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The Way the Advancement of Integrated Circuit Technology Bolsters IT Education

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Abstract. IT education is popular among the world right now. However, it was not the case when the first PC was invented. This paper would analyze the advancement of integrated circuit bolsters IT education in three ways: Technology is pushing the processors to be cheaper, making more people be able to afford computers thus making IT education possible; Processors are becoming more and more powerful that they are greatly contributing to increasing productivity, thus making the IT education more and more important to meet those goals; The low power-consuming high-performance processors are applicable to portable devices (smartphones, tablets, etc.), making IT education more accessible to children. As the time went by, the processors would be cheaper, more powerful, and less power-consuming. The IT education will have a brighter future.

1. Introduction

Processors used to be very expensive. And they were not very powerful and power-consuming at all. These all became the barriers for IT education—no one would be able to afford a computer; there was no need for IT education; children and teenagers hardly had access to IT education. Thankfully, due to the advancement in IC technology, these problems are alleviated.

2. Advancement of IC technology bolsters IT education

2.1. Cheaper processors make IT education possible

Processors have been very expensive since they were first invented in 1971. Back in 1971, Intel published its first processor—Intel 4004. In today's opinion, it would be a processor that is even much less powerful than the processor in a toy car. (see Figure 1[1]) It was already the most advanced processor adopted in “computers” at that time.

1971	4004	Intel	740 kHz	4	10 μm	2,250 pMOS
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Figure1. The statistics of Intel 4004

Intel 4004 was sold at the price of \$200 in 1971[2], while the index of annual income of Americans was still \$9000[3]. The price of the processor alone accounted about 1/3 of the monthly income, let alone the entire machine. The computer, even the chip, was not affordable for many people, making the IT education completely impossible in that period.

During the development of the IC technology, the cost of producing per wafer, the fundamentalist of producing processors, grew from \$731 to \$2375. (see Figure 2[3])

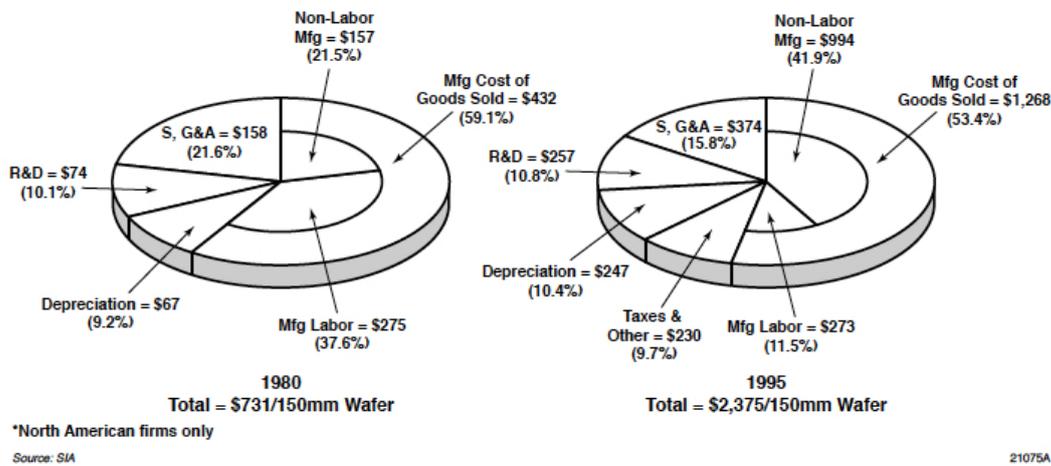


Figure2. The cost of each element in the wafer production

However, the cost per wafer is distinguishable from cost per processor. Despite the horrible increasing in the figure, the number of transistors that can be put on a wafer, has grown faster than manufacturing costs. In detail, this ever-increasing cost per wafer is offset by the ability to shrink feature size by 30 percent each device generation, thereby decreasing the manufacturing cost per transistor. Apart from the processors, the effective price of DRAMs that is measured in cost per bit, also falls by 30 percent per year. There are three advancements that make the manufacturers be able to put more transistors on the chip:

2.1.1. *The precision of photolithography increased.* The precision of the photolithograph is increased by the increase of the numerical aperture and the decrease of k1 factor. (see Table1[4])

