Yet Another Briefly Introductory Overview On Quantum Computing

Gustavo A. Bezerra (Koruja)
`https://gustavowl.github.io/`
gustavowl@lcc.ufrn.br

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Introduction

Motivation

- Nature is described by the laws of Quantum Mechanics;
  - Quantum Mechanics for modelling system;
  - Classical vs Quantum;
- Computer components' size limitation;
  - Moore's Law;
  - Physical limit;
  - Quantum phenomena.

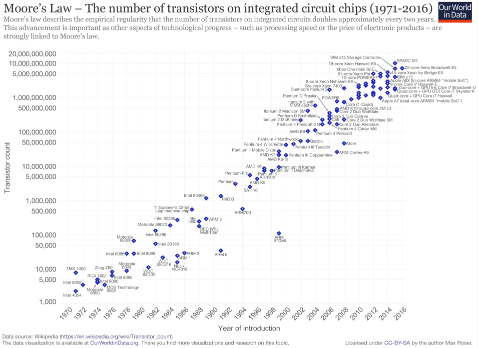

Figure 1: Graphic illustrating Moore's law.
Image downloaded from https://en.wikipedia.org/wiki/Moore%27s_law on March 15, 2019.

History - The Beginning

- 80's;
    - Solid theoretical basis [1] [2] [3] [4];
- From Science to Companies;
- News;
    - Superficial explanation;
    - Advantages highlighted;
    - Problems not mentioned;
    - Reader concludes: Quantum Computing will save the World!

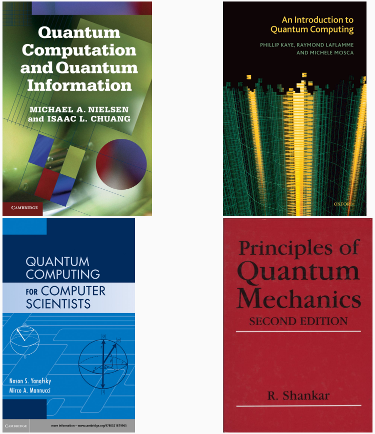

Figure 2: Recommended books.

Meta Frame

- Talk objective: destroy the idea of "Perfect" Computing.

What’s Going On?

A Bit of Information

- Computers process information (Information Technology);
- Information is physical;
- Classical computer information: *bit*;
- From circuits to higher levels of abstraction.

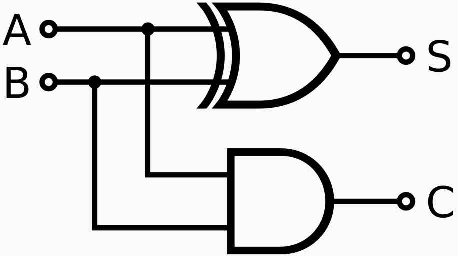

Figure 3: Half adder circuit.
Image downloaded from `https://en.wikipedia.org/wiki/Adder_(electronics)` on March 15, 2019.

A Qubit of Information

- Computers process information (Information Technology);
- Information is physical;
- Quantum computer information: *qubit* (**Qu**antum **bit**);
- From circuits to no level of abstraction;
- Back to assembly good old days.

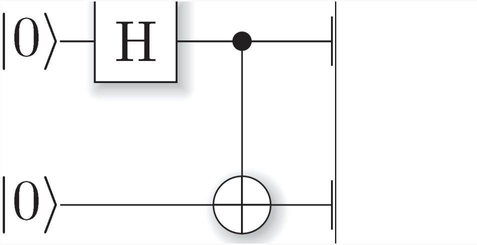

Figure 4: Quantum circuit to generate a Bell state.

Image downloaded from `https://en.wikipedia.org/wiki/Bell_state` on March 15, 2019.

Companies

- Companies own Quantum Computers;
  - Around 50 companies;
  - IBM;
  - Google;
  - D-Wave;
- Why?
  - Costly;
  - Engineering challenge;
  - Qubits are unstable;
  - Avoid interactions;
  - Extreme conditions: $\frac{1}{10}$ K;

Companies - IBM

- 50 Qubits;
- IBM-Q Experience (https://www.research.ibm.com/ibm-q/);
- Qiskit.

Figure 5: IBM's Quantum Computer.
Image downloaded from https://www.technologyreview.com/s/609451/ibm-raises-the-bar-with-a-50-qubit-quantum-computer/ on March 14, 2019.

Companies - Google

- Claimed 72 Qubits;
- No news ever since.

Figure 6: Google's Quantum Processor.
Image downloaded from `https://www.technologyreview.com/s/610274/google-thinks-its-close-to-quantum-supremacy-heres-what-that-really-means/` on March 14, 2019.

Companies - D-Wave

- 2048 qubits;
- Specific purpose.

Figure 7: D-Wave's 2000Q.
Image downloaded from `https://www.dwavesys.com/d-wave-two-system` on March 15, 2019.

