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Viewpoint: The Physics in the New Era of Computing

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Abstract

The 21st century is the Information Age, characterised by an economy based on information computerisation. In this new era of computing, the role of physics is becoming crucial and practical. Thus, physics is not seen anymore as an abstract and purely academic endeavour. This study addresses physics inventions' contributions to computer science, society, and the economy. In particular, the physics discoveries in superconductivity, quantum mechanics, elementary particle physics, vacuum tubes, transistors and integrated circuits, electronic digital computer, fibre optics, lasers, and quantum computers will be discussed.

Keywords: Information Age, Computers, Quantum Computing, Quantum Computer Intelligence

Introduction

Computer terms, such as *vacuum tubes*, *transistors*, *the electronic digital computer*, *fibre optics*, and *laser*, which are also the foundation of today's modern technology, are all invented using the laws of physics. Even *quantum computing*, a pretty exciting area of research in this 21st century, uses fundamental laws of physics, such as quantum physics.

This study mentions only the discoveries and inventions made in physics that led to innovations in computer technology and possible future development and discoveries.

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Superconductivity

Superconductivity is a macroscopic quantum phenomenon of zero electrical resistance; in some materials, the expulsion of magnetic fields occurs when cooled below a critical temperature. The first low-temperature (up to 30 K) superconductor was discovered in 1911 (Onnes, 1911). The first microscopic theory of superconductivity was developed in 1957, known as the BCS theory (Bardeen, Cooper, & Schrieffer, 1957; Bardeen, Cooper, & Schrieffer, 1957). Superconductivity, which is still an active area of research, shows promise for broadly impacting society.

High-temperature superconductivity remains an active area of research because of many relevant potential applications and the desire to create new superconducting materials at room temperature. Bednorz and Müller discovered the first high-temperature (up to 130 K) superconductor in 1986 (Bednorz & Müller, 1986). Alexei A. Abrikosov, Vitaly L. Ginzburg, and Anthony J. Legget were recognized for their contributions to the theory of superconductors and superfluids (Ginzburg & Landau, 1950; Abrikosov, 2003).

According to (Mann, 2011), there is still a heated debate about how it works because there is no unique theory, but there are many theories that most people can not agree with.

Computer science is a pretty exciting application area of superconductivity (Buck, 2014). That can be achieved by incorporating "Josephson junctions" into field-effected transistors, becoming part of the logical circuits with processors. One hundred billion Josephson junctions on 4000 microprocessors can be necessary to reach a speed of 32 petabits per second. At Weizmann Institute, small magnetic field penetration Type II superconductors are used for storing and retrieving digital information. Nanotechnology work (Omari & Hayward, 2014) predicts that future computers may be built from magnetic *tornadoes*, showing that it can be possible to create magnetic logic gates using magnetic materials as fundamental building blocks of a Central Processing Unit (CPU).

NSF, NASA, DARPA, and various universities worldwide are pursuing research in "petaflop" computers, performing a thousand-trillion floating-point operations per second. Today, the fastest computers have only recently reached these speeds, where the fastest supercomputer is "Sequola" in the Department of Energy (USA), which can operate 16.32 petaflops per second. The fastest single processor is the *Lanslet optical DSP*, running at eight teraflops. However, the main focus is to effectively use these machines soon (with tens of petaflops per second having millions of fast processor cores and designed for low power consumption at peak performance) (Schulten, Phillips, Kale, & Bhatele, 2008).

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According to (Omari & Hayward, 2014), magnetic materials are helpful for data storage because they can retain information without consuming energy. Thus, a computer built around a magnetic-made CPU should be much more power-efficient.

Quantum Mechanics

Quantum mechanics was the most fundamental field of physics that made most of the discoveries and inventions of the 20th century and continues to play an essential role in the 21st century. The foundations of quantum mechanics were formulated between 1900 and 1930 (Planck, 1943; Bohr, 1922; Broglie, 1929; Heizenberg, 1933; Schrödinger, 1933; Dirac, 1933; Einstein, 1923).

The structure of every atom, as we well know, is determined by quantum mechanics. The introduction of quantum mechanics made it possible to understand the universe's fundamental laws with great economic importance. Chemistry could, in principle, be explained in terms of the theory of quantum mechanics, as the great physicist Paul Dirac said in 1929. It is a fact that all chemistry and material science courses and physics courses include quantum mechanics in their curricula. Physics has traditionally inspired other scientific research fields and significantly contributed to the progress made in this area. Between 1950 and 1960, the birth of molecular biology has shown that quantum mechanics and physics (Schrödinger, 1944; Davies, 2008). That inspired the biologists Francis Crick, James Watson, and Maurice H.F. Wilkins to use these laws in the discovery of DNA (Crick, 1962; Watson, 1962; Wilkins, 1962) and biophysicists Max Delbrück, Alfred D. Hershey, and Salvador E. Luria for their discoveries related to the replication mechanism and genetic structure of viruses (Delbrück, 1969; Hershey, 1969; Luria, 1969).

