Chapter 0

The Evolution of Computers

The modern computer has evolved generation after generation. We have advanced through four generations and have entered the fifth, Artificial Intelligence. Each generation is defined by significant technological advancements of hardware and software. Over the decades, the evolution of computer technology has seen many improvements to the size, cost, power, efficiency, and reliability of computers.

Contributions and Pioneers of Computing History

Innovation of technologies, discoveries in the sciences, and sociopolitical factors involving many thousands of people over hundreds, and even thousands, of years have contributed to what are today's modern computer systems. Computers were originally humans who would compute calculations by hand, but the definition has evolved over time to define technology as computers, rather than people; the earliest use of the later definition was in 1897, though it took several decades beyond 1897 to more fully transition to the new definition.

Perhaps the most significant tool of use in premodern times to calculate was created over 4700 years ago and is known as an abacus. Any construction material may be used in concept, but most often abaci were/are created with bamboo, wood, stone, or metal frames enclosing grooves or rods in which place beans, beads, or disks will sit. Using an abacus involves moving these beans, beads, or disks from one end to other, filling a place holder, and counted.

By manipulating these place holders, rudimentary math may be performed such as addition, subtraction, and multiplication as well as more complex calculations. The invention of the abacus has been a boon to humans' ability to calculate correctly and efficiently where, in some cases, it is still utilized to this day. Though not the first machines capable of arithmetic, a few significant machines of note are : the Pascaline, the Leibniz wheel, and Analytical Engine.

Persons of Interest

The following compilation includes people who have contributed to computer technology, either directly or indirectly.

Muhammad ibn Musa al-Khwarizmi (c. 780 – 850)

Al-Khwarizmi was a Persian scholar of the sciences and created several books during his life. Algebra had been around for centuries prior to his being; however, he is known as the founder of algebra due to his accomplishments and discoveries in the field of algebraic mathematics. Through translation, the term algebra derives its origins from the title of a book he created around the year AD 820, *The Compendious Book on Calculation by Completion and Balancing*. His most notable work may be *On the Calculation with Hindu Numerals*, which led to the spread of the Hindu-Arabian numeral system(*base 10*) which spread to western civilizations and is now commonly used globally. Looking at the etymology of the word 'algorithm' we find that it has its origins from an Arabic to Latin translation of his book, *On the Calculation with Hindu Numerals*.

Ismail al-Jazari (1136 – 1206)

Al-Jazari was a famous engineer and inventor. Notable creations of his are the camshaft, crankshaft, various automata and clocks, and the first water supply system to be driven by gears and hydropower. His astronomical clock, known as 'castle clock', is considered the first programmable analog computer as it could be reprogrammed to modify the length of day and night during the year.

Blaise Pascal (1623 – 1662)

Another great contributor to the sciences. Known as a Pascaline, he created the first mechanical calculator capable of computing basic arithmetic. Later in his life, Pascal became involved with the rising christian sect of Jansenism. Pascal had an early death as result of chronically poor health.

Gottfried Wilhelm Leibniz (1646 – 1716)

A well-regarded polymath of the enlightenment, Leibniz wrote several works in a gamut of fields of the time: mathematics, physics, philosophy, natural sciences, social science, and more. He invented the Leibniz wheel, a cylindrical object with teeth of varying lengths representing different digits/values, which was used in the arithmometer mechanical calculator and his very own stepped reckoner. Leibniz's work expanding upon the binary number system, digital mechanical calculators, and ideas of combining

binary with programmable machines would soon be envisioned in future technological innovations.

Joseph Marie Jacquard (1752 – 1834)

Notable invention of his is the Jacquard loom; a fully programmable loom utilizing a line of taped together punch cards. This method of chaining punched cards together will be adopted by Ada Lovelace and Charles Babbage in the Analytical Engine and future, modern era computers.

Charles Babbage (1791 – 1871)

Famous for designing the Difference Engine and Analytical Engine. Both, however, were never completely built during his lifetime. The building designs of both devices may be comparable to the foundations of modern computers developed in the 1930's and 1940's. Charles Babbage's Analytical Engine made use of punched cards for programmability and would have been the first device to be considered Turing-complete, had it been built. The Analytical Engine was to be a general-purpose computer capable of arithmetic, branching, looping, and memory storage.

Ada Lovelace (1815 – 1852)

Considered by some to be the first computer programmer, she developed an algorithm to compute Bernoulli numbers on Babbage's Analytical Engine. In the history of computer science, the

characterization of first programmer is controversial among scholars because Charles Babbage had created personal, unpublished programming instructions for his Analytical Engine years before her published notes on the Bernoulli algorithm. Regardless, Lovelace was an accomplished analyst of contemporary papers of her era.