Companies

- Why are companies interested?
  - Money;
  - To accelerate;
  - Though costly, some Quantum Algorithms are faster than classical;
  - Quantum Supremacy;
- Quantum Computers will probably be hybrid;
- Quantum Computers occupy a lot of space...

Doesn't it look familiar?

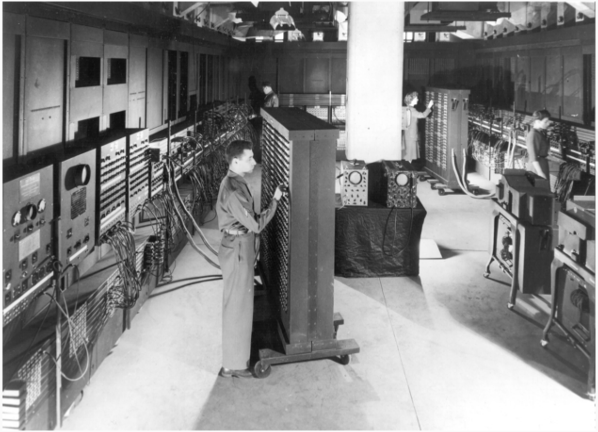

Figure 8: ENIAC.
Image downloaded from `https://en.m.wikipedia.org/wiki/ENIAC` on March 14, 2019.

Beware of Hype Cycle!

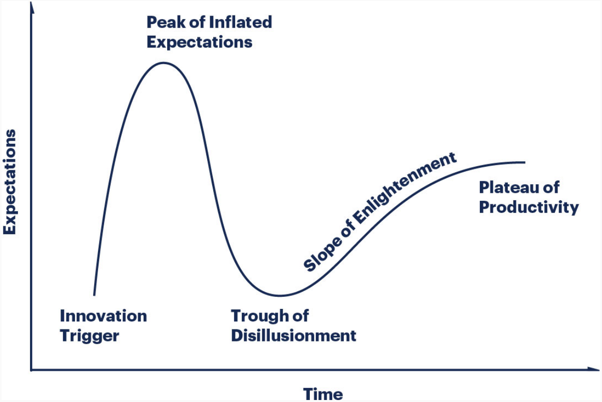

Figure 9: The Hype Cycle.

Image downloaded from `https://www.gartner.com/en/research/methodologies/gartner-hype-cycle` on March 14, 2019.

Scratching The Surface of Quantum Algorithms

Scratching The Surface of Quantum Algorithms

- Parallelism and Quantum Parallelism;
- Quantum superposition and Schrödinger's cat;
- There is *no* perfect analogy;
- The best way to understand Quantum Mechanics is...

Mathematics!

- Linear Algebra time!

4.6.3 Equations 2.208 and 2.209

When I firstly read these equations I thought there was a possibility that an extra explanation would be necessary. This thought raised, most likely, because I was unaccustomed to Tensor Product Properties and the Reduced Density Operator.

Using $|AR\rangle$ as defined in Equation 2.207:

$$|AR\rangle\langle AR| = \left(\sum_i \sqrt{p_i}\,|i^A\rangle\,|i^R\rangle\right)\left(\sum_j \sqrt{p_j}\,\langle j^A|\,\langle j^R|\right) \tag{130}$$

$$= \left(\sum_i \sqrt{p_i}\,|i^A\rangle \otimes |i^R\rangle\right)\left(\sum_j \sqrt{p_j}\,\langle j^A| \otimes \langle j^R|\right) \tag{131}$$

$$= \sum_{ij} \sqrt{p_i p_j}(\ |i^A\rangle \otimes |i^R\rangle\ )(\ \langle j^A| \otimes \langle j^R|\ ) \tag{132}$$

Then, by applying the properties as similarly defined in Equation 2.46:

$$\sum_{ij} \sqrt{p_i p_j}(\ |i^A\rangle \otimes |i^R\rangle\ )(\ \langle j^A| \otimes \langle j^R|\ ) = \sum_{ij} \sqrt{p_i p_j}\,|i^A\rangle\langle j^A| \otimes |i^R\rangle\langle j^R| \tag{133}$$

Therefore, using the definition of the Reduced Density Operator (Equation 2.178):

$$tr_R(|AR\rangle\langle AR|) = tr_R\left(\sum_{ij} \sqrt{p_i p_j}\,|i^A\rangle\langle j^A| \otimes |i^R\rangle\langle j^R|\right) \tag{134}$$

$$= \sum_{ij} \sqrt{p_i p_j}\,|i^A\rangle\langle j^A|\,tr(|i^R\rangle\langle j^R|) \tag{135}$$

Figure 10: Snippet of Quommentaries.

Image extracted from `https://github.com/gustavowl/quommentaries` on March 15, 2019.

