From Babylonians to Post-Computer Era:

A Brief History of Computing

Abstract

In the past 5,000 years, humans have witnessed countless developments and inventions in the field of computing. People from early Babylonians to modern computer scientists have derived numerous algorithms and computing devices, and developments of computing tools and algorithms are closely related. Before the invention of electronic computers in 1944, development of algorithms advanced in a slow pace, as people relied solely on mechanical computing tools that were only marginally faster than papers and pencils; however, after humans entered the electronic age, humans have seen an explosion of new inventions in both areas. It is worth remembering that early people were important contributors of modern mathematics and computer science; looking at the history of computing helps us better define the future of computing.

Introduction

When ancient Babylonians were using formulas on their stone tablets to multiply numbers around 4000 years ago [1], they never imagined that after millennia, humans would hold tablets much thinner than theirs that were able to perform billions of multiplications in one second. In ancient and medieval times, most ordinary people had little interest in computing; however, in modern times, rapid growth of computing needs has led to development of both faster algorithms and more portable computing devices. Often, development of algorithms was bottlenecked by lack of reliable computing devices, while the power of fast computing technologies could not be fully utilized due to inefficient algorithms. However, development of both has been continuously shaping human history. For example, scientists in the Apollo Program needed to perform a series of complex computations to decide the best way to send spaceships beyond the earth orbit onto the moon [2]; financial analysts in the constantly changing stock market need to quickly predict future market trends to bring cash to their company; operation managers need to use optimization algorithms to find out the most efficient allocations of their firm's resources; and, the Allies' intelligence agencies in World War II had to decrypt Nazi Germany's encrypted code fast to shatter its evil development of nuclear weapon [3]. Without efficient and reliable computations, the world would look completely different today. The world could still be under the cruel, dark and hopeless rule of the Axis Powers; people might still have to send letters back and forth to our friends, and wait anxiously for months before hearing back; we could be stuck in the heavy traffic in LA since there is no efficient traffic management system. In short, the role of fast computation is so crucial today that

destroying all computers and forgetting all algorithms would send us back to the dark Middle Ages. But how did early people strive to live happily without our advanced computing technologies and methods?

Earliest Algorithms: Babylonian Mathematics

According to Oxford Dictionary of English, algorithm is defined as 'a process or set of rules to be followed in calculations or other problem-solving operations'. The emergence of the term 'algorithm' can be traced back to the ninth century after the great Persian mathematician al-Khwarizmi [4], but actual development of computing process began as early as 2000 BC. Multiplying two numbers is a simple skill taught in elementary schools today, but ancient Babylonians struggled to derive a method to multiply two numbers. They used a formula that is considered awkward today [5]:

$$ab = \frac{1}{2}[(a + b)^2 - a^2 - b^2]$$

Figure 1: Babylonian Square Table.

As Figure 1 illustrates, Babylonians kept square tables on stone tablets where they could look up the value of the squares, and then use the formula above to perform the multiplication. They didn't have a good start on how to multiply, since they made one single operation into three. The reason behind this 'awkward' formula was that they lacked an effective device to perform multiplication; nevertheless, their mathematic knowledge left valuable treasures for people even today. For example, one may wonder why one hour is divided into 60 minutes, and one minute divided into 60 seconds; in fact, it came from Babylonian's sexagesimal number systems and is still used by virtually everyone to track time today [6]. Babylonians also derived approximations of square roots that are deemed incredible today; they estimated square root of 2 as 1.41421296, which is extremely close to the exact value [7]. Their formula for the approximation is still used today:

$$\sqrt{a^2 + b} \approx \frac{a + b}{2a}$$

Although distant from today, Babylonian's contributions to computing are remarkable, as we still make use of some of their thoughts today. They played a fundamental role in the

establishment of computing theories; however, they failed to make substantive contribution to computing devices, as the most advanced technology they used was the stone tablet.

Abacus: the First Computing Device

Now, only people in a small portion of the world still use the abacus as their primary computing device, but the abacus has a significant position in the history of computing devices. The date when abacus first appeared was unclear, but as early as 4,500 years ago in the ancient state of Mesopotamia, people were already using the Sumerian abacus to perform basic calculations such as additions and subtractions [8]. However, more complicated operations such as multiplication were impossible via early abacus. Therefore, people of the same age including Babylonians could only rely on rudimentary technologies such as square tables.

