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

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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. 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].

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 NISQ computer containing a few dozen 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.

[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., Nature 627, 772 (2024).

Theme

Theme 1. Energy advantage and cost of quantum technology

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