Quantum Information Processing

Tue/Thu 2:45-4:00pm, Rockefeller 230

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Office Hour: Wed 2-3pm

Course Texts: Mermin “Quantum Computer Science”, Aaronson notes, Nielsen/Chuang “QC and QI”
Quantum Computing in the NISQ era and beyond

John Preskill

Noisy Intermediate-Scale Quantum (NISQ) technology will be available in the near future. Quantum computers with 50–100 qubits may be able to perform tasks which surpass the capabilities of today’s classical digital computers, but noise in quantum gates will limit the size of quantum circuits that can be executed reliably. NISQ devices will be useful tools for exploring many-body quantum physics, and may have other useful applications, but the 100-qubit quantum computer will not change the world right away — we should regard it as a significant step toward the more powerful quantum technologies of the future. Quantum technologists should continue to strive for more accurate quantum gates and, eventually, fully fault-tolerant quantum computing.

https://arxiv.org/abs/1801.00862
Repeated Quantum Error Detection in a Surface Code

Christian Kraglund Andersen, Ants Remm, Stefania Lazar, Sebastian Krinner, Nathan Lacroix, Graham J. Norris, Mihai Gabureac, Christopher Eichler, Andreas Wallraff

The realization of quantum error correction is an essential ingredient for reaching the full potential of fault-tolerant universal quantum computation. Using a range of different schemes, logical qubits can be redundantly encoded in a set of physical qubits. One such scalable approach is based on the surface code. Here we experimentally implement its smallest viable instance, capable of repeatedly detecting any single error using seven superconducting qubits, four data qubits and three ancilla qubits. Using high-fidelity ancilla-based stabilizer measurements we initialize the cardinal states of the encoded logical qubit with an average logical fidelity of 96.1%. We then repeatedly check for errors using the stabilizer readout and observe that the logical quantum state is preserved with a lifetime and coherence time longer than those of any of the constituent qubits when no errors are detected. Our demonstration of error detection with its resulting enhancement of the conditioned logical qubit coherence times in a 7-qubit surface code is an important step indicating a promising route towards the realization of quantum error correction in the surface code.
The Physics of Quantum Information

John Preskill

Rapid ongoing progress in quantum information science makes this an apt time for a Solvay Conference focused on The Physics of Quantum Information. Here I review four intertwined themes encompassed by this topic: Quantum computer science, quantum hardware, quantum matter, and quantum gravity. Though the time scale for broad practical impact of quantum computation is still uncertain, in the near future we can expect noteworthy progress toward scalable fault-tolerant quantum computing, and discoveries enabled by programmable quantum simulators. In the longer term, controlling highly complex quantum matter will open the door to profound scientific advances and powerful new technologies.

Subjects: Quantum Physics (quant-ph); Strongly Correlated Electrons (cond-mat.str-el); High Energy Physics – Theory (hep-th)
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(or arXiv:2208.08064v1 [quant-ph] for this version)
https://doi.org/10.48550/arXiv.2208.08064
 Suppressing quantum errors by scaling a surface code logical qubit


Practical quantum computing will require error rates that are well below what is achievable with physical qubits. Quantum error correction offers a path to algorithmically-relevant error rates by encoding logical qubits within many physical qubits, where increasing the number of physical qubits enhances protection against physical errors. However, introducing more qubits also increases the number of error sources, so the density of errors must be sufficiently low in order for logical performance to improve with increasing code size. Here, we report the measurement of logical qubit performance scaling across multiple code sizes, and demonstrate that our system of superconducting qubits has sufficient performance to overcome the additional errors from increasing qubit number. We find our distance–5 surface code logical qubit modestly outperforms an ensemble of distance–3 logical qubits on average, both in terms of logical error probability over 25 cycles and logical error per cycle (2.914% ± 0.016% compared to 3.028% ± 0.023%). To investigate damaging, low–probability error sources, we run a distance–25 repetition code and observe a 1.7 × 10^-6 logical error per round floor set by a single high-energy event (1.6 × 10^-7 when excluding this event). We are able to accurately model our experiment, and from this model we can extract error budgets that highlight the biggest challenges for future systems. These results mark the first experimental demonstration where quantum error correction begins to improve performance with increasing qubit number, illuminating the path to reaching the logical error rates required for computation.
InAs–Al Hybrid Devices Passing the Topological Gap Protocol