Table1. The evolution of photolithography techniques

Wavelength	436 nm	365 nm	248 nm	193 nm
NA	0.28	0.40	0.57	0.85
Resolution (nm)	1400	700	250	80
k₁-factor	0.90	0.77	0.57	0.35
1st prototype	1975	1987	1995	2003

1) The light that is used to photolithograph has shorter and shorter wavelength

To photolithograph smaller ICs, the light which is used to carve on the wafer, has shorter and shorter wavelength due to diffraction limit. The light that is used for the photolithography has been changing due to the requirements of precision. For lights of different wavelengths, they have their own diffraction limits. When the size of the transistor has gone beyond the diffraction limit of a certain type light and no other special techniques can help with etching the photoresist, the light will not be able to photolithograph on the wafer to that precision any more. Hence, the light that is used to etch on the photoresist has been switched from visible light to ultra violet, from the wavelength of 436nm, 365nm, 248nm, 193nm, all the way down to 13nm.

2) The material that is used for the gates has changed

The gate material that is used by transistors is changed from polysilicon to metal, avoiding many negative effects such as heating, polysilicon depletion effect, etc., making fitting in more and more transistors possible.

Since polysilicon is also silicon, its conductivity is never as good as metal. According to ohm's law, $Q=I^2R$, the heat produced by polysilicon is much greater than metal. The transistor itself already generates a great amount of heat. With extra heat from the polysilicon, as the transistors' number increasing, the heat would burn down the entire transistor. However, when polysilicon is switched to the metal, it is plausible to fit in more and more transistor into one processor.

2.1.2. The mass production also makes the processors cheaper. Intel's best i7 processor, which was called i7 8700k, published in Oct. 2017, sold at \$350. And Intel 4004 was about \$200 at 1971. For 2016, the national average wage index was \$48642.15, which equaled to about \$4053.5 monthly; for 1971, the national average wage index was \$6497.08[5], which equaled to around \$541 per month. Compared with the price of processors that time, the processors today are much cheaper. Nevertheless, the cost of producing the processors are growing more and more expensive. The photolithography machine manufactured by ASML today could be as expensive as \$100 million. Plus, the R&D investment must be much greater than before because for now there are much more technology barriers than before. And the advertising cost of today's processor is much greater than before. However, while Intel core 8700k has sales of 18k sales until Mar. 2018 on JD in China alone, let alone the Taobao, amazon, etc., Intel 4004 has sales fewer than 10k (Since Intel 4004 is made for a calculator for a Japanese company which is called Basicom, even though the sales statistics of Intel 4004 cannot be found, the sales of the calculator must below 10k) This makes the difference. Since all those manufacturing costs, R&D costs, and advertising costs are divided to processors, the more the sale is, the cheaper the price is. With such gap of sales between Intel 4004 and Intel i7 8700k, the price of 8700k could be cheaper than 4004 concerning the inflation and economy growth.

2.1.3. The Moore's law is a strong catalyst lowering the processors' price. Even though Moore's law is now used by the Intel & AMD as a marketing policy, to fulfill the Moore's law, Intel & AMD have been working hard to reach the goal that the computing ability and the number of transistors double every 18 months. This leads to the phenomenon that a generation of processors will drop to half of the initial price after 18 months. Except for some of the fields, IT education don't require the latest and most powerful processors in the world. The processor of the last generation is enough for IT education. And this kind of processor has the best performance-price ratio.

2.1.4. Conclusion. Due to the reduced cost of producing per processor, many sold processors are dividing the R&D, advertising and manufacturing cost, and the price of the processors is going down quickly, the processors are much cheaper than before. That makes the foundation of IT education—PC—more affordable, making the IT education possible.