George Boole (1815 – 1864)

A self-taught professor of mathematics at Queens College Cork in Ireland and recipient of numerous accolades, two of which from the Royal Society and the Royal Society of Edinburgh. Boole became a Fellow of the Royal Society in 1857. Boole's fame arises from his second published book, *An Investigation of Laws of Thought on Which are Founded the Mathematical Theories of Logic and Probabilities*, which led to a more formal branch of mathematics known as Boolean Algebra. Boolean algebra's variables hold the values of True/False and may be denoted as 1 or 0, respectively. Boolean algebra is now fundamental to modern computing and the digital logic it makes use of.

Herman Hollerith (1860 – 1929)

Founded the Tabulating Machine Company in 1896, which through amalgamation (business merger) became the Computing-Tabulating-Recording Company in 1911 and renamed to International Business Machines Corporation (IBM) in 1924. His breakthrough invention was an electromechanical tabulator used originally and primarily for the US Census Bureau and other countries' censuses beginning in the late 1800's. It, too, made use of

punched cards to read data; an adoption replicated in several of the first modern computers of the 1930's and 1940's.

Alan Mathison Turing (1912 – 1954)

Considered to be the founder of the field of computer science. Possibly Turing's most notable achievement is his assistance to Britain's Government Code and Cypher School during WWII. At GC&CS he improved upon Britain's version of the Polish bomba electromechanical machine used to break German ciphers used by the Enigma Machine. Turing published a paper in 1950, "Computing Machinery and Intelligence", that included a method to determine if a machine is intelligent; the Turing Test. The Turing Test is still used today but is only one factor of many used to determine if artificial intelligence is achieved.

Claude Shannon (1916 – 2001)

An accomplished mathematician, electrical engineer, and cryptologist. Shannon has received dozens of awards for his works furthering knowledge and science. He is the founder of digital circuitry with his designs laid out in master's thesis, "A Symbolic Analysis of Relay and Switching Circuits", in 1937 at the age of 21. His thesis awarded him the Alfred Noble American Institute of American Engineers Award. Inspiration for his digital circuitry came from the works of George Boole, whom Boolean Algebra is named after. Another accomplishment of his was an article published in 1948, "A Mathematical Theory of Communication", in the Bell System Technical Journal. This paper is the foundation upon which information theory derives.

John von Neumann (1903 – 1957)

A physicist, mathematician, and computer scientist, von Neumann published over 150 papers. Being an expert of explosions and consultant for the government, he was employed to work on the Manhattan Project during WWII and designed the shaped charges(explosive lenses) used to detonate nuclear weapons. In 1945, he created the merge sort algorithm for the EDVAC(Electronic Discrete Variable Automatic Computer) electronic computer. Now recognized as von Neumann architecture, his paper, "First Draft of a Report on the EDVAC", describes a computer architecture employed by most computer systems today.

William Shockley, John Bardeen, Walter Brattain (1940's – 1950's)

William Shockley was the manager of the solid-state research group these three physicists were part of at Bell Labs in the 1940's with a mission to replace vacuum tubes. In 1947, their team created a transistor that ultimately won them the 1956 Nobel Prize in Physics. Shockley left to start his own business, Shockley Semiconductor Laboratory, in Silicon Valley. Just one year later, a falling out between him and eight of his employees resulted in their leaving and forming of a new company, Fairchild Semiconductor.

Robert Noyce (1927 – 1990)

Worked with William Shockley at Shockley Semiconductor Laboratory but left soon after with seven other employees to form Fairchild Semiconductor where he would help to develop the first practical integrated circuit made of silicon. He would work at

Fairchild for nearly ten more years. In 1968, he and Gordon Moore would form Intel, one of the most successful tech companies. He would continue his leading roles until 1978 to become chairman of the Semiconductor Industry Association. Noyce had acquired 16 patents over his career and several awards; three of which came from US Presidents Jimmy Carter, Ronald Reagan, and George H.W. Bush.

Grace Murray Hopper (1906 – 1992)

Hopper was a computer scientist and US naval officer who emphasized the need for programming languages independent of the computer it is being executed on. Her work on this in the early 1950's led to the creation of the first compiler, linker, capable of translating English terms into machine code. This achievement made possible the concept of high-level programming languages, leading to the development of FLOW-MATIC and later heavily influenced the design and creation of COBOL, an early English-based high-level programming language. Among her many honors, Grace Hopper has had a naval destroyer named after her and posthumously received the Presidential Medal of Freedom from President Obama in 2016.

Masatoshi Shima (1943 -)

Shima was a co-designer of the Intel 4004; the first microprocessor. He initially created a 3-piece chip design in 1968, which would be the basis for the single-chip 4004 developed in 1970. Shima performed a few more years of work for Intel before transferring to the company Zilog, where he helped to develop the

Zilog Z80 and Z8000 with Federico Faggin. In 1997, Shima was awarded the Kyoto Prize, one a Japan's most prestigious awards.

