SAMPLE

Quantum Computing

Computing Beyond Bits

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This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

A quantum computer is a machine that stores and manipulates information according to the rules of quantum mechanics, the physics that governs the very small. Ordinary computers, from the phone in a pocket to the largest supercomputer, hold their data in bits, tiny physical systems that sit in one of two conditions, on or off, one or zero. A quantum computer instead uses qubits, physical systems such as superconducting circuits or trapped atoms that can occupy a combination of conditions at once, a thing called a superposition, and that can be linked across distance in a way classical physics does not permit, a thing called entanglement. Because of these two abilities, certain computations can be arranged so that wrong answers cancel one another out while right answers reinforce, the way overlapping water waves can crowd together or flatten away, and the final measurement is then likely to land on a useful result.

This book follows that idea's whole story: where it came from, what it can and cannot do, how it is being built, and what remains uncertain. The chapters run in a natural order, from the qubit itself and the founding decade of the nineteen eighties, through the great algorithms of the nineties and the long engineering campaign that followed, to the machines now running in laboratories, the cryptographic consequences, the honest limits, and the trivia the field has accumulated along the way. The account keeps to plain language throughout, uses no equations, and sorts carefully between the demonstrated, the expected, and the hoped. The reader who finishes it will understand both why so many serious people have spent so much money on this machine and why so many careful people still ask whether it will ever pay its way.

Chapter 1: The Bit and the Qubit

Every computer ever sold rests on a single, humble convention: information cut into pieces with exactly two values. A bit is one such piece, and its two values go by many names, one and zero, true and false, on and off, but the naming does not matter, only the two-ness does. The convention works because two-valued pieces are easy to make physical, a switch open or closed, a magnetization pointing one way or the other, a patch of charge present or absent, and because any message, number, picture, or sound can be translated into a long enough string of such pieces. Classical information theory, built in the middle of the twentieth century, rests entirely on this convention, and it is worth pausing on how total the convention is: the bit is the atom of the information age, indivisible, obedient, and identical everywhere.

A qubit is also a two-valued thing, but a two-valued thing with a strange middle. Physically it is any quantum system with two usable states, the spin of an electron or a nucleus, two energy levels of an atom, two orientations of a current in a superconducting loop, and by tradition the two states are called zero and one, the names of the classical values. The difference appears the moment the system is left alone. A classical bit is always in one of its states. A qubit, unmeasured, can be in a blend of both, a condition written with the word superposition, and the blend is not a matter of ignorance, a hidden fact we happen not to know, but a genuine indeterminacy in the world itself, one of the founding surprises of quantum mechanics.

A superposition has weights, and the weights are the heart of the subject.

When a physicist prepares a qubit in a blend, the recipe specifies two numbers, called amplitudes, one attached to the zero condition and one to the one condition, and these amplitudes can be positive, negative, or even more exotic quantities that point in an abstract direction. The amplitudes themselves are never seen. What is seen, when the qubit is finally measured, is one of the two plain outcomes, zero or one, and the chance of each is fixed by a simple rule from the theory's early days: the probability is the size of the amplitude multiplied by itself, a rule associated with Max Born and now called the Born rule in his honor.

After the measurement, the blend is gone, the qubit sits plainly in the outcome that was read, and any further measurement just reads the same thing again. This collapse, as it is often called, is not a footnote; it is the hinge on which every quantum computation turns, because it means a machine of superpositions still has to answer questions in ordinary bits at the end.

There is a useful picture, not the whole truth but a good servant, in which the state of a single qubit is drawn as an arrow of unit length pointing somewhere on a sphere. The north pole is the plain zero state, the south pole is the plain one state, and every other point on the sphere is some blend of the two. The picture is called the Bloch sphere, after Felix Bloch, and it earns its keep whenever one wants to reason about what a quantum operation does: most operations on a single qubit amount to turning the arrow, tipping it toward this pole or that, spinning it around the axis it currently points along, and a computation on one qubit looks like a carefully choreographed sequence of such turns. A classical bit, in this picture, is a marble frozen at one of two poles; a qubit is a compass needle free to point anywhere, and a skilled programmer can use that freedom.

One more piece of vocabulary completes the starter kit: entanglement. Two qubits can be prepared in a way that has no description in terms of the parts, a joint superposition in which neither qubit has a state of its own and only the pair does. Measuring one member of such a pair instantly constrains what will be found when the other is measured, regardless of the distance between them, and though this connection cannot be used to send a message faster than light, a fact the later chapters return to, it is a resource with no classical equivalent. Superposition gives the quantum computer its breadth, entanglement gives it a way to make its parts answer to one another, and interference, the subject of the next chapter, gives it the means to turn a huge span of possibilities into a useful answer.

The qubit deserves one closing caution, because the popular telling oversells it. It is often said that a quantum computer tries every answer at once, and in a loose sense an algorithm's early steps do place the machine in a superposition spanning an enormous number of candidate inputs. But the machine does not report every answer; measurement yields exactly one outcome, and all that preparation is wasted unless the algorithm arranges for the wanted outcome to be likely. The craft of quantum computing is not in spreading wide, which is easy, but in folding the spread back down to something worth reading, which is hard, and the whole history of the field, from its first algorithm to its newest chip, is the history of people learning to fold.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.