2.2. More advanced processors desire a booming IT education as a backup

The computing ability of processors haven't reached 500MHz until 1998 (see Figure 3)

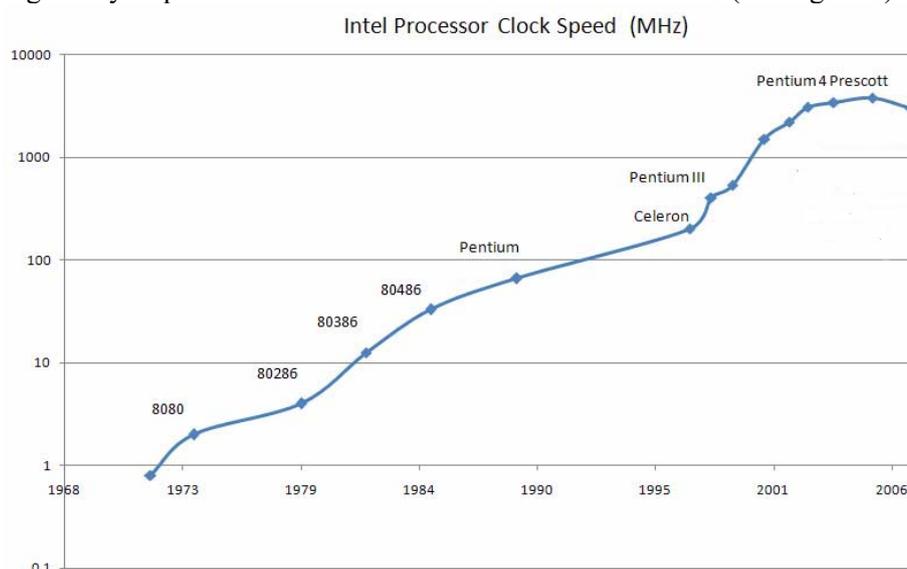


Figure3[6]. The clock rate of processors over time

The computing ability during the early 1990s of the processors were too poor that they were almost merely used to process words and tables [7]. Photoshop of that time didn't have the concept of layer. The web browser was text-only. Hence productivity that was provided by the computer that time was limited. The need to propagate IT education during that period was trivial. However, the computing ability quickly grew during the 1990s. First, in 1998, it reached 500MHz, then in 2000 it reached 1GHz.

Furthermore, the emergence of x64 architecture also boosted the ability of processors. Although it didn't really increase the processors processing ability, it expanded the general-purpose registers from 32-bit to 64-bit and added the number of registers, enlarging the maximum DRAM size from 4 GB to 16EB. When a x64 processors were executing the same command as x86 does, due to x64 processors' faster speed to read the data from caches and DRAMs, its processing speed would be faster than the x86 processors did even if they had the same processing ability.

More and more powerful processors have greatly increased productivity. One example is virtual reality in the industrial manufacturing. Before, the processors were not be able to provide 360° surrounded high-definition realistic environment for us users because their computing ability was limited. To accomplish this, the processors must be able to process much more pixels than before on the screen. In recent years, the processors in the graphics cards have this kind of ability. [8] By allowing for an immersive view of the 2D and 3D objects, all the objects, processes, activities and principles that are involved in the virtual reality environment, and virtual reality can offer users the opportunity to simulate the manufacturing without concerning any possible mistake.

[8] Virtual reality can be used for manufacturing training. When the actual manufacturing environment is quite dangerous, expensive or impossible to use, while Virtual reality can simulate the real scenario and help train the employees due to its ability to highly simulate. With this method, neither will the employees' safety be endangered, nor the company would take the risk or spend a lot of money. The employees could also be successfully trained.

[8] Virtual reality can be used for designing. The designs are first given in the form of CAD. In the past, when they wanted to check viability of the entire design, they had to make many physical prototypes before they were going to have the final design. Plus, the time consumed in the process made the physical prototypes great. With the help of Virtual reality software, the designers can immediately see the real-time 3D model, to check their viability, eliminating the waste of labor, time and money.

However, the convenience of virtual reality manufacturing needs great help from hardware and software developers. Without those people, the virtual reality technology would not exist. Furthermore, as the time goes by, the manufacturing industry will need more and more virtual reality hardware and software since the virtual reality's great ability to increase productivity. Hence, the cultivation of the professionals in IT field is needed to improve the productivity brought by the powerful processors.

2.3. The application of ARM processors give rise to portable devices

ARM processor has been in existence for 33 years, first produced by a British company called Acorn computers. Compared with those x86 architecture processors using CISC (Complex Instruction set Computer, whose instructions will take several CPU cycles to execute), the ARM processors use RISC (Reduced Instruction set Computer, whose instructions will only take one CPU cycle to execute). First used by the Nokia 6110[9], the ARM has been used by over 165 licenses and has produced over 10 billion chips since 1994.