Quantum mechanics is necessary to engineer, for instance, solid-state devices (such as transistors, as the building blocks of any electronics and computer). It would be impossible to understand to a reasonable extent, semiconductors, or any material, using only *classical physics* before quantum mechanics and relativity discoveries. The so-called quantum electrodynamics describes the lasers and the interaction of light with the matter due to the fundamental work in quantum electrodynamics (Schwinger, 1965; Feynman, 1965; Tomonaga, 1966).

Elementary Particle Physics

Elementary particle physics describes the basic building blocks of the universe in terms of *relativistic quantum field theory* (Schwinger, 1965); it is a combination of quantum mechanics and Einstein's theory of relativity. The

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information age, including modern science, would probably not exist today without quantum mechanics.

The discovery of the electron (Thomson, 1906), the first subatomic particle by Sir Joseph J. Thompson in 1897, opened the way to developing areas such as electronics, chemistry, materials science, and medicine. These are all related to an understanding of the electron.

In developed countries, the amount of Gross Domestic Product is related to science and engineering developments (such as vacuum tubes, transistors, computers, lasers, and fibre optics) (Board, 2012). It would not have existed today without the discoveries of the electron and quantum mechanics.

Vacuum Tube

As an electronic device, a vacuum tube controls the electric current through a vacuum in an isolated glass tube. The electrical contacts are put on the ends to get a current to flow through the vacuum tube. First, this was observed by Thomas Edison in 1883 (Patent No. U.S. Patent 307,031, 1884). In 1904, Sir John A. Fleming invented the two-electrode vacuum-tube rectifier (the oscillation valve, thermionic valve, vacuum diode, Kenotron, thermionic tube, or Fleming valve) (Patent No. U.S. Patent 803,684, 1904).

Today vacuum tubes are an extinct technology. However, some surprising suggestions are that vacuum tubes can build integrated circuits with modest changes to fabrication techniques. At NASA Ames Research Center, scientists develop the so-called *vacuum-channel transistors*. Although the work is earlier, scientists say it could be up-and-coming technology as vacuum-channel transistors can work ten times faster than ordinary silicon transistors and eventually operate at terahertz frequencies (Han & M. Meyyappan, 2014).

Transistors and Integrated Circuits

The transistor amplifies and switches the electronic signals and electrical power. It is composed of semiconductor material and is the fundamental building block of modern electronic devices. It was invented at Bell Laboratories (in 1947) (Shockley, 1956; Bardeen, 1956; Brattain, 1956). The transistor's invention is considered the most crucial discovery of the 20th century because it led to the telecommunications and information age revolution. That has also marked the beginning of the field of solid-state physics, one of the most active and vital areas of physics research today.

The *integrated circuit or chip puts together several electronic circuits in one chip.* The chip is a small plate made of semiconductor material, usually silicon. Today's technology can create integrated circuits with up to billions of transistors (and other electronic elements) in a tiny area of tens of nanometers (Intel, 2014). The first integrated circuit (five transistors on a semiconductor-

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like amplifying device) was developed in 1949 (Patent No. DE 833366, 1952). Other scientists (Alferov, 2000; Kroemer, 2000; Kilby, 2000), conceived the idea to invent integrated circuits, also named the IEEE Milestone. This chip was made of germanium. Later, the idea was developed further by Robert Noyce, who came up with his silicon chip (Noyce, 1977). These developments were the basis of the first silicon-gate integrated circuit technology, the main component of today's Complementary Metal Oxide Semiconductor (CMOS) computer chips, developed by Federico Faggin in 1968, who developed the first Central Processing Unit on one chip (Intel 4004) (Faggin, 1992).