Federico Faggin (1941 -)

In 1968, at Fairchild Semiconductor, he created the silicon-gate technology(SGT), a type of self-aligned gate used on metal-oxide-semiconductor(MOS) transistors, that made possible the development of the first series microprocessors at Intel. Most microprocessors still use this technology. Cofounder with Ralph Ungermann of Zilog, Inc. in 1974, which later employed Masatoshi Shima. He conceived of the Z80 microprocessor which he and his team created in 1976. During his career, Faggin created multiple companies and has been awarded dozens of accolades; most notable may be the National Medal of Technology and Innovation, awarded in 2009 by President Obama.

Tim Berners-Lee (1955 -)

Sir Timothy John Berners-Lee, knighted in 2004, created the World Wide Web in 1989 by connecting an HTTP client and communicating with a server. Much of the technology behind WWW had already been created, however, nobody had yet thought of a way to combine it in such a way resembling the World Wide Web. Info.cern.ch, hosted on a CERN server, was the first ever created website. It included information explain what the WWW was and support for other people wanting to set up their own websites. Berners-Lee founded the World Wide Web Foundation in 2009, aimed at using the internet to create positive change in humanity.

Linus Torvalds (1969 -)

Creator and chief developer of the open-source Linux kernel. He has developed an estimated 2% of the Linux kernel's code base himself; his primary work now consists of managing which code gets patched into the official kernel. Another significant contribution he has made is the creation of the version control system Git in 2005, which is a widely used aid in software development.

Stephen Wozniak and Steve Jobs (1970's -)

Both men are cofounders of Apple, Inc. in 1976. Stephen Wozniak was the creator and developer of the Apple I and Apple II computers while Steve Jobs was more focused on operating the company. Both of these computers, the Apple II more so, were quite successful and launched a revolution of personal computing. Wozniak temporarily took absence in 1981 and both would officially leave Apple in 1985, just one year after the release of the first Macintosh computer. Wozniak went on to pursue more education and to practice philanthropy, while Jobs advanced his business career, eventually coming back to Apple and becoming CEO.

Bill Gates and Paul Allen (1970's -)

Cofounded Microsoft, which would become the worlds leading PC software developer. Paul Allen relinquished his position on Microsoft's board of directors in 2000 and Bill Gates stepped

down as chairman in 2014. During and after their stints at Microsoft, both men would devote tremendous time, work, and funding directed towards philanthropic projects.

Larry Page and Sergey Brin (1990's -)

Larry Page and Sergey Brin are two friends who met each other in the computer science PhD program at Stanford University in the mid 1990's. At Stanford they developed a web scraper, BackRub, and an algorithm, PageRank. Using these two in tandem, Page and Brin were able to create their first search engine. In 1998, Page became CEO and Brin became President of the newly formed Google, Inc. From 2001 to 2011, Page stepped down as CEO to become President of Products; however, he was still viewed as the boss by Google's employees. In 2015, Google would be restructured under a new parent company, Alphabet, Inc, with Page as CEO and Brin as President. Both men are ranked 12th and 13th of the wealthiest men in the world and both support philanthropy through individual donations and through their companies.

Computer Generations

There are generally five different 'generations' of computers that have been recognized. Each subsequent generation has unique characteristics that sets it apart from the others before it.

First Generation Computers (1940 - 1956)

Computers that were developed from 1940 to 1956 were called first-generation computers. First-generation computers utilized vacuum tubes to perform logic operations. A vacuum tube consists of a glass tube encompassing a filament, which when passing electricity, operates as a simple logic gate. These computers performed basic operations and were used for simple and complex computations, as well as storage and control of information. Vacuum tubes served as binary switches represented by being either ON or OFF (1 and 0 respectively). Vacuum tubes generated a lot of heat, which was often the cause of their malfunctions. They were first used in radios and later adopted during World War II to be used in computers. The computers during this era were expensive, large and would typically occupy an entire room. Magnetic tape or magnetic drums were used for longer term storage of information when the computer was not in operation.

First generation computer operations relied on machine language, the lowest level programming language. First-generation languages, or 1 GL, are low-level languages (machine language). For input, these first computers were programmed using punch cards, paper tape, and/or patch cables and switches. Problems were

computed one at a time until a solution was found, and the output would be printed on paper. Examples of first-generation computers are UNIVAC (Universal Automatic Computer) and ENIAC (Electronic Numerical Integrator and Calculator).

