Quantum Computation and Information

A Gentle Introduction

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Contents Overview

What is Quantum Computing?

Quantum Computing is the application of **Quantum Information Science (QIS)** to the development of *machines* capable of performing operations and calculations based on quantum logic instead of the usual classical logic.

The usefulness of this kind of computation lays not only on the ability to engineer exponentially faster machines, but also on things such as being able to **efficiently simulate nature at the quantum level**, or creating encryption systems which are fundamentally secure.

CLASSICAL LOGIC

Set Theory (Boolean algebra)

- **AND** $\Rightarrow$ $A \cup B$
- **OR** $\Rightarrow$ $A \cap B$
- **NOT** $\Rightarrow$ $\overline{A}$
- **XOR** $\Rightarrow$ $A \cap B - A \cup B$

QUANTUM LOGIC

Quantum Theory (Non-Commutative)

- **Probabilistic measurement**
- **Measurement causes disturbance**
- **Superposition**
- **Entanglement**
- **Uncertainty principle**

The Abacus Effect

To try to understand the power of Quantum Computing in abstract, we can resort to what might be called **"The Abacus Effect"**.

Before the abacus was invented, the only way of counting was through a "thermometer-like" scale, which was highly inefficient as it meant adding one physical bead per unit. The abacus did something great: it introduced the concept of **digits**, which was later put into an even more concise notation by the Arabs through the introduction of **numerals**.

This means that, instead of counting up to N using N raw elements, we can count using only $\log_b(N)$ abacus elements —where b is the base of our number system (i.e. the amount of beads per row in the abacus). Therefore, for $b \geq 2$, the abacus introduced an **exponential decrease in resource requirements** to represent the exact same thing.

Quantum computers do something analogous. To represent the quantum state of a system made out of N subsystems —each of which with b degrees of freedom— we would usually need b^N classical elements (i.e. numbers). By using quantum systems for this representation, we would only need N quantum elements (i.e. each subsystem). Again, an exponential decrease in resource requirements.

Quantum Software: IBM's Qiskit

Analog VS Digital

References

"The only thing demonstrated by an impossibility proof is a lack of imagination."
– John Stewart Bell –

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