The transistor is the basis of all modern electronics and computers, including battery-operated watches, coffee makers, cell phones, and supercomputer (Vardalas, 2003). At the beginning of the development of integrated circuits, only a few transistors could be placed on one chip. The number of transistors in a chip increases by about 50-60 % yearly (Hennessy & Patterson, 2006). As historical advancement of Intel Microprocessors, for instance, the number of transistors grew from 6,000 in 1974 for the Intel 8080 processor to 42 million in 2000 for the Intel Pentium 4 processor (Turban, Rainer, & Potter, 2005). Today's microprocessors for modern personal computers contain billions of transistors in a chip. Due to transistors, today's personal computers can pack all their computational power into a tiny microchip at a relatively cheap cost, which uses very little electricity. Due to the transistor and integrated circuits, the affordability, small size, and power of modern computers and electronics are possible.

Lasers

Albert Einstein first developed the modern photon concept in 1905 to explain the experimental results, which could not be explained using the classical view of light as a wave. This discovery made possible the invention of the *laser*.

First, in 1954, Charles Townes built the microwave laser (H. C. Townes, 1999). In 1960, Theodore H. Maiman built the first optical laser (Maiman, 1959). With the laser, we understand a device that emits light through optical amplification of the stimulated emission of electromagnetic radiation (Gould, 1960).

In 1964, the fundamental research in quantum electronics (Townes, 1964; Basov, 1964; Prokhorov, 1964) led to the invention of microwave laser, the so-called MASER (Microwave Amplification by Stimulated Emission Radiation), an optical laser. The lasers have many applications, including CD players, CD-ROMs, CD-burners, DVD players to read/write data, and fibre optics.

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Computers

In 1939, Professor John Atanasoff and his physics graduate student Clifford Berry built the first electronic digital comput (Atanasoff, 1973; Atanasoff, 1984). This first electronic digital computer is sometimes called the Atanasoff-Berry Computer (ABC), a small-scale special-purpose electronic digital machine containing around 300 vacuum tubes to solve systems of linear algebraic equations. In 1990, USA's President George H.W. Bush awarded John Atanasoff with the National Medal of Technology to recognize his achievements related to technological progress.

Vacuum tubes were used as switches making it possible to build an electronic computer; however, the cost and relatively short mean-time-to-failure of tubes were limiting factors. The first electronic digital programmable computer, Colossus, in 1934, containing over 3,000 tubes in small independent modules, was designed by Tommy Flowers, who discovered the way the vacuum tubes could operate reliably for very long periods, mainly if their heaters were run on a reduced current (Flowers, 1983). He pioneered using tubes as high-speed electronic switches (compared to electromechanical devices).

ENIAC (Electronic Numerical Integrator And Calculator) (Patent No. U.S. Patent, 1973) was the first fully-operational electronic general-purpose computer. It was Turing-complete, digital, and capable of being reprogrammed to solve a large class of numerical problems. It took 30 months with 200,000 person-hours to build the ENIAC, and it was publicly disclosed in 1946. The ENIAC was enormous (around 100 feet long, $8\frac{1}{2}$ feet high, several feet wide, and weighing 30 tons) and contained 18,000 vacuum tubes. The device took days to program and could only store 20 numbers. In 1944, after John von Neumann joined the ENIAC project, the EDVAC (Electronic Discrete Variable Automatic Computer) was proposed as a binary and a stored-program computer. This proposal has been used to name this computer the *von Neumann* computer, but John Mauchly and John Presper Eckert have equally contributed to the invention of the machine, according to (Hennessy & Patterson, 2006).

The quality of the tubes on one side and the diversion of skilled people during World War II limited the tubes' quality (Randall, 2006). After the war, development continued with tube-based computers. In 1949, the EDSAC (Electronic Delay Storage Automatic Calculator) was built to store computer programs, using mercury delay lines for its memory (V., Wheeler, & Gill, 1951; Wilkes, 1985). A smaller prototype was built earlier, in 1948, at the University of Manchester, named Mark I, which could be called the first available operational stored-program machine. The instruction set architecture

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of the EDSAC, an accumulator-based architecture, remained popular until the 1970s.

Quantum Computers

A new challenge came when Richard Feynman, known for his work on quantum mechanics' *path integral formulation*, theory of quantum electrodynamics, superfluidity, and particle physics, suggested that it would be possible to simulate quantum systems using quantum mechanics. That alluded to some proto-quantum computer.

A quantum computer is a system that can store and process information according to the laws of quantum mechanics. The idea took shape in 1985 when, based on Feynman's ideas, David Deutsch proposed a new architecture based on quantum mechanics, assuming that all physics is derived from quantum mechanics (Deutsch & Ekert, 1998; Nielsen, 2002). An object can simultaneously exist in two different states in a quantum world, a phenomenon known as superposition. That means that in contrast to the ordinary bit in classical computers, a quantum bit (or *qubit*) in quantum computers can be placed in a complex state where it is both 0 and 1 simultaneously. When measuring the qubit's value, it must only take on one of these values.