We present measurements and simulations of semiconductor–superconductor heterostructure devices that are consistent with the observation of topological superconductivity and Majorana zero modes. The devices are fabricated from high-mobility two-dimensional electron gases in which quasi-one-dimensional wires are defined by electrostatic gates. These devices enable measurements of local and non-local transport properties and have been optimized via extensive simulations for robustness against non-uniformity and disorder. Our main result is that several devices, fabricated according to the design's engineering specifications, have passed the topological gap protocol defined in Pikulin {\textit{et al.}} [arXiv:2103.12217]. This protocol is a stringent test composed of a sequence of three-terminal local and non-local transport measurements performed while varying the magnetic field, semiconductor electron density, and junction transparencies. Passing the protocol indicates a high probability of detection of a topological phase hosting Majorana zero modes. Our experimental results are consistent with a quantum phase transition into a topological superconducting phase that extends over several hundred millitesla in magnetic field and several millivolts in gate voltage, corresponding to approximately one hundred micro-electronvolts in Zeeman energy and chemical potential in the semiconducting wire. These regions feature a closing and re-opening of the bulk gap, with simultaneous zero-bias conductance peaks at both ends of the devices that withstand changes in the junction transparencies. The measured maximum topological gaps in our devices are 20–30 μeV. This demonstration is a prerequisite for experiments involving fusion and braiding of Majorana zero modes.
Quantum Computing Hype is Bad for Science

Victor Galitski
Professor, Joint Quantum Institute, Univ. of Maryland (all views are my own)
Published Jul 16, 2021

Unless you’ve been living under a rock, you’ve probably noticed the recent proliferation of striking headlines about revolutionary developments in quantum science and technology, amazing recent successes of world-changing quantum startups, and huge government and private investment in quantum computing to capitalize on the imminent second quantum revolution. Being a bit familiar with quantum physics and having recently spent some time trying to understand how the new “quantum industry” operates, I am getting more and more concerned that this recent quantum computing (QC) commotion is a self-perpetuating “intellectual” Ponzi scheme, a bubble, which may sooner or later crash and take legitimate research and innovation efforts down with it. To be sure there are gems in this "quantum technology space," but they are far and few between. Most ventures are questionable at best and are kept afloat by a huge & growing influx of funding, which is not based on any rational thinking or reasonable expectations.

It appears that the US government is pouring money into "quantum" because China seems to be doing the same. China is doing it presumably to compete with the US and EU, all racing to build a QC. The same "logic" probably applies to the major Big Tech companies (company G does it because company M does it and vice versa). Certain deeptech VCs want "quantum" in their portfolio not so much because they believe it will actually work (whatever "work" even means in this context), but to spice up their portfolio with cutting edge quantum stuff. It is often a purely PR move to lure unsuspecting investors, who have no idea what's going on, but don't want to miss out on the world-changing QC efforts.

This creates an unhealthy situation where there is too much hype in a niche nascent field, where the hype is based on unrealistic expectations. Crazy headlines abound: "quantum computing will solve global warming," "Quantum science and industry," etc etc. These statements are not all, they are not even wishful thinking. The number of hype promises advantage over classical computation, is just a "global warming" for sure). More importantly, exactly zero demonstrated in practice so far and the gap between what currently available hardware is huge, and it's not just a qualitative challenges with scaling up, which will likely

Arguably, there have been successes in "quantum simulation problem with definition: What does “quantum simulation" mostly involved doing the same experiments, quantum decades anyway, but renaming the observed phenomenon way (for example, one can title a paper with identical e.g., Mott insulator with [whatever]” or “Quantum simulation quantum computer”). The former will result in an unreviewed journal, the latter will be welcomed by a high-impact science news coverage and potential investment into the revolution.
On the verge
Ben Schumacher introduced the idea of a bit of quantum information in a paper presented in 1992.

In my paper I present a “quantum coding theorem” that is analogous to the noiseless coding theorem of Shannon. The theorem and its proof have some novel features:

1. The classical binary digit is replaced with a quantum two-state system, such as the spin of the atom. These “qubits” are the fundamental unit of quantum information.

2. A measure of the fidelity of a quantum coding scheme is introduced. A code has high fidelity if it preserves the Hilbert space relations between signal states.
appearances of qubit in arXiv, dec'94-Jun'22

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#docs/month (total=65225)