High Speed Computing with Clustered and Quantum Computers

M. A. Robson[1]

LASACS Department
Liberal Arts and Science Academy

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What Is Quantum Computing?

Quantum computing covers many concepts, but it is important to first start with classical computing.

Classical Information

In a classical computer it stores information as a 1 or a 0 in what is called a bit.

Some Common Gates

NAND, NOR, AND, OR, XOR $\rightarrow$ Complex structures such as ALUs and data storage.

$$\mathrm{A} \;\text{—}\; \boxed{NOT} \;\text{—}\; \bar{A}$$

Circuit Complexity

In circuits it is important to cover the complexity required to achieve certain goals. Complexity is classified in Big O Notation.

Additionally, we can classify these further into P, NP, NP-complete, etc.

Time Complexity Example

A loop of N elements has a time complexity of $\mathcal{O}(N)$.

Theorem 1.0

Any NP complete problem can be solve in polynomial time on a classical computer.

Turing Completeness

Simply, a Turing-complete computer is one that is able to compute any and Turing-computable function.

Definition 1.0

Some computational device is taken as Turing-complete or Turing-equivalent if it is probable that it can compute the values for a function for every function of its argument. ie. A common place computer.

While Turing-complete computers are powerful, they begin to break down at the meta level in cases such as the infamous Halting Problem. (see the LASACS lunch time lecture)

A Single Qubit

A single qubit is given by $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$.

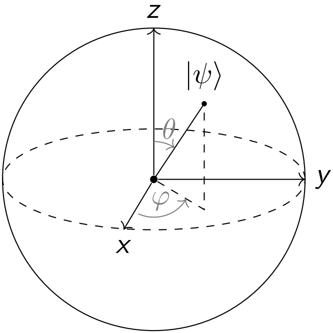
α is given to be a number in the reals and β is given to be a number in the complex space. Because of this we use a global phase to ensure α stays real.

Definition 2.0

A qubit is best described by $|\psi\rangle = e^{i\gamma}(\alpha|0\rangle + \beta|1\rangle)|\alpha\epsilon\mathbb{R}, \beta\epsilon\mathbb{C}$

Quantum Representation

$$|\psi\rangle = e^{i\gamma}(\alpha\,|0\rangle + \beta\,|1\rangle)|\alpha\epsilon\mathbb{R}, \beta\epsilon\mathbb{C}$$



$$\alpha = \cos\frac{\theta}{2}$$
$$\beta = e^{i\varphi}\sin\frac{\theta}{2}$$

Linear Algebra Crash Course

In terms of our qubit we can define some vectors to represent our previous kets for 0 and 1:

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Plugging this into our previous formulas we can see:

$$|\psi\rangle = \alpha \begin{pmatrix} 1 \\ 0 \end{pmatrix} + \beta \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

We rewrite all of this work we have done in terms of vectors because it allows for our later use of matrices to act as the gates and for massively parallelized work.

More Linear Algebra

Now with the use of these vectors we can perform some algebraic operations such as the tensor product allowing for us to combine gates and qubits.

$$\begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix} \otimes \begin{pmatrix} A & B \\ \Gamma & \Delta \end{pmatrix} = \begin{pmatrix} \alpha \begin{pmatrix} A & B \\ \Gamma & \Delta \end{pmatrix} & \beta \begin{pmatrix} A & B \\ \Gamma & \Delta \end{pmatrix} \\ \gamma \begin{pmatrix} A & B \\ \Gamma & \Delta \end{pmatrix} & \delta \begin{pmatrix} A & B \\ \Gamma & \Delta \end{pmatrix} \end{pmatrix} =$$

$$\begin{pmatrix} \alpha A & \alpha B & \beta A & \beta B \\ \alpha \Gamma & \alpha \Delta & \beta \Gamma & \beta \Delta \\ \gamma A & \gamma B & \delta A & \delta B \\ \gamma \Gamma & \gamma \Delta & \delta \Gamma & \delta \Delta \end{pmatrix}$$