Quantum superposition enables quantum computers to simultaneously consider and manipulate all combinations of bits, making quantum computation powerful and fast. The main point is that often we are interested in only a subset of the calculations. Measuring the final state of a quantum computer will give us only one answer randomly chosen, which may or may not be the desired solution. Thus, the art of a quantum algorithm is to get the answers that are not needed and cancel them out so that only one answer is left, which is a solution to the problem.

We first need the qubit's fundamental computing element to build a quantum computer. A qubit could be any object, obeying the laws of quantum physics that can be placed in a superposition of states. A quantum degree of freedom can be a charge, spin, photon polarization, or magnetic flux. Quantum systems are being explored as qubits, with their specific advantages and challenges: single atoms in ion traps, nitrogen-vacancy defect centres in diamonds, and superconducting circuits. Qubits based on semiconductors are attractive because of their electrical tunability. They can easily be integrated into the electronics industry, but searching for a perfect semiconductor that satisfies the requirements of fast quantum control, long coherence time, and scalability to thousands of coupled qubits continues.

The only company selling a quantum computer is D-Wave Systems. D-Wave uses qubits based on superconducting loops, although these qubits are wired together to make a computer that operates differently from a universal quantum computer. This company uses an approach known as

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adiabatic quantum computing, in which the qubits are placed initially in a state that relaxes into an optimal configuration. Although this approach can quickly solve specific optimization problems, D-Wave's computers can not implement arbitrary algorithms. The quantum computing community is still debating the extent to which the D-Wave's hardware behaves according to quantum mechanics laws. Since 2009, Google has been working with D-Wave Systems, and their independent tests found that D-Wave's computer may not use quantum physics to solve problems. John Martinis, a physicist, and professor at the University of California, Santa Barbara, has joined Google to establish a new quantum hardware lab working on constructing superconducting quantum circuits (Barends, et al., 2014).

Quantum Computer and Intelligence

We want to answer whether a computer can think like a human for arbitrary computer architecture. That would make a computer an *intelligent* machine. From the viewpoint of the Turing test, the responses from a hidden source can be either human or artificial. According to Turing, one must be intelligent if one can not distinguish between the two sources.

The idea that quantum mechanics and consciousness are related is essential in quantum mechanics. The human brain and its mental aspects are connected with classical brain physiology and the multidimensional quantum physics universe. The universe can be seen as a (4 + D) dimensional space, or $R+iR_I$, where R is the usual 4-dimensional space-time and iR_I is the D-dimensional space-time. Here, D is related to the individual mind, an expression of a universal mind through holonomic communication with quantum fields (Bhadra, 2017). Many other theories of consciousness relate (Penrose, Shadows of the Mind. An Approach to the Missing Science of Consciousness, 1994).

Furthermore, the coherence of quantum states among the brain proteins leads to material changes in brain physiology; that is, a collapse of the quantum coherent states of tubulin proteins occurs due to quantum gravity at the spin level (Jibu, Yasue, & Hagan, 1997; Carvallo, 1997). Here, it has been postulated that gravity is the entropic compensation for the motion of mass or information rather than a force (Verlinde, 2011) and hence argued that the consciousness may originate from a gravity-mediated reaction on the entropic displacement of information occurring in the high-density human brain (Meijer, 2012).

Returning to our original question of whether a computer can think like a human would mean an algorithm can think like a human. However, the human brain does not work simply by applying some algorithm but based on a trial-and-error basis, using prior experience. The Turing machine model can run the same algorithm indefinitely to solve a problem, leaving away human

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reasoning. However, mathematical models, such as machine learning or deep learning, may be used to build model systems closer to the nature of human reasoning than to the functioning of the Turing machine model. The basis of these mathematical models is trial-and-error reasoning, using prior experience, and not general rules applied to algorithms (Bhadra, 2017).

Based on (Koch & Hepp, 2006), human consciousness emerges from computations among brain neurons, each receiving and integrating synaptic inputs. Note that the human brain is a network of about 10^{11} neurons, and together with these chemical synapses, they are considered a fundamental building model for computer simulations of brain function in the area of Artificial Intelligence. However, viewing the brain as a computer may need to be complete (Hameroff & Penrose, 1996). Thus, it was suggested that consciousness depends on biologically inspired quantum computations in clusters of microtubules within brain neurons responsible for regulating neuronal activities (Hameroff & Penrose, 1996). In this view, the quantum world's objective reality may play an essential role in consciousness or intelligence. It is also possible to have a robotic computer with a human-like brain. Then its robotic brain functions like a human brain if trained with some initial information. Furthermore, the intelligence may not only be related to the quantum level but also Einstein's space-time (Bhadra, 2017) (and the references therein); thus, the quantum-gravity may play an essential role in the next generation of quantum machines and perhaps help to answer the question if the quantum computers can think, based on that they have a quantum architecture (Penrose, On gravity’s role in quantum state reduction, 1996).