IT education, which is mainly about programming, has been relying on the PC for many decades. The x86 architecture (including the x86_64 architecture) always has greater computing ability over the ARM architecture, so the x86 processors dominate the PC market. During earlier decades, because of the low power consumption, the ARM processors were only used by cell phones, and the computing ability of the ARM chips remained quite low before the 2010s (see Figure 4[10])

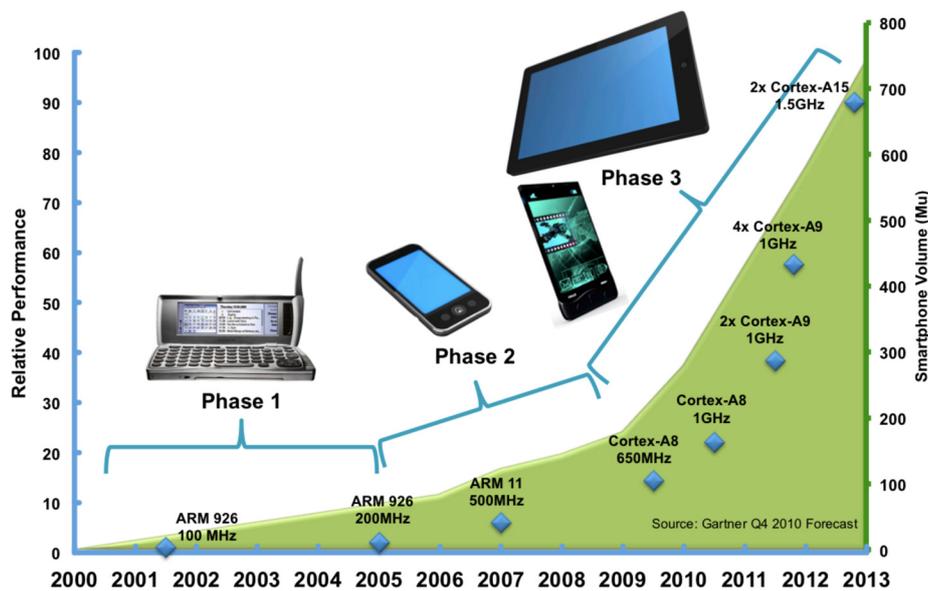


Figure 4. the clock rate of ARM processors over time

However, year 2010 is the turning point of the ARM processors. In this year, the computing ability of the ARM processor increased greatly, from 650MHz to 1GHz. This provided the chance for smartphones to thrive. On the one hand, the processors of the smartphones must be powerful enough to run a much-more-complicated-than-before cell phone operating system. (Both Android and IOS are the descendants of UNIX, they are simplified and highly modified). On the other hand, since the capacity of the battery of smartphone was limited, the processor must be low power-consuming. The x86 architecture processors could definitely suffice the computing need of smartphones. But the lowest TDP of that generation of x86 processors was 15w, and the TDP of ARM processors was 3-4w. If the smartphone's battery capacity was only 1420 mAh (take iPhone4 as an example), using x86 processors would only quickly drain out the battery, reducing the cell phone's usable time to only 1-2 hours. Hence, the ARM processors became the best option for smartphones. Not only smartphones, tablets and single-board computers also used ARM processors. There might be 3 reasons that made the ARM processors much more power efficient than x86 processors[11]:

The ARM processors are slower. The operation of the ARM processors costs lower power than the x86 processors do. To reach that goal, lower-speed transistors are used, which offers improved current leakage and lower minimum voltage. Hence, we have low power-consuming processors, despite the fabrication technology might 1-2 generation(s) behind the contemporary x86 processors.

The ARM processors are smaller. Because ARM is RISC structure, fewer transistors are used. As a result, massive operations are processed in small simple chunks at the expense of more machine code being executed. This enables the ARM processors to have fewer single-use parts that dissipates power while not in computation, thus making it more energy-efficient.

The ARM processors can let some of its cores go to sleep. Some modern processors will stop the core from working until it receives an instruction to do something. However, the x86 structure processors can only lower the frequency of the cores by lowering the voltage, or shutting down the periphery parts of the processor.

