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Quantum Computing: Coping with Underpowered, Inaccurate, but Astonishing Quantum Computers

Cristian S. Calude[1]

Why quantum computing?

Gordon E. Moore's 1965 law is the empirical observation stating that the number of transistors on a chip doubles about every two years. This prediction has defined the trajectory of computing technology and, in some ways, it marked the progress itself.

In early 1990s talks about the eventual decay of Moore's law lead to the question: what happens when Moore's Law (inevitably?) ends? Among various possibilities, the advance of new models of computation, called *unconventional,*[2] was one. At that time there was a widespread belief that the P vs. NP problem – currently still open – will be solved in the negative before the end of the century. This motivated the need to find fast algorithms to solve NP problems, a computational challenge unlikely, if not impossible, to succeed using Turing machines. Even more daring, could it be possible to design new models of computation capable of transgressing Turing's barrier? Quantum computing, invented by P. l Benioff and Y. I. Manin in 1980 and R. Feynman in 1982, offered a possible path to answer both questions. In 1985 D. Deutsch quantised the universal Turing machine.[3] The quantum algorithms designed by P. Shor in 1994[4] and L. Grover in 1996[5] have been land-mark results that made quantum computing a bright beacon in computer science and led to a surge of theoretical and experimental results.

What is quantum computing?

Classical computers store and process information using binary states called bits. Quantum computers use quantum bits, or qubits, for the same purpose. Bits are fictional mathematical objects which are implemented in computers by hardware-bits, physical systems – like electrical voltage or current pulse – which can be in two different states. Similarly, qubits are mathematical objects which can be physically "created" in different ways, for example with superconductivity. Hardware-bits are robust at room temperature, but hardware-qubits must be kept very cold as any heat in the system can introduce errors. This is the reason why quantum computers operate at temperatures close to absolute zero.

Rather than having a definite position, unmeasured qubits are in a mixed "superposition," similar to a flipping coin in the air before it lands with head or tail. After measure, the qubit is in one of two distinct states. Qubits can have strange properties: some qubits are entangled with others, meaning the measurements performed on them can be perfectly correlated. Superposition is not a specific feature of quantum mechanics, but entanglement has no counter part in classical mechanics. These features can be exploited to build quantum computers which are inherently parallel, hence the hope (belief) that some quantum algorithms could solve problems like predicting multiple particle interactions in chemical reactions faster than classical algorithms complex mathematical. Quantum algorithms are probabilistic and give the correct answer with high probability; the probability of failure can be decreased by repeating the algorithm.

A new wave of ambitious industry-led research programmes in quantum computing – led by D-Wave Systems, Lockheed Martin, Google, IBM, Microsoft, Honeywell, IonQ and others – has emerged and, with it, a sense of high optimism has spread within both industry and academia; unprecedented funding has been pledged for quantum projects.

Models of quantum computing and the state of the art

The *circuit (gate) model* is the most popular model of quantum computing: quantum algorithms are built from a small set of quantum gates.[6] The younger *adiabatic quantum computing* relies on the adiabatic theorem to do calculations[7] and the D-Wave series of machines uses this model. J. Preskill, from California Institute of Technology, called current quantum computers "noisy, intermediate-scale quantum devices": noisy because qubits cannot be adequately controlled and intermediate-scale due to their reduced number of qubits. *The question is to figure out how to get the best from them.*

Quantum computers are notoriously difficult to compare. IBM *quantum volume* is a metric that measures the performance of a quantum computer operating with quantum gates, by aggregating into a single number several features, including the number of qubits, gate and measurement errors, crosstalk and connectivity. Theoretically, the higher the quantum volume, the more complex problems a quantum computer could solve. IBM has achieved a volume of 64 in a 27-qubit system (August 2020). The company IonQ, reported a "32 perfect qubits with low gate errors" (2 October 2020) and claimed to be the most powerful quantum computer; it expects to reach a quantum volume of 4,000,000. D-Wave Advantage has 5,000+ qubits and a 15-way qubit connectivity (29 September 2020). D-Wave Systems asserts that their quantum computing platform handles problems with 1 million variables.

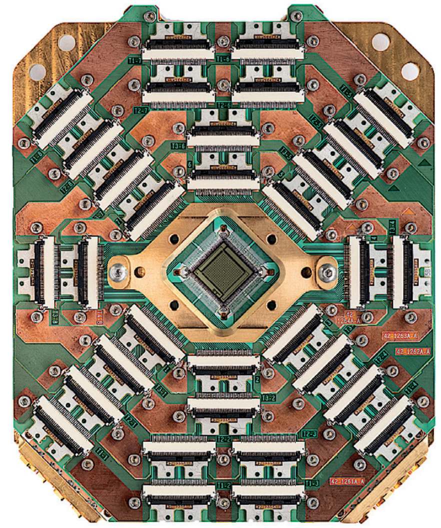

Fig. 1. D-wave-advantage-chip.
https://tinyurl.com/y5pz7cx5

Fig. 2. IonQ 32 perfect qubits.
https://tinyurl.com/yyzw6s5e

Quantum speedup and quantum computational supremacy

It seems that to run an accurate classical simulation of a quantum system one must know a lot about the system before the simulation is started. Manin[8] and Feynman[9] have argued that a quantum computer might not need to have so much knowledge. This line of reasoning seemingly inspired Deutsch[10] to postulate that *computational devices based on quantum mechanics will be computationally superior compared to digital computers.* A spectacular support for this postulate came from Shor's 1994 polynomial factoring quantum algorithm[11] in spite of the fact that the problem whether factoring is classically solvable in polynomial time was, and still is, open. The same situation holds for Deutsch-Jozsa algorithm and various others in the "black-box" paradigm. In contrast, Grover's quantum algorithm for "inverting a function" *provably achieves a polynomial speedup over any classical algorithm*.

