Understanding Quantum Computing

Quantum computing is a difficult concept to comprehend, and this can be attributed to the complex physics and mechanics that are involved. Before delving into the specifics of quantum computing, it is important to understand how traditional computer processors work because some fundamental concepts are shared between the two. A modern-day processor consists of packing millions, and even billions, of transistors onto a die. These transistors can either be on or off, or in the binary terms a 1 or 0. The intricate layers of circuitry that connects these transistors allows bits of information to be processed with great efficiency. Intel released an excellent visual representation of the process which can be seen in Figure 1 and 2 [1].

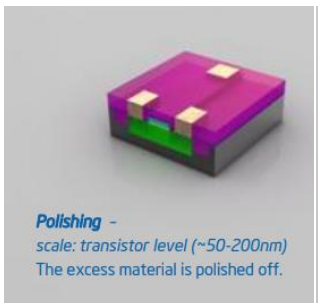

Figure 1.

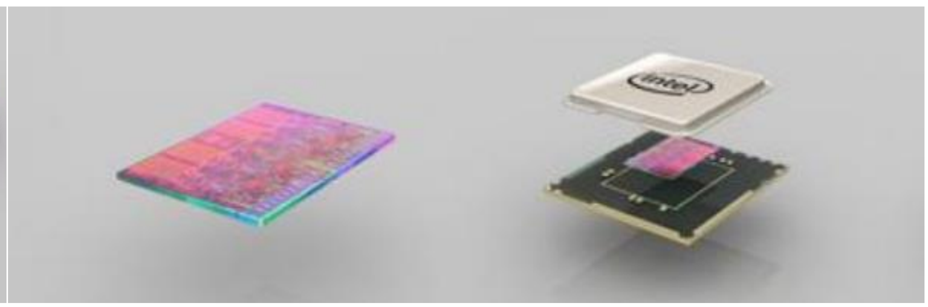

Figure 2. The making of a modern processor (Intel, 2009). Graphics provided by Intel.

As shown in the graphic above, transistors are on the 50-200nm scale; to put this into perspective, the width of a human hair is about 60,000nm [2]. These transistors are about 300 to 1,200 times smaller than said hair and going any smaller would prevent them from functioning properly. The argument of simply increasing the size of the chip or die is viable, which can be seen in larger processors that fit 4 or more of these dies, however not viable forever. At some point in time, processors will peak and become limited by a combination of several factors including but not limited to size, heat, power consumption, efficiency, cost, and more. Quantum processors circumvent this by harnessing quantum mechanics to process information at speeds unheard prior.

Quantum Physics and the Qubit

The speed of a conventional processor can be increased by combining multiple processors, or cores, in parallel. However, as stated previously this is limited by physical space. Quantum computers are different in that the amount of parallel processing that can be accomplished increases exponentially relative to their size [3]. Where a conventional processor uses physical transistors to process zeros and ones, a quantum system can harness properties of particles like photons to perform the same tasks [4].

A qubit, or quantum bit, is used to describe the chosen particle to manipulate. The qubit is defined as a unit vector in a two-dimensional complex space, and the polarization of a particle in this space determines the value of a qubit to be a 1 or 0 [3]. This complex space also relates to the concept of superposition. In terms of quantum mechanics, superposition is the principle that any number of qubits can be combined and will result in another completely valid quantum state [5]. It is this principle that allows a qubit to be in infinitely many states at any moment in time.

Although qubits represent an infinite amount of states, only a single bit of data (1 or 0) can be retrieved at once. Furthermore, when extracting data from a qubit the state is then altered as a result [3]. This presents challenges that will be discussed later in the report.

Groups of qubits are also subject to entanglement. Entangled qubits cannot be deconstructed into meaningful information for each qubit individually. This phenomenon has no comparable counterpart to traditional computers, which leaves the possibilities for its use, if any, up to the engineers.

The Relevance of Moore's Law

Moore's Law is the idea that computer processing power will double every two years. This rule has held true until the 2000s, when progress on increasing processor speed began to decline. The frequency a processor operates at, commonly measure in gigahertz, began to remain in the same range, but the processors were still improving in other ways. In order to continue relevance, the law was revised to describe the doubling of the number of transistors every two years instead of just raw power [6].

This revision led to some companies abandoning the concept, while others continue to accept it. However, quantum computing will likely invalidate the law altogether. Not only do these computers operate without the use of transistors, but the processing power won't just double, but multiply by the hundreds or thousands. Another revision, or new law entirely, may have to be required in order to account for quantum computers.

References

[1] Intel, "From Sand to Silicon: The Making of a Chip Illustrations," May 2009. [Online]. Available: www.intel.com/pressroom/kits/chipmaking. [Accessed May 7, 2019]

[2] "Diameter of a Human Hair," 2011. [Online]. Available: https://hypertextbook.com/facts/1999/BrianLey.shtml. [Accessed May 7, 2019]

[3] E. Reiffel and W. Polak, "An Introduction to Quantum Computing for Non-Physicists," *ACM Computing Surveys*, September 2000. Available: Computer Database, http://link.galegroup.com.libproxy.oit.edu/apps/doc/A74089509/CDB?u=s8375154&sid=CDB&xid=f7ed33b9. [Accessed May 1, 2019]. [Accessed May 7, 2019]

[4] "Qubit," March 2019. [Online]. Available: https://en.wikipedia.org/wiki/Qubit. [Accessed May 10, 2019]

[5] "Quantum superposition," April 2019. [Online]. Available: https://en.wikipedia.org/wiki/Quantum_superposition. [Accessed May 10, 2019]

[6] "Moore's Law." [Online]. Available: http://www.mooreslaw.org/. [Accessed May 12, 2019]