Microprocessors, touchscreens, artificial intelligence, and consciousness

In a recent conference held at the University of Brasov, Romania, Federico Faggin described his “four lives”, from Italy to Silicon Valley, in a remarkable journey of inventions, entrepreneurship, and self-discovery culminating with the creation of a new scientific theory of consciousness and free will.

Born in Vicenza, in northern Italy during the second world war, Faggin spent six early years in a small town in the countryside untouched by the industrial revolution. Back in Vicenza a few years after the war, he went to a technical high school, graduating in 1960 in radio engineering. His first job was at the R&D Laboratory of Olivetti in Borgolombardo, Milan, where he spent the entire year 1961 designing in part and building a small experimental electronic computer using transistors rather than vacuum tubes.

Faggin realized that computers and transistors were the future of electronics and decided to leave Olivetti to study physics at the University of Padua. He wanted to understand quantum physics, the discipline that explains how transistors function. After graduating summa cum laude toward the end of 1965, he spent the academic year 1955-1966 teaching electronic laboratory to third-year physics students. In the summer of 1966, he left the University to join a startup near Milan and he was sent to take a one-week course on MOS integrated circuits (ICs) in the nascent Silicon Valley, near San Francisco. The course was given by GMe, General Micro electronics, the first company to commercialize MOS ICs. Previously, all ICs used bipolar transistors, a mature technology that appeared unbeatable.

Nine months later, Faggin joined the R&D Laboratory of SGS-Fairchild in Agrate Brianza, near Milan, where he developed their first MOS process technology starting from scratch. At SGS he also designed their first two commercial MOS ICs. In February 1968, newlywed Faggin was sent to Fairchild Semiconductor to work for 6 months at their R&D Laboratory in Palo Alto, California, in an engineering exchange program.

This was the beginning of Faggin's second life, starting in a new country with a new language and a different culture in a place that was to become the world's high-technology Mecca.

The life of an inventor

Faggin was assigned to lead the development of the MOS silicon gate technology, reporting to Les Vadasz, the head of the MOS process development group. Tom Klein, had been working for several months on a self-aligned-gate process technology using silicon as a gate material, based on some preliminary work done at Bell Labs. He had shown that the threshold voltage of transistors with a silicon gate would be 1.1 volt less than the one of comparable transistors with aluminum gate.

However, there was no known method to precision-etch thin films of silicon, and no process architecture to properly shape the geometries of the masks needed to fabricate self-aligned transistors suitable for ICs. Vadasz and Klein had not been able to solve these problems despite trying for several months.

In short order, Faggin developed an etching solution, and invented a new process architecture that was very challenging to figure out. Later he created a test pattern to be able to measure all critical process parameters, and designed all the 30 or so processing steps necessary to make ICs with SGT. After the process was working, Faggin designed a silicon-gate version of a commercial MOS product that was difficult to manufacture because it needed strict specifications, namely the Fairchild 3705, an 8-bit analog multiplexer with decoding logic. By mid-July 1968, Faggin had fully functional chips of the world's first commercial IC with self-aligned gates: the Fairchild 3708. Using the 3708 as a test vehicle, he then made major improvements to the process and, by the end of 1968, the first 3708s were sold commercially.

Compared with the 3705, the 3708 achieved far better characteristics: the 8 large switches had three times less ON resistance, between 100 and 1000 times less leakage current, and the switching speed was more than 3 times faster. During the same year, Faggin also invented and developed the "buried contact", a new way to make direct contacts between polysilicon gates and junctions. This invention allowed two layers of interconnections, which doubled the transistor density of random logic designs.

Only one limitation remained, the non-feasibility of "bootstrap loads", a type of circuit that required an isolated capacitor, and was indispensable to make complex random-logic chips with two-phase dynamic logic. Given the importance of these types of circuits, Fairchild did not want to replace the incumbent technology with SGT.

