# Institut für Experimentalphysik

**Leopold-Franzens-Universität Innsbruck**

Dr. Thomas Monz

Technikerstraße 25
A-6020 Innsbruck


Innsbruck, am 07.02.19

**Letter on Standards, Metrics, and Benchmarks in Quantum Technologies**

To whom it may concern,

There are currently efforts both in Europe as well as in the US to agree on standards, metrics and benchmarks concerning quantum technologies. The goal seems to facilitate the communication of the status-quo, highlight progress in the field, provide means to compare approaches and architectures, and ease joint development with commercial partners. These goals all deserve our support. However, **quantum technologies, to a very large degree, are still fundamental research. Metrics and standardization may misdirect these efforts to the detriment of the progress in quantum technologies.**

In the following potential risks by certain benchmarks in the field of quantum computation shall be discussed to motivate our hesitant stance of metrics and benchmarks:

- **Number of qubits:** Recent press releases from Google, Intel and IBM presented qubit numbers on the order of 50 to 70 qubits. However, the performance of these qubits has not been disclosed, the connectivity could be very limited … it's not even clear, that the chips work at all. Peer-reviewed work of these entities is still focusing on 10-20 qubits. The ion-trap community might be tempted to load a large string of ions and then claim that they outperform IBM, Google and others, again without any performance indication – a scenario confirmed by a recent press release from IonQ stating 160 qubits. Essentially, the number of qubits, as single figure of merit, does not describe the system capabilities at all.
- **Gate fidelity:** The field of fault-tolerant quantum computing relies heavily on high-performance quantum gate operations. However, while these research efforts are important, they might stall progress on controlling an increasing number of qubits.
- **Randomized benchmarking:** Certain routines of benchmarking provide average gate fidelities, also in a scalable fashion (for instance cycle benchmarking). However, it's unclear whether a single fidelity number, again, provides any meaningful information about the scalability or predictability of the system.
- **Quantum volume:** This measure has been proposed by IBM to combine number of qubits, gate fidelity and connectivity in a system. However, the computation of this measure has not been standardized yet.
- **Number of entangled qubits:** Creating entanglement is a demonstration of high-fidelity control of a quantum system. Increasing the number of entangled qubit is thus a straight-forward benchmark for quantum control. However, creating a specific state does not mean that the system is suitable for universal computation.

- **Markovianity and cross-talk:** Ideally the performance of combined components ought to be predictable from the performance of its constituents. For this, the system ought to be markovian and ideally have no cross-talk. These characteristics, however, have little connection to the number of qubits or gate fidelity … and yet are essential if we want to scale up towards larger quantum systems. If markovianity and cross-talk would be the figure of merit, one could simply create two entirely independent qubits to show that there is neither cross-talk nor any non-markovian behaviour. But such a system wouldn't be able to compute anything.

Note that pushing these benchmarks would nevertheless not provide any motivation for customers to become interested in quantum technologies – because benchmarking is independent from applications. For this reason, we in Innsbruck prefer to pursue a holistic approach to "actually get quantum computing done". Our realisations force us to constantly increase the number of qubits, improve the system performance, extend control capabilities, … but most importantly: realize and demonstrate novel applications of quantum technologies.

This should not mean that realizing a set of algorithms is sufficient as a benchmark. Realizing applications of quantum technologies provides motivation to further push our field. But demonstrations do not necessarily provide an understanding about the system performance, how the performance scales with system size, why the performance might deviate from predictions based on the performance of constituents, how to overcome limitations, etc. As such, the **demonstration of novel applications needs to be complemented by quantum characterisation, verification and validation methods.**

I believe that the field of quantum technologies is too young yet to push towards standardisation. We will need standards, but likely only 3-5 years down the line. Metrics can mislead, benchmarks may be too system specific. More importantly, it is likely that none of these benchmarks and metrics provide an incentive to actually push the field of quantum technologies forward. Unsuitable benchmarks might rather misdirect efforts to increase a particular number only for the sake of a press-release (something we have seen recently in the field of quantum computing)

In summary, there are very few and very selected quantum demonstrators – in Europe and on a global scale. These units are all subject to research and development efforts, constantly changed and altered. **There are too many open questions and problems for quantum technologies right now, to start to restrict the evaluation of progress in research and development to a few metrics and benchmarks.**

Sincerely yours,

Thomas Monz