Speed versus temperature for energy-efficient quantum computing: learning from existing spin-qubits

Robert Whitney (1)
Konstantina Koteva (2,3), Alexia Auffèves (3).

(1) Université Grenoble Alpes & CNRS (LPMMC) Grenoble, France.
(2) Université Grenoble Alpes & CNRS (Inst. Néel), Grenoble, France.
(3) MajuLab, International Joint Research Unit CNRS, Sorbonne Université, NUS & NTU, Singapore.

robert.whitney@grenoble.cnrs.fr

As quantum technologies advance, it will be important to have methods to minimize their resource consumption without impact-ing their performance. Here, we show how to use experimental data to build and optimize a system-level (full-stack) model of a quantum computer, within the *Metric-Noise-Resource approach* [1]; a model that contains everything from the *qubits* to the *end-user*. We use it to explore the interplay of qubit temperature and gate-operation speed, while maintaining a target fidelity for the noisy qubit circuit to perform a desired algorithm. The resource minimized is the energy consumption of the algorithm.

Conclusion: While a given target fidelity can be achieved by either (i) calculating slowly with cold qubits, or (ii) calculating fast with hot qubits, we show that *both* come at a large energy cost. Minimal energy con-sumption is at a sweet-spot of intermediate speed and temperature [2].

Details: We demonstrate the approach [2] by building a system-level model of using experimental data for silicon spin-qubits taken from recent publications, such as [3]. We use the model to optimize a small NISQ computer containing up-to 20 spin-qubits. We thereby find the speed-temperature sweet-spot for such a NISQ computer. We show that this sweet-spot depends on:

- **Algorithm factors:** the number of qubits needed by the algorithm.
- **Microscopic hardware factors:** type of noise felt by the qubits.
- **Macroscopic hardware factors:** type of cryogenics and wiring.

We consider various examples of these, to find which are most suitable for energy-efficient quantum computing.

References

[1] M. Fellous-Asiani, J.H. Chai, Y. Thonnart, H.K. Ng, R.S. Whitney, A. Auffèves, PRX Quantum **4**, 040319 (2023)

[2] K. Koteva, A. Auffèves & R.S. Whitney, *in preparation* (2025).

[3] J.Y. Huang et al. High-fidelity spin qubit operation and algorithmic initialization above 1 K, Nature 627, 772 (2024).

Figure 1