Quantum mechanics laws explain how living brains obtain information using sensory systems, where the entangled radical electrons play an essential role. Besides, other complex brain functionalities depend on the specific nuclear spins, which can be explained only using quantum mechanics laws. Until now, no reliable experimental methods have been established to distinguish classical from quantum correlations in living brains (Kerskens & Pérez, 2022).

From the classical mechanics’ viewpoint, the relationship matter-energy is local and involves direct contact, which is also standard in quantum mechanics. However, from a quantum mechanics viewpoint, quantum particles can correlate instantaneously at any distance; relationships can be non-local. The non-locality is in favour of the existence of multidimensional space-time reality (Bhadra, 2017). There is a dualism of the energy waves; the energy of particles at the stages of symmetry group SU(11) are in the form of waves, which by symmetry breaking produces the energy sources of location SU(6), responsible for the biological intelligence, and energy sources SU(5), responsible for the physical-material of the universe and living creatures, including human. Here, the particles of the energy sources of stage

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SU(5) obey the physics laws of dual wave-particle behaviour; that is, entanglement, and hence in our physical universe, the energy sources producing intelligence and those growing physical matter always behave like entanglement. Further, the intelligence may frequently change due to the random superposition of the wave functions. Moreover, one can expect that energy sources SU(6) produce intelligence elements belonging to the energy sources SU(5) by transferring non-ordinary matter into ordinary matter and hence making biological cells. The energy sources SU(6), responsible for natural intelligence, creates the individual identity (such as plants, animals, human, and so on) (Penrose, The Emperor's New Mind. Concerning Computers, Minds, and the Laws of Physics, 1989; Penrose, Shadows of the Mind. An Approach to the Missing Science of Consciousness, 1994).

The coupling of wave information to intelligent processes suggests that the wave information transmits from and into the brain by wave resonance. Further, the quantum system of the human brain interacts with a quantum environment from which the phase information is lost. Moreover, the quantum coherence in biological cells or human brains may have long-range spatial behaviour by entanglement. Very recently, an experimental method was established to measure the quantum correlations in the living brain for the first time (Kerskens & Pérez, 2022). The idea was to witness the entanglement by searching for auxiliary quantum systems measured using a non-invasively approach (such as nuclear magnetic resonance) in the consciously aware brain, which can be used as sufficient proof of the quantum mechanics' function of the brain. The experimental evidence was found that quantum entanglement was created for the physiological and cognitive processes in brains; hence, consciousness/intelligence is non-classical.

Moreover, very recently, it has been shown that a new phase of matter was created that has never been seen before, where the atoms have two-time dimensions (Dumitrescu, et al., 2022). That new phase was completed by hitting with a laser pulse based on the Fibonacci sequence at atoms used inside a quantum computer. This is a breakthrough in quantum computing because one can protect stored information from errors. Besides, the discovery of the time that exists in two dimensions may lead to the 5th dimension of the phase of matter, an element of the SU(5) group, because they are considered as higher dimensions phases of matter projected into lower dimensions, similar to a 2D Penrose tiling is a slice of projected 5D lattice (Dumitrescu, et al., 2022). Further, the higher dimensions go behind the physical 3D spatial dimensions; hence, it is reasonable to assume that they are elements of the SU(5) group. Based on the duality between SU(6) and SU(5) discussed above (Bhadra, 2017), human consciousness/intelligence could be created inside quantum computers. Interestingly, using the time to control the boundaries around the phase of matter to create a so-called dynamic topological phase or

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time-crystals (quasicrystals flowing in one of the dimensions) has been subject to the previous study (Mi & al., 2022; O'Sullivan, et al., 2020; Andersen, 2019).

According to Hartmut Neven, Director of Engineering at Google, *quantum machine learning may provide the most creative problem-solving process under the laws of physics.*

Conclusion

I discussed the role of physics in the 21st century, considered the *information age*, characterized by an economy based on information computerization. In this new computing era, physics should no longer be seen as an abstract and purely academic endeavour.

I want to encourage fundamental research in physics at both the academic and Research & Development levels.

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