Second Generation Computers (1956 - 1963)

The second generation of computers replaced vacuum tubes, which were bulky, produced undesirable amounts of heat, and were relatively inefficient in power consumption, with transistors. Transistors were invented at AT&T Bell lab in 1947 but were not used in computers until the late 1950s. The scientists who developed transistors were John Barden, William Brattain and William Shockley. The transistor was much smaller than vacuum tubes, resulting in computers becoming quite small in comparative size. The computers during this period consumed less power, had better performance, and were cheaper than those of the prior generation.

Transistors are mostly made of silicon or germanium and other semiconductor materials, which makes it less sensitive to temperature; thereby, reducing the risk of overheating. A transistor has at least three terminals in which to connect to a circuit: Collector, Base, and Emitter. It is a device that regulates current or flow of voltage. Depending on the type of transistor, NPN or PNP, current will flow from the collector to emitter or from the emitter to the collector (respectively).

Second generation computers used a second-generation language, or 2GL, known as assembly language. Assembly language uses mnemonic operation codes and addresses in place of binary (1's and 0's) stored in magnetic tapes and magnetic disks. High-level

languages, such as FORTRAN and COBOL were being developed at that time. Compilers were developed to translate high-level program into corresponding assembly language program which was then translated into machine language. IBM 650, IBM 1401, ATLAS and Mark III are some examples of second-generation computers.

Third Generation Computers (1964 - 1971)

Integrated circuits (IC) were introduced during the development of the third-generation computers. An Integrated Circuit is an electronic device that is like a transistor in terms of size, but it can work as fast as thousands of them. Integrated circuits once again made computers faster, cheaper, and smaller than second-generation computers. They use less electricity and make fewer mistakes. In this generation, RAM (Random Access Memory) and ROM (Read Only Memory) is introduced as primary storage. RAM and ROM are semiconductor memories that replaced magnetic core memories used in earlier generations. Operating Systems were implemented during this generation making sharing of a computer system by several user programs more efficient by utilizing time-sharing and multiprogramming.

Other type of memory systems introduced during this generation are cache memory and virtual memory. Cache memory is provided to the IC (Integrated Circuit) and is typically faster than RAM. Virtual memory increases the amount of working RAM available to the operating system; however, it is not located on a stick of RAM, but rather on the system's more permanent storage system (HDD or Hard Disk Drive). Though making use of virtual memory will result in slower access times when data stored on the HDD is called, more value is realized with greater amounts of free space on

the faster RAM modules. Most often, data which needs to be part of the working memory system, but not used often enough to be held in RAM, will be stored in virtual memory on the HDD.

Third-generation languages, or 3GL, are high-level languages such as C or Java. High level languages were standardized by ANSI (American National Standards Institute), for example ANSI FORTRAN and ANSI COBOL.

Third generation computers were smaller in size, less expensive, faster and more accurate than second generation computers. IBM 360 and System 360 Mainframe from IBM are examples of third-generation computers.

Fourth Generation Computers (1971 - 2010)

The development of fourth-generation computers made use of microprocessors. A microprocessor consists of a small silicon chip on which thousands of circuits are integrated. They were designed using LSI (Large Scale integration) and VLSI (Very Large-Scale Integration) technology. The Intel 4004 chip was developed in 1971 and was able to locate all the components of the computer; everything from the CPU to memory to input/output controls. Semiconductor memory is replaced by magnetic core memory, which results in fast random-access memory. Microprocessors were introduced as CPU (Central Processing Unit), which are full processors and a major section of main memory is implemented in a single chip.

Due to the technological development of the fourth-generation computers, IBM released the first home computer in 1981. Operating systems for home users came about during this time, a

couple of which were MS-DOS and MS Windows. Apple followed with the release of the Macintosh in 1984. Peripheral devices developed, such as CRT (Cathode Ray Tube) monitors, mice, scanners, and laser/inkjet printers.

Fourth-generation languages, or 4GL, are languages that are more relatable to human language. They are commonly known as scripting languages and widely used in database programming and systems administration. Examples include SQL, Python, and Ruby.

The fourth generation of computers are smaller, portable, and cost less than previous computers. They generate less heat and use less electricity. Computers created during this era were powerful and lead to the development of networks, GUIs (Graphical User Interface), and handheld devices.

Fifth Generation Computers (2010 -)

The fifth generation of computers, referred to as AI (Artificial Intelligence), is currently still in development. They will be able to understand vocal input, learn, and make decisions on their own, like humans. Artificial Intelligence will be useful in robotics, design, and military or systems defense. The use of parallel processing and superconductors will aid in the development of artificial intelligence.

We have begun to witness, experience, and rely on IoT (Internet of Things) in our daily lives: embedded computers in automobiles, household appliances, smartphones are but a few. As we become more dependent on computers and is integrated in our daily routine, quantum computation, molecular and nanotechnology will be using to change computers.