effect that is due to the quantum indistinguishability of two photons (being bosons, the trajectory where they are both reflected at a beam splitter interferes destructively with the trajectory where they both cross the beam splitter, which gives rise to the so-called « bunching » effect). This thesis will explore the extension of quantum interference for more than two (indistinguishable) photons based on a newly developed framework exploiting the generating function of the matrix elements of Gaussian unitaries in Fock basis.

3) Quantum cryptography with coherent states of light
Supervisor : Nicolas Cerf

The most common quantum cryptographic protocols enable us to distribute a secret key between two authorized parties, the security of the key solely relying on quantum physics (no computational hypotheses are needed unlike in most classical cryptographic protocols). For example, the impossibility of measuring conjugate quadratures of the electromagnetic field (behaving as x and p, hence obeying the uncertainty principle) can be exploited to build a quantum key distribution protocol. This thesis will explore new quantum cryptographic schemes aimed, for example, at authentication, which would be based on quantum parameter estimation. Quantum estimation theory focuses on finding the optimal measurement to estimate the parameters encoded in a quantum state. The quantum Cramer-Rao bound, which is a key tool in this context, has recently been applied to the quadratures of N coherent states of light in a general setting. The objective of the thesis is to build a quantum cryptographic scheme inspired from such a multi-parameter estimation of correlated quadratures.

4) Quantum sorting under partial information
Supervisor : Jérémie Roland

Sorting by comparison is probably one of the most fundamental tasks in algorithmics: given n distinct numbers $x_1, x_2, ..., x_n$, the task is to sort them by performing comparisons of the type "$x_i < x_j$?". Classical sorting algorithms can solve this problem using O(n log n) comparisons, and this is known to be optimal. It was also proved that quantum algorithms provide no speed-up for this problem.

Sorting under partial information is a natural variation of this problem where some of the comparison outcomes are already known, that is, some partial order is already given. In this case, the optimal number of comparisons required by a classical algorithm scales as the logarithm of the number of permutations compatible with the given partial order. An important question is whether quantum algorithms can provide a speed-up for some partial orders. It is conjectured that this is not the case, but this conjecture could only be proved for some restricted classes of partial orders. The goal of this thesis will be to study how to extend this result to larger classes of partial orders.

5) Adiabatic quantum computing via Markovian dynamics
Supervisors : Jérémie Roland & Ognyan Oreshkov

Quantum computers promise to solve certain problems more efficiently than classical computers. The standard model of quantum computation works by applying a sequence of quantum gates (or unitary operations) on a set of qubits. An alternative model, which is equivalent in computational power, is Adiabatic Quantum Computing. In this model, the quantum computer is initially prepared in the ground state of a specific Hamiltonian, and the computation works by slowly turning off this Hamiltonian while at the same time turning on another one whose ground state encodes the solution of the computational problem. If this interpolation is performed slowly enough, the quantum adiabatic theorem guarantees that the initial ground state will be transformed into the final ground state.

Recently, the adiabatic theorem was extended from the case of closed quantum system undergoing Hamiltonian dynamics to the case of open quantum systems undergoing dissipative Markovian dynamics, and it was shown that this more general type of adiabatic dynamics can be used to perform various tasks. This project will explore the possibility to perform adiabatic quantum computation via adiabatic Markovian dynamics.

6) Applications of the quantum linear systems algorithm
Supervisor : Jérémie Roland

Algorithms to solve linear systems find applications in a wide range of fields. Quantum algorithms for solving linear systems outperform its classical counterpart and in some regimes, fare exponentially better. This project would aim at exploring the applications of this quantum algorithm to various problems and also at techniques that help in extracting useful information from its output. This would also involve analyzing existing techniques by which quantum computers can simulate quantum systems faster than any classical computer. Successful completion of this project will lead to improving existing quantum algorithms for data-fitting and to better quantum algorithms for estimating the time required by a quantum walker to hit a given set of vertices in a graph.

7) Computational limits on thermodynamical processes
Supervisor: Raul Garcia-Patron

Starting from basic principles, the laws of thermodynamics allows us to quantify and put limits on the efficiency of heat transfer processes, engines or chemical reactions among other processes. More recently people has been interested in studying thermodynamics at the nano-regime, which combines quantum mechanics with thermodynamics. In this work we want to study how thinking about a thermodynamical processes as a computational process bring new and additional constraint to this processes on top of those brought by the laws of thermodynamics.

8) Quantum simulators for vibronic chemistry processes
Supervisors: Raul Garcia-Patron & Leonardo Novo

Quantum simulators may change the way we simulate physical systems in the future. It may allow us to simulate large-size systems, such as large-size molecules or high-temperature semiconductors, which may not be accessible with current classical computational resources. There has been important proposal to simulate the fermionic component of molecules but there has been nearly no work addressing the vibronic aspect of molecules. In this project we intend to explore the use of optical quantum simulators to solve problems related to the vibration of molecules, such as the vibrational spectra of large-size molecules.

9) Processes with indefinite causal structure in quantum theory
Supervisor : Ognyan Oreshkov

It was recently found that quantum theory permits higher-order processes in which the order of the operations performed by separate parties is not definite, similarly to the way the position or momentum of a quantum particle may be indefinite. This thesis will explore the possibility of realizing this phenomenon in practice, as well as the novel information-processing capabilities it allows.

10) New symmetry transformations through post-selection
Supervisor : Ognyan Oreshkov

The concept of symmetry is fundamental for our understanding of the laws of physics. It was recently shown that reconciling the probabilistic laws of quantum theory with the requirement for time-reversal symmetry requires a generalized formulation of quantum theory, which implies the possibility for more general symmetry transformations than those previously believed possible. This thesis will explore the possibility of realizing this new type of symmetry transformations through post-selection.