Faggin did not give up and continued to think about how to solve this nagging problem until, in early 1970, he finally cracked it. Now the SGT was invincible, for it could achieve, with the same power dissipation and cost, 5 times the speed, twice the circuit density and at least 100 times less leakage current than metal-gate MOS. Moreover, floating gates and multiple gates empowered new functions impossible with metal gates. With SGT, dynamic random-access memories (DRAM), non-volatile memories (EPROM), and microprocessors were developed in 1971, leading to a computer on a single chip less than 10 years later. Moreover, SGT allowed commercializing CCD image sensors for the first time in 1974, and Flash memories in 1987.

The SGT became the basis of all modern NMOS and CMOS integrated circuits, eventually superseding all the ICs built with bipolar transistors. By 1990 nearly all new integrated circuits fabricated in the world used SGT, an achievement that was unthinkable in 1968.

Faggin's next challenge was to prove that the SGT was far superior to metal-gate for random-logic applications, vindicating the refusal of Fairchild to adopt the SGT soon after its invention. The opportunity to do so was offered by a project at Intel that no one could have accomplished without Faggin's invention of the bootstrap loads in silicon gate. This was a custom family of chips for Busicom, a Japanese calculator manufacturer, later named MCS-4 family. At the heart of the MCS-4 was a single-chip CPU, the world's first microprocessor, with the other chips performing the read-only memory (ROM), DRAM, and input-out (I/O) functions of a general-purpose computer. Faggin was very excited at the thought of designing the 4004, the most complex random logic chip ever made.

When Vadasz, Faggin's boss at Intel, gave him the timetable promised to Busicom, his jaws dropped. It was clear that his boss had no understanding of the scope and complexity of the project. For example, the layout of the 4004 was planned to be 7 weeks with two draftsmen whereas it took 17 weeks with three draftsmen. Vadasz was familiar only with memory chips, Intel's main line of business, in which all memory cells are identical. In random-logic circuits almost every circuit is unique, and the connections are quite tricky, therefore far more time and skill are required.

Another surprise was that no work had been done in the six months that followed the agreement on the development schedule. All that was given to him was a block architecture and the overall specifications. Thus, the project was already half a year late before its development got started. Faggin also discovered that the architecture conceived by Ted Hoff, Stan Mazor, and the Busicom engineers could not be realized without his buried contact and his most recent invention of the bootstrap load. Intel and Busicom did not know they had endorsed an unfeasible project!

Furthermore, Intel had no design and simulation tools, no library of basic circuits, and no testers for random logic chips like all other companies offering custom-logic chip services had. All the phases of logic, circuit, and layout design plus the characterization and production testing fell entirely on Faggin's skills and leadership, since Les Vadasz was totally preoccupied with the 1103 DRAM development, considered vital at Intel.

After 11 months of grueling work with help from Masatoshi Shima of Busicom for six months, the entire family of chips was fully functional, and production could start. The 4004 was the first significant example of large-scale integration (LSI) that highlighted the superiority of SGT for both analog and digital applications, replacing existing multi-chip CPUs with higher speed and lower cost.

When Faggin completed the 4004 layout, he felt like this work had established a new state of the art in semiconductor technology, and with spontaneous pride signed the artwork with his initials, F.F., in a corner of the chip. This innovative layout served as a model on how to use the SGT for complex random logic circuits, thus accelerating the adoption of SGT by the global semiconductor industry.

Faggin also played a leadership role in convincing Intel's management to sell the 4004 and the 8008 microprocessors to the general market, instead of being solely custom products.

In early 1972, after supervising the design of the 8008, Faggin conceived the 8080 architecture, a second-generation 8-bit microprocessor, machine code compatible with the 8008 architecture, which originated from Datapoint, its intended customer. The 8080 was a major step forward compared with the 8008, for it was 6 times faster, much easier to interface with memories and I/O circuitry, and it had other major architectural improvements. It took Faggin 9 months of lobbying management before being allowed to begin the project. This delay reduced Intel's leadership in microprocessors from 15 to 6 months. Faggin was disheartened and this lack of understanding convinced him to start Zilog, Inc., a company entirely dedicated to microprocessors and microcontrollers. Intel was a memory chip company that did not yet believe in the future of microprocessors.