Double Slit Experiment - Try To Keep It “Simple"

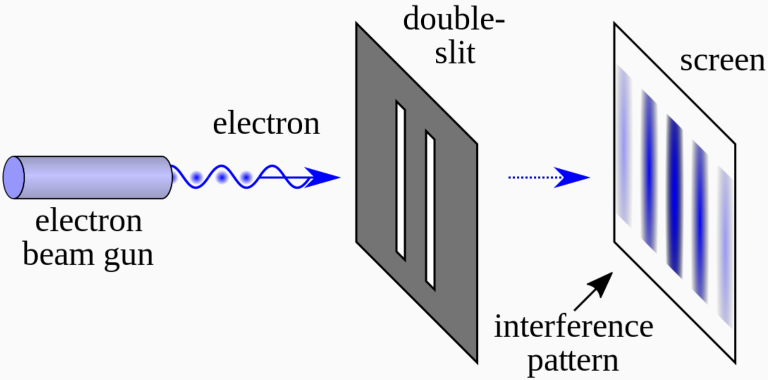

Figure 11: Double slit experiment.
Image downloaded from `https://en.wikipedia.org/wiki/Double-slit_experiment` on March 15, 2019.

An Outer Space Analogy

- Two alien friends: Nawibo, and Odeerg;
- North or South Pole;
  - Nawibo: relative position;
  - Odeerg: Poles.

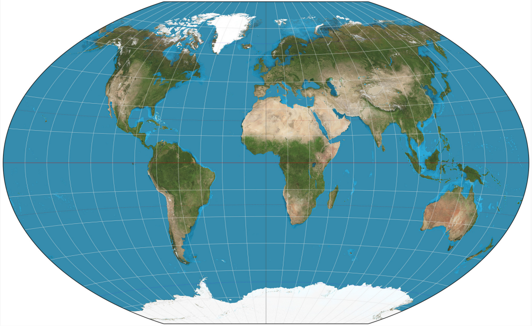

Figure 12: World Map.
Image downloaded from `https://en.wikipedia.org/wiki/World_map` on March 15, 2019.

Bloch Sphere

- Nawibo describes a state;
- Odeerg measures a state;
- Qubit as a vector, $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$, where $\alpha, \beta \in \mathbb{C}$, and $|\alpha|^2 + |\beta|^2 = 1$;
- Qubit as a point on the Bloch sphere, $|\psi\rangle = cos\frac{\theta}{2}|0\rangle + e^{i\varphi}sin\frac{\theta}{2}|1\rangle$, where $\theta \in [0, \pi]$, and $\varphi \in [0, 2\pi)$;
- Schrödinger's cat.

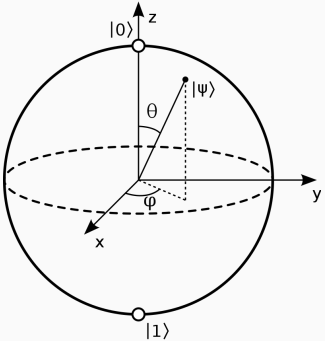

Figure 13: Qubit representation on a Bloch sphere.

Image downloaded from `https://en.wikipedia.org/wiki/Bloch_sphere` on March 15, 2019.

Confused? Do It Yourself

- First chapter of *An introduction to Quantum Computing* by Kaye, Laflamme and Mosca [2];
- Mach–Zehnder interferometer;
  - Why complex numbers are necessary.

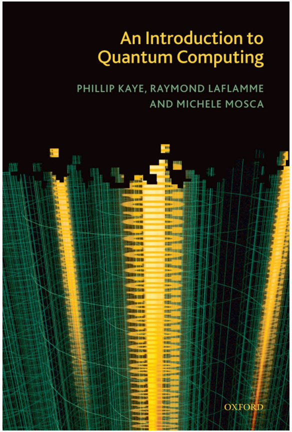

Figure 14: An Introduction to Quantum Computing's book cover.
Image downloaded from `https://books.google.com.br/` on March 15, 2019.

Back To Quantum Parallelism

- Use superposition to compute all possible values at once;
- $|\psi\rangle = \frac{|0\rangle+|1\rangle}{\sqrt{2}}$ (equatorial line);
- Apply the desired operations;
- Verify the results;
    - Verify = measure;
    - Information loss;
    - Workaround.

Conclusion

Conclusion

- Hype Cycle;
  - Get ready for disappointment;
  - Unpredictable future;
- Quantum Computing is difficult;
  - Strong Mathematical basis required;
  - Steep learning curve;
  - Develop a Quantum Algorithm is challenging;
  - It is hard to debug.

References

- M. A. Nielsen and I. Chuang, "Quantum computation and quantum information," 2002.
- P. Kaye, R. Laflamme, M. Mosca, *et al.*, *An introduction to quantum computing*. **Oxford University Press, 2007.**
- N. S. Yanofsky and M. A. Mannucci, *Quantum computing for computer scientists*. **Cambridge University Press, 2008.**
- R. Shankar, *Principles of quantum mechanics*. **Springer Science & Business Media, 2012.**

Questions?

- **Questions?**
- More info;
  - Blog: $|\psi\rangle$ence $|\varphi\rangle$ction;
  - **E-mail: gustavowl@lcc.ufrn.br**;
  - Github: gustavowl;
  - **Website: https://gustavowl.github.io/**.