QSS13 - Olivier Pfister - Questions & Answers

Olivier Pfister

William D. Phillips: Could you say a little bit about how error correction works with one-way QC with cluster states (how do you get logical qubits out of physical ones, and different levels of concatenation, for example) and how it is done with continuous variables.

OLIVIER: I replied to this and outlined it in the talk: GKP ancillas [PRA 64 012310 (2001) https://journals.aps.org/pra/abstract/10.1103/PhysRevA.64.012310 can be attached to the cluster graph by CZ gates and used as ancillas. In addition, higher dimensional (eg 3D) cluster states can be used to implement topological protection identical to Kitaev's surface code [Raussendorf et al. (2006), see talk].

William D. Phillips: The idea that 20 dB of squeezing can lead to 10^{-6} error rate seems magical. Can you say more about how this is possible?

OLIVIER: Yes, achieving 6 orders of magnitude error reduction with only two orders of magnitude of quantum noise reduction might sound unconvincing but this is not a linear-gain, analog process. It relies on a binary, qubit encoding of continuous-variable quantum information and is, in particular, highly efficient at correcting small drifts of continuous variables (|q> going to |q+dq>), which the Gottesman-Kitaev-Preskill code was specifically designed to do [PRA 64 012310 (2001) https://journals.aps.org/pra/abstract/10.1103/PhysRevA.64.012310. Nick Menicucci showed that GKP states generated with no more than 20.5 dB of squeezing were able to reach the 10^{-6} error rate [PRL 112 120504 (2014) https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.120504]. More recently, Kosuke Fukui found that architectures that use GKP states as qubit encodings can need as low as 10 dB squeezing [PRX 8 021054 (2018) https://journals.aps.org/prx/abstract/10.1103/PhysRevX.8.021054].

Yu-Ting Chen: Could you please elaborate on how squeezed state can be explained classically? Can the explanation be applied to Dicke states (maximally squeezed)? Thanks. (I was thinking about atomic states)

OLIVIER: Squeezing is nonclassical. But it can be described with ad hoc additions to classical electrodynamics, such as additional noise terms (whose physical origin can remain unspecified). However, such ad hoc additions to classical physics, such as Bell's local hidden variables, are ruled out by nonpositive Wigner functions, which only quantum physics can describe correctly. Dicke states are W states and are described by spin variables rather than position-momentum variables. Spin squeezing is a valid concept, of course, but it is physically different from quadrature squeezing, even though the two can be related in the Holstein-Primakoff picture for large spins, as Eugene Polzik's work has shown.

Abdul Kareim Obeid: Firstly, what topics would you recommend for newcomers into quantum computational research coming from studies of foundational concepts of quantum theory? Especially for the purpose of contributing to the scientific community i.e. particularly, are there any open conjectures or cutting-edge problems that could warrant intensive usage of quantum probability calculus?

OLIVIER: I'm not an expert in quantum information theory but I seem to remember a mention that finding quantum algorithms might be, in and of itself, a hard problem… Certainly, Shor's algorithm has been the long-cited answer to integer factorization and, of more interest to physicists, quantum simulation, first proposed by Feynman, promises exponential speedup in principle. This is problem-dependent as well, though. Physics has been very good at solving hard problems using approximations, which tends to push the complexity bar toward large-scale systems.

Yu-Ting Chen: It sounds like you can create high dimensional space. would it be possible to generate a space that is like a Möbius strip? Would that be useful for quantum computation?

William D. Phillips: It sounds like you can create high dimensional space. would it be possible to generate a space that is like a Möbius strip? Would that be useful for quantum computation?

OLIVIER: Not sure who to credit for another excellent question. I guess this would refer to whether the cluster state graph could be shaped as a Möbius strip. In principle, a Möbius strip cluster state is quite doable in a bottom-up construction, by linking individual qubits with CZ gates. I'm not sure whether such a graph would have any use in one-way quantum computing, for which the graph is embedded in a plane. It's possible Raussendorf or Briegel investigated this.

whitedaniel53: Is there any room for topological photonic phenomena to help with perhaps the stability of such systems?

OLIVIER: This was answered in the talk: fascinating question, but only if topological photonics can be made low-loss.

David Nadlinger: What is the biggest limitation for the number of modes in current experimental platforms?

OLIVIER: This was answered in the talk: phase-matching bandwidth in the frequency domain (still alows 10^4-10^5 modes), infinite in the time domain as long as the experiment is stable.

Aggie Branczyk: Hi Olivier. I imagine the freq modes are narrow, which would make them long in time. Does that cause any issues eg a slow "clock rate" for the computation? Or is this just not an issue in one-way QC?

OLIVIER: Hi Aggie, great question and spot on! The clock rate is really limited by the mode spacing: you want to be able to tell them apart. Then they can be made broader (lower-finesse cavity) to speed up the clock rate. Sort cavities (microresonators) lead to very separated modes, possibly at the expense of their number if phasematching bandwidth doesn't increase as well, but that can be engineered. And there's the temporal degree of freedom.

Xueyue Zhang: What's the major source of errors in this quantum computing scheme?

OLIVIER: This was answered in the talk: optical loss, by far. But it can be made very small.

Elizabeth Goldschmidt: Can you also make one-way quantum repeater states with the cluster state geometries you are considering?

OLIVIER: This was answered in the talk: Yes! But it wouldn't be quite as useful for CVs for which EPR measurements are deterministic, unlike Bell measurements for qubits.

David Nadlinger: When fibres are used in these experiments (and integrated optics in the future), is dispersion a big problem for cleanly manipulating these states? Or can that easily be compensated at the source?

OLIVIER: We use single-mode fibers for the TES PNR detector. In our squeezing experiments, dispersion plays practically no role because the modes are only 1 GHz apart. In integrated optics, dispersion is very important and has to be engineered correctly, which is doable.

Valentina Parigi: Could you compare a little more the TES based tomography with the standard quantum homodyne tomography? In homodyne tomography you can deconvolve losses as well.

OLIVIER: Yes, good question. Comparing w/ quadrature measurements, I didn't say the most important part: the PNR tomography methods require no heavily numerical reconstruction using inverse Radon transform or maximum likelihood algorithms. In fact, our method even beats machine learning methods that were recently published in Optica by Lvovsky's Moscow group. So, the advantage here is different.

In fact, I actually didn't believe the PNR method could be used with a 50/50 beamsplitter and also be made insensitive to calibrated losses but my students convinced me that an original ideal of Ulf Leonhardt's, later exploited by Christine and Ian, can be applied even more efficiently when one does generalized overlap tomography.

Valentina Parigi: You say that the scalability problem is solved while coherence is not, in photonics I would say that the opposite is true, especially because the scalability of non-Gaussian operation is not solved…

OLIVIER: Well, I meant Gaussian cluster-state scalability is solved. Entirely. Theoretically, decoherence has been solved but not yet in the lab. Then you need at most N GKP states for N qumodes (if you QEC the thing to death, and why the heck not?). Once we generate GKP states this is a linear overhead. In the time domain, it's instataneously available by fusing GKP to cluster lattice. I think it can also be done on chip.