The development of the early microprocessors is bound up with the natural evolution of the MOS SGT from P-channel transistors to N-channel, and later to N-channel with depletion loads. Faggin was at the forefront of this revolution, first by developing the P-channel and N-channel SGT at Fairchild, the technology that made it all possible, and then in 1973 developing at Intel the first high-speed, N-channel, fast static RAM using N-channel technology with depletion load.

The life of an entrepreneur

In November 1974 Faggin founded Zilog, Inc. with Ralph Ungermann, one of the managers who reported to him at Intel. At Zilog Faggin conceived and directed the development of the Z80-CPU, a third-generation microprocessor, and conceived the Z8 microcontroller. These processors used depletion loads; a technology that continued to be vital before the general shift to CMOS technology that occurred in the early 1990s.

The Z80 and the Z8 became best sellers in their categories and are still in production in 2024.

The foundation of Zilog ended Faggin's second life, that of an inventor of technologies and products, propelling him into his third life as a high-tech entrepreneur. From the personal development perspective, his 35-year career as founder and CEO of three startup companies, CEO of a fourth company, and angel investor led him to a remarkable inner growth.

The first step of this growth was taking full responsibility for what happens in his life, whether good or ill, by recognizing that blaming others was a way to avoid looking into one’s deeper motivations. This new attitude allowed him to later recognize that for many years he had been pretending to be happy when he was deeply suffering, despite his major accomplishments. Taking responsibility for this state allowed him to accept it and decide that it was necessary to look within more deeply to understand what was happening.

At that time Faggin was running his third startup, Synaptics, a company that was developing artificial neural network chips using analog technology. While also studying biology and neuroscience, Faggin realized that these disciplines, especially neuroscience, were completely neglecting the role of consciousness, that same consciousness which was the source of his unhappiness. Faggin then tried to program a computer to be conscious and realized that this was a fool’s errand. In fact, there is no known physical phenomenon capable of transforming electrical and biochemical signals in the brain into the sensations and feelings – what philosophers later called qualia – with which consciousness perceives and understands its own state.

During the 1990 Christmas holidays, Faggin had an extraordinary experience of consciousness that showed stunning properties he could not have possibly imagined. This awakening experience is described in detail in his book, *Silicon. From the invention of the microprocessor to the new science of consciousness*. It revealed that each of us is a *part-whole* of the Universe, just like each cell of our body is a part-whole of the entire organism. This is a remarkable holographic property since each cell contains the entire genome of the fertilized egg that created the organism. Thus, each *part* contains the potential knowledge of the *whole*.

Faggin’s awakening experience was so powerful that his perspective about the nature of self and the nature of physical reality were drastically changed, motivating him to start a deep exploration of the nature of his own consciousness, the only one that can be known directly.

Leading a double life

This experience changed the trajectory of Faggin's life, marking the beginning of his fourth life. For the following many years Faggin conducted a "double life", combinig his third life of entrepreneur with the fourth life of an explorer of consciousness.

About one year later in his third life, Faggin identified a potential new product: replacing the trackball used in laptop computers with a solid-state solution. Brainstorming with a small team of engineers, they found together the solution in a few months. It was the invention of the touchpads and touchscreens that have changed the way we interface with our mobile devices. The first touchpads were created in 1993 and that same year Faggin decided to stop the neural network research that, though promising, would have required many more years before it could turn into a real business.

The first touchpads became available in mid 1994, and high-volume production began in early 1995. The success of the touchpad was fueled by the rapid growth of laptop PCs, and Synaptics became the top producer of touchpads with 70-80% market share against formidable competitors. This was primarily due to the high quality and innovative features of its products. Later, Synaptics pioneered the use of touchscreens for smart phones and the company has been a leader in human-to-computer interface devices ever since. Faggin led Synaptics until 1999 and then he became its chairman until 2009.