Later, as shown in Figure 2, the Chinese invented their version of the abacus, the first comprehensive computing device that is still used by many today [9]: it is capable of performing additions, subtractions, multiplications and divisions. There are numerous vertical rods on a Chinese abacus, with a horizontal bar separating each rod into top and bottom. Five beads lay on the bottom part and two beads lay on the top part, while a bead on the top counts as five and a bead on the bottom counts as one. The rod on the right end represents the least significant digit, while the one on the left end represents the most significant digit. Although the abacus is a relatively comprehensive computing tool, it is not very intuitive to use. For example, to multiply or divide using an abacus, people still need to perform a series of single-digit multiplications in our minds, shift the columns and then add up the results: it is fairly easy to make a mistake during any step. Thus, simpler tools, such as the slide rule and the Pasculine, substituted for it later.

Figure 2. The Chinese Abacus.

Diophantus: the Father of Algebra

While the lack of efficient computing devices might have prevented ordinary people to pursue deep in the field of mathematics, the Middle Ages still saw an abundance of inventions and developments of algorithms. Some of them are foundations of the modern algerbra. For example, the following is a poem that praises Diophantus of Alexandria for his marvelous contribution to mathematics [10]:

This tomb holds Diophantus. Ah, what a marvel. And the tomb tells scientifically the measure of his life. God vouchsafed that he should be a boy for the sixth part of his life; when a twelfth was added, his cheeks acquired a beard; He kindled for him the light of marriage after a seventh, and in the fifth year after his marriage He granted him a son. Alas! late-begotten and miserable child, when he had reached the measure of half his father's life, the chill grave took him. After consoling his grief by this science of numbers for four years, he reached the end of his life.
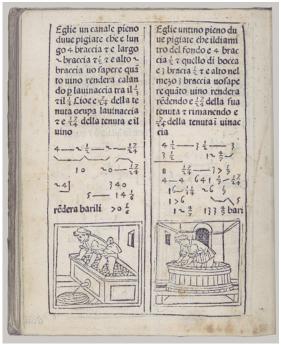

Figure 3: Arithmetica.

This poem looks similar to an algebra problem we often see today, and we could infer from this poem that Diophantus passed away at 84. Indeed, Diophantus is named "the father of algebra." His publication, the Arithmetica as shown in Figure 3, is one of the most influential works in the history of mathematics. It contains about 300 problems as well as their solutions. He provided general solutions for both determinate and indeterminate equations, and these solutions served as important insights and inspirations for latter mathematicians, as well as the keystone of the linear algebra and number theories. He even left a problem that is still unsolved today, known as the Congruent Number Problem, which has sparked innovations in the algorithm field in the 1960s [12].

The First Concept of Electronic Computers

We have seen some great concepts and computing methods derived in the pre-Industrialization era, but humanity's computational speed is still bottlenecked by the speed of writing and manipulating mechanical computing devices, no matter how brilliant the early algorithms were. After people in the past saw several more inventions of rather uninspiring computing tools that still relied on mechanics and only marginally increased their computing speed, Ada Lovelace became the pioneer who proposed the idea of programming and invented an analytical engine, which was based on the first computer programming in the world [11]. Her work was 100 years ahead of the next piece of computer programming written in comtemperorary programming language. In her work, she and another great mathematican Charles Babbage designed an 'analytical engine' which used punch cards to record things from the past and followed a predefined sequence of instructions to 'foresee and act upon its foresights.' [11] Their conceptual computer's ability to act on its is valuable to humanity. It allows people to walk away from computers and do their own work while their loyal computers

are doing jobs assigned to them; this autonomy drastically increases humanity's computational efficiency.

The use of punch cards had an astonishing similarity with today's memory in computers, and the 'flow of instructions' defined by them mimics today's computer program, as modern computer programs contain a series of instructions for a CPU to execute. Babbage predicted that it would take fifty years for a real machine out of his concept to be developed, but it actually took about one hundred years, until code breakers in the World War II felt the urgent need to develop such machine [3]. Lovelace's and Babbage's foresight truly impressed us today and left us with intriguing ideas to predict what computing might be like in the future.

Colossus: the First Electronic Computer

Figure 4: the reconstruction project of Colussus in 1994.