Those portable devices have made many things much more convenient, such as gaming, watching movies and working, etc. They also have made IT education extending from adults to children. With highly interactable and extensive programing teaching app, children are easily attracted to learn coding. Apple has released a coding game which is called Swift Playgrounds. In the app, the player, who is the child, will follow program instructions for the robot to reach the goals set in every level. (see Figure 5[12])

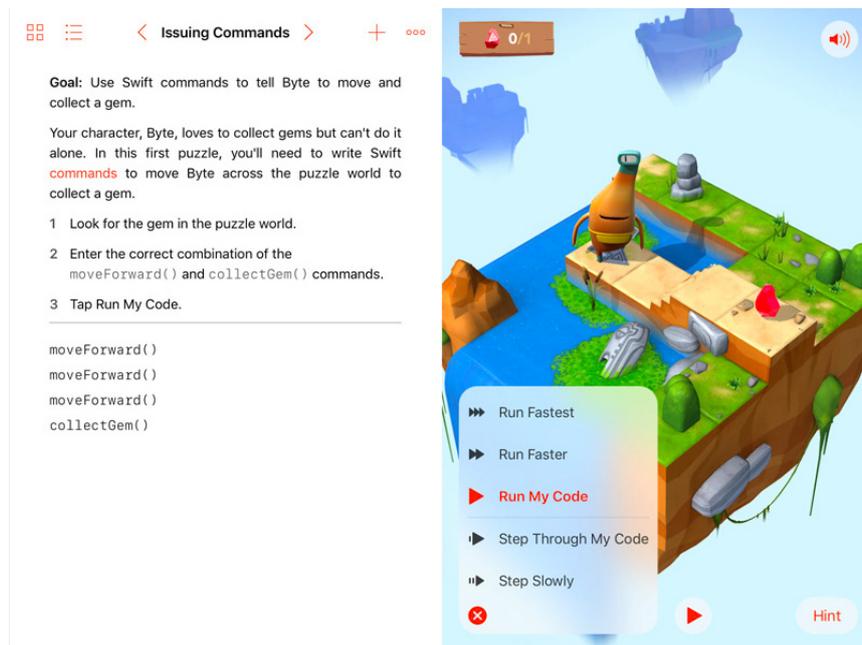


Figure 5. The Swift Playground app

Not only Apple, but also other companies have released their own programming-teaching application: Mimo (a pure programming teaching platform), Code Karts (an app that lets children use programmed commands to control a kart to win the racing game), Hopscotch (a platform for children to use visual programming to create and upload games), etc. Some online education platforms also released their applications, such as Coursera, Khan Academy, etc. Furthermore, a game called 'Human Resource Machine' bases itself on simplified visual assembly language. The players have to give correct instructions to the employees in the game to finish the tasks in the game.

ARM processors also bolster IT education hardware. A type of ARM-based single-card computer called Raspberry Pi was released by a British organization--Raspberry Pi Foundation. Raspberry Pi is optimized for children and teenagers aging from 7-18. With many built-in IDEs for different programming languages and a friendly GUI, it is a very powerful tool to learn coding. And the software called 'Scratch', which is developed by MIT to help children learn programming, is preinstalled in the system. Furthermore, there is a 40-pin GPIO port on the single-board computer. Not only can children and teenagers learn programming, but they can learn how to handle the hardware I/O easily. On this platform, children and teenagers are not just learning the knowledge; they are able to use the knowledge they have learned to create something unique.

Without the ARM processors, all these things could not have happened. The platforms emerged due to ARM processors have offered great software and hardware environments for children. The portable devices enable children to have access to IT knowledge more easily, and the single-board computers enable children even the teenagers to acquire the ability to play with their code. Hence, the advancement of ARM processors really brings children and teenagers into this field.

3. Conclusion

In conclusion, the advancement of integrated circuits bolsters IT education in three ways: lowering the cost of processors and making computers more affordable for IT education; the increase of productivity that is achieved due to powerful processors needs IT education; the low power-consuming high-performance ARM chips make the device more portable, enabling children have the access to IT education.

It is important to realize that the IT education is still moving forward. With the help of the integrated circuit advancements, the IT education can be accessible not only to adults, children and teenagers, but

also to the elderly; the IT knowledge teaching will not be restrained to coding itself, but also to make our daily life much smarter and more convenient.

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