In his exploration of consciousness, Faggin realized that the deep unity of the universe described by quantum physics could help illuminate the nature of reality that must include not only the outer reality of objects in space-time, but also the inner reality of qualia, comprehension and meaning. This intense personal work gradually led him to the hypothesis that consciousness and free will must exist from the very beginning of the universe, contrary to the materialist view that consciousness is a property of a functioning brain, and free will does not exist.

In 2003 Faggin became CEO of Foveon, a company making advanced image sensors, and in 2008 the firm was sold to a Japanese company. That same year, Faggin decided to dedicate the rest of his life to studying consciousness with the objective of merging physics and spirituality. By mid 2009 he had gradually shed all his other business commitments to finally be free devote himself full-time to the new project. To this end he also established with his wife in 2011 a non-profit organization named Federico and Elvia Faggin Foundation.

The merger of physics and spirituality

The major accomplishments of this new enterprise have been a scientific theory of conciousness and free will developed with G.M. D'Ariano, an authority in the field of quantum information, and a more recent theory that merges physics and spirituality. The first theory (D'Ariano-Faggin) has just been published in a book titled, *Irreducible. Consciousness, life, computers, and human nature,* translated from the original Italian version that was published in 2022. The second theory by Faggin has also been published this year in Italy with the title, *Oltre L'invisibile. Dove scienza e spiritualità si incontrano*. The book will soon be translated in English with the title, *Beyond the Invisible. Where science and spirituality merge*.

This latest theory begins with a postulate, the *Postulate of Being,* which states: *One, All that is, is dynamic, holistic and wants to know Itself*. Starting with this postulate we can then explain why quantum physics and classical physics must exist and have the crucial properties they have, especially those that have been controversial to this day.

The consequences of this testable theory are extraordinary because they fundamentally change how we conceive physical reality and ourselves. It is especially timely given the recent progress in artificial intelligence (AI), with its promises to soon create conscious robots and intelligence superior to ours.

According to this theory, we are *seities,* i.e., quantum fields with consciousness and free will, a new name necessary to distinguish them from the quantum fields of quantum physics that are neither conscious nor have free will.

Seities and their conscious experiences exist in a quantum reality much vaster than the symbolic one that only exists in space-time. Conscious experiences are private and non-reproducible, like the pure quantum states of quantum field theory. Together the seities create a semantic inner world of qualia perception, comprehension, and meaning knowable only by them.

Seities may communicate with other seities or with quantum-classical bodies using what Faggin calls *live* symbols, and bodies communicate with the quantum-classical physical reality in space-time using *classical* symbols.

Live symbols are virtual particles, elementary particles, nucleons, atoms, and molecules in space-time, interacting quantumly with each other. These are *coherent* structures that also exist inside the living cells of which our physical bodies are made.

Classical symbols are *incoherent* collections of large numbers of live symbols that behave deterministically, thus forming classical physics and classical symbols.

The human body senses only a minute portion of the classical symbols existing in space-time and processes this information producing classical symbols outside, and live symbols inside, the inner machinery of its cells. A portion of the live information of the body's cells is then perceived and transformed by the seity into her conscious experience.

Contrary to the claims of scientism, we are not our bodies in space-time but are seities existing in a deeper reality than space-time. As seities, we control our bodies that behave like semi-autonomous drones, through which we experience the "physical reality" largely produced by our bodies, and only for as long as our bodies live.

The ego is that small portion of a seity that believes to be the body. When the latter dies, the ego "wakes up" from its identification with the body and realizes it is other than the body.

Our bodies exist in a quasi-virtual reality to serve the seities' deeper purpose of knowing themselves. The seities interact in space-time using that marvelous instrument that is our quantum-classical body, a far more sophisticated machine than any classical computer or robot we know.

Being quantum fields, we will not die. Our creativity derives from our volitional quantum-field nature, capacities that cannot be duplicated by either classical or quantum computers. The sooner we understand this message, the sooner we will learn that creative and hearfelt cooperation, and not competition, is the only way out from the major social and environmental problems that our materialist and reductionist outlook has created.