In 1939, a group of mathematician of extraordinary talents gathered together to break Nazi Germany's code. When German U-boats carrying uranium essential for development of nuclear weapon were knocked down by the Alliance, furious Adolf Hitler might never have an idea on how his enemies broke his elegantly encrypted codes. [3] Breaking code is a task that requires enormous number of calculations; LW LV XQOLNHOB WR EH DFFRPSOLVKHG VLPSOB EB KXPDQ KDQGV. Encrypted sentences such as the previous one are easy to decode today; if all letters are shifted by three, it becomes 'it is unlikely to be accomplished simply by human hands.' Without fast computers, however, it takes several seconds to shift a single letter by hand, and there have 25 possible keys to try if the sentence is encrypted by letter shift. Moreover, it is worth remembering there were huge numbers of encrypted communications within the Nazi army in those days, and they are encrypted by double letter shifts, which generate 625 possible ways of encryption. The need for massive computations to break German codes led to the birth of human's first electronic computer, the Colossus, which drastically reshaped history.

As depicted in Figure 4, Colossus was huge as we could also infer from its name. It had about 2,400 vacuum tubes and consisted of five different parts: a tape reader, an adder, a logic unit, a master control and a printer. Its maximum computing capacity was about 9,700 characters per second, which was dramatically faster than human's reading speed [3]. With the help of 10 Colossuses, most German codes after 1944 were broken in less than two hours [3]. Although invented decades ago, Colossus made the first use of shift registers and arrays, which are designs still prevalent in today's electronic devices.

Back to Multiplication: Evolution of Algorithms in the 20th Century

With the help of electronic computers, humans can perform thousands of computations every second. However, some problems may still take centuries, or even forever, for the fastest electronic computers to solve if people do not any wiser algorithms. For instance, let us consider a common problem for any city planner in the world: if there are one million homes in a city and we know the exact locations of them, how could 5,000 fire stations be set up so that they offer maximum coverage to those homes? The easiest method to tackle this problem is to seek help from computers, and let them try every possible allocation of those fire stations, which is known as the brute force solution. This method yields roughly 10^{33000} attempts; if all computing devices in the world are utilized, they still cannot finish the computation before the universe comes to an end.

Therefore, computer scientists constantly feel the urgent need to devise faster algorithms. In fact, if we do not seek the best solution but only one that is good enough, planning problems similar to the one above could be solved in a matter of seconds, thanks to approximation algorithms. However, before 1960s, even one of the simplest operations, multiplications, was a pain for both human beings and computers. Let us think about how we multiply two ten-digit numbers by hand: we start from the least significant digit of one number and multiply it by every digit in the other number, and then we move to more significant digits of the first number. In total, we need 10*10=100 digit-by-digit multiplications and about 20 additions. In general, multiplying two n-digit numbers takes roughly n^2 operations.

Professor Anatolii Alexeevitch Karatsuba invented a fast algorithm for multiplications in 1962, using the method as known as divide and conquer, which effectively reduced the number of operations required from n^2 to $n^{1.5}$ [12]. If n equals 100, the algorithm reduces number of operations from 10,000 to 1,000. In the following years, rapid development of different algorithms and computing theories has further accelerated various computing tasks. For example, multiplication of two 100-digit numbers can be done with less than 700 operations with the help of Fast Fourier Transform algorithm [13].

Conclusion: the Future of Computing

Figure 5: The Intel 4004.

From early years in the ancient Babylonian state to the current time, development of algorithms and computing devices has brought vitality to human history as it leads to better understanding of our world and faster exploration of the unknown. 5,000 years are merely an instant in the earth's history, but humans have gone from stone tablets that made multiplication more complex, to electronic tablets which make fast computing anywhere a reality. Meanwhile, people have gotten rid of many cumbersome formulas and embraced miraculously fast algorithms such as the Fast Fourier Transform. As we move forward to discover the future of computing, we will

unleash more possibilities and explore the areas and knowledge we have never imagined before. In the late 20th century, thanks to the invention of transistors such as the one shown in Figure 5, and the integrated circuit technology, computers have become smaller, portable, personal and faster. Now, most of humans' daily tasks, such as learning, communication and entertainment, are done 'electronically'; in the next a few decades, we will see even more inspirations in the field of computing. Robots will free humans from doing repetitive and boring work in the assembly lines; more portable, smaller and cheaper forms of mobile devices will make our advanced technologies available in classrooms in Africa; further development of cloud computing will allow us to store, create and share new ideas anywhere in the world in a very efficient manner; and computing chip's interactions with human brains will boost humans' ability to memorize and reason. In short, the future potential of computing is unlimited. We should appreciate those marvelous creations early mathematicians and computer scientists left for us, and embrace as well as participate in the exciting future of computing.

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