The syntagma "quantum supremacy" was coined and discussed by J. Preskill in his Rapporteur talk at the 25th *Solvay Conference on Physics* (2011):[12]

> *"We therefore hope to hasten the onset of the era of quantum supremacy, when we will be able to perform tasks with controlled quantum systems going beyond what can be achieved with ordinary digital computers."*

Various claims about achieving quantum computing supremacy failed. On 23-24 October 2019, a Google team published in *Nature*[13] a paper announcing the experimental realisation of quantum supremacy with a programmable machine with 53 qubits that "*takes about 200 seconds to sample one instance of a quantum circuit a million times – our benchmarks currently indicate that the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years. This dramatic increase in speed compared to all known classical algorithms is an experimental realization of quantum supremacy for this specific computational task, heralding a much-anticipated computing paradigm.*" Almost simultaneously, an IBM team posted on the archive[14] a paper showing that "*… an ideal simulation of the same task can be performed on a classical system in 2.5 days and with far greater fidelity.*" Simultaneously, *Nature* published also an anonymous editorial[15] including the following significant sentence: "*As the world digests this achievement – including the claim that some quantum computational tasks are beyond supercomputers – it is too early to say whether supremacy represents a new dawn for information technology.*" As of 15th October 2020, the dilemma was yet not resolved.

Would quantum computing make classical computing obsolete?

The discussion about quantum supremacy suggests a misleading comparison between

classical and quantum computing. If a quantum computer can outdo **any** classical computer on one problem, we have quantum supremacy, even if classical computers could be at least as good as quantum ones in solving many (most?) other problems. *Quantum supremacy, if achieved, won't make classical computing obsolete*. A hybrid approach combining quantum and classical computing could be a better strategy in solving some (many) difficult problems.[16]
Many important theoretical and experimental results have been obtained, so the field captured the interest and imagination of the large public and media, and not surprisingly, unfounded claims about the power of quantum computing and its applications have proliferated.

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A promising perspective in *searching for information.* "Horizon 2020"

Marcin Sobieszczanski

Navigation as a metaphor. Navigation is not only one of the biggest factors for the extent of culture, but also a cognitive achievement, constantly varying, which the field of travel/transportation shares with domain of the knowledge acquisition. The Californian anthropologist Edwin Hutchins[1] makes the cruising activity, held on the basis of the Bristish neuroscientist David Marr's theory of vision, the central axis of his theory of culture and communication. In this same perspective, we further assume that the cognitive models successfully applying to the situation of the visual wandering and acting in geographical space, can be, mutatis mutandis, a common epistemological basis for the search about the information in the individual immersive computerised environments and in the networks connecting multiple devices of this type.[2] In addition, these models remain valid both in the case of modal media with visual dominance and for multimodal media.

Wandering in the environment currently has three types of modelling:

- The modelling of neural processing of the retinal image from real scenes, by the neuronal cells in the visual cortex, and the Anterior Inferotemporal Cortex (AIT) and Inferotemporal Cortex (PIT).[3]
- The modelling of enactive dimension in the process of vision, combining research on the neurophysiology of vision, the cognitive praxis of active extraction of the environmental information from the stream of the retinal image, during the process of upholding of the programmed path (the *cap*) and the guidance comportments.[4]
- The modelling of various environmental affordances in terms of 3D rendering of real environments.[5]

Specifically, with reference to the work passed in 2009 by joint team of Boston University, Department of Cognitive and Neural Systems and the Center for Adaptive Systems / Center of Excellence for Learning in Education, Science and Technology,[6] we see as main axis the common research on the *immersive interface* and *networking architecture*, the American psychologist James Gibson's inspired models,[7] commonly used in navigation systems, especially in the situations where environmental information from natural scenes, striking the moving subject, is rich and structured.

"Warren, Kay, Zosh, Duchon, and Sahuc (2001)[8] have shown that humans can make use of both strategies and suggest that, in featureless environments where heading is hard to estimate, egocentric goal position information is used, but in richer environments, heading is used."[9]

Three types of models are used in this framework:

- Differential motion models,[10]
- Decomposition models,[11]
- Template models.[12]

Transposing models

But to translate these results valuable for the individual subject that is immerged in a real or artificial visual scene, in the terms of "navigation" in information networks, it must have a vision of the networking architectures that is both: spatial and cognitive. Indeed, these architectures, as they were already considered in the pioneering work of the physicist and mathematician Paul Baran,[13] are not only the "eloquent furnishings" of geometric figures.
They are schematic representations of different conditions of collective access to the knowledge of the object with a *floating* location. They make explicit, in each place of the relational tissue, when the object of knowledge is there, the informative possibilities available to the individual subject from its epistemological scope and referred to the presence of the co-agents with the same "interest." The