IJMSIT

International Journal of Multidisciplinary Studies and Innovative Technologies

Volume : 5
Number: 1
Year: 2021
Pages: 27 - 29

Principles of John von Neumann as a basis of the Electronic Calculating Machine

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Abstract – In the paper the basic principles of John von Neumann from the point of view of their methodological significance for teaching the course of Informatics and ICT is considered. And also have been approved that the principles of John von Neumann served as the basis for creating not only the architecture of modern computers, but also modern information technologies. Moreover, these principles make it possible to harmoniously combine into a single whole - an ECM (Electronic Calculating Machine).

Keywords – John von Neumann principles, computer science teaching methodology, John von Neumann architecture, processor discreteness, RAM

I. Introduction

The study of informatics certainly begins with the John von Neumann principles. The basic principles of John von Neumann, served as the basis for the architecture of computers (modern, including) and modern information technology.

Firstly, it must be emphasized that attribution of absolutely all the merits to John von Neumann would be incorrect, since in fact, he just generalized the ideas that were laid down by the works of Charles Babbage, Alan Turing, Howard Aikin, John Eckert and many other scientists and inventors. In fact that J. Neumann, G. Goldstein and A. Barks [2] only managed to generalize the scientific developments and discoveries of many other scientists and formulate on their basis the fundamental foundations of the architecture of ECM (Electronic Calculating Machine-computer).

Moreover,

1) Until the end of the 50s dominated *relay computing devices* on the world and no one yet understood *what is a ECM and what is its architecture*.

2) Programming ENIAC (Electronic Numerical Integrator and Computer, 1946 - officially recognized as the first ECM in the world) was carried out by switching a special overlap on the *system panel* of the computer and this could take far more than one day. This can be compared to a modern computer as they are *reprogrammed* in just one second. Besides that, ENIAC [4] functioned in decimal, not binary and the EDSAC computer (Electronic Delay Storage Automatic Calculator - an electronic computer created in 1949 at the University of Cambridge, Great Britain) was more suitable for the recognition of the first real computer.

II. Materials

John von Neumann formulated his principles that a computer is a programmable device. A computer is a complex of special devices for collecting, storing and processing information, which functions under the control of programs. Or, if very briefly:

Computer = HardWare + SoftWare where HardWare is any part of computer that has a physical structure of a computer, and SoftWare is program containing instructions written in computer language comprehended by computer hardware.

It follows from the definition of a computer that all information technologies, including modern ones, should always methodically considered in two aspects: hardware (physical) and software (logical).

In the original papers [1-2] the John von Neumann principles are not formulated clearly, but in a modern interpretation, they sound as follows:

The principle of binary coding. According to this principle, all information entering to the computer encoded using binary signals.

The principle of programmed control. It follows that the program consists of a set of commands that are run by the processor automatically after another in a certain sequence.

The principle of memory homogeneity. Programs and data are stored in the same memory. Therefore, the computer does not distinguish what is stored in a given memory cell - a number, a text or a command. You can perform the same actions on commands as on data.

The principle of addressness. Structurally the main memory consists of numbered cells; any cell is available to the processor at any time. Hence follows, it is possible to give names to memory areas, so that the values stored in them could be subsequently accessed or changed during program execution using the assigned names.

From a methodological point of view, we propose to formulate the John von Neumann principles as follows (taking into account that we are talking only about computers (devices) with one processor and single core):

I. *Principle of discreteness (PD).* The processor, which the main device of any computer (device, mobile phone, SmartTV), is capable of functioning only discretely, i.e. the processor processes the readable commands from the RAM, just one at a time - one by one.

However, modern processors (even with single core) can simultaneously process up to 30 commands (steps). In order to increase the speed of the processor and maximize the use of all its capabilities modern microprocessors use the conveyor

principle of information processing. This principle implies that at each point in time the processor is working on different stages of execution of several commans, with separate hardware resources allocated for the execution of each stage. At the next clock pulse, each command in the pipeline moves to the next stage of processing, the executed command leaves the pipeline, and a new one enters it.

Therefore, for modern processors, the principle of discreteness should formulated as following:

The processor cannot complete the $(N+1)^{th}$ command until it has completely finished processing the N^{th} command.

The principle of discreteness is of great methodological meaning importance for understanding the principles of creating and using not only modern information technologies, but also technologies of the future. Indeed namely, *PD* underlies the fundamental idea of creating a computer as a programmable device, since one of the main properties of a computer algorithm – programs also are discreteness.

This implies that computer was *born* as a phenomenon of the fusion of the physical and logical (material and intellectual) = discreteness of the processor + discreteness of the machine algorithm created in the human head. Moreover, it is the *PD* that is the fundamental theoretical justification for the creation of a fifth-generation computer - a computer of the *Artificial Intelligence* type [3].

However, *PD* also has a negative side. *PD* is the main obstacle to improving computer performance. The principle of discreteness is a *law* that cannot violated and therefore can argued that the whole story history of the computing technology's development is the history of the *struggle* with *PD*. The stages of this *struggle* well known to everyone:

Increase of the number of processors. If one processor processes one command in 1 unit of time, then two processors will process two commands in the same unit of time, etc. Hence concept idea of *Supercomputer* (*SuperECM*) arose as a computer with multiple processors (in the modern interpretation, with multiple cores).

Increase clock speed. For nearly four decades, improvements in desktop performance could only achieved by increasing the processor clock speed, which in many ways determines the number of operations performed per second. For example, if you have a liquid nitrogen cooling system, modern processors can be overclocked to 8 GHz and higher. However, for serial computers, these figures are absolutely unattainable, so good modern processors operate in the range 3.4-4.0 *GHz.*

Improvement of the processor architecture. Clock speed and the technical process prevailed of increasing performance is borne only by the improvement of the processor architecture. First, we are talking about the creation of microprocessor crystals with several cores, the number of which even in serial processors reaches 8. It all started with the appearance of FPU (Float Point Unit), L_1 memory cache in Intel 386 and AMD Am386 processors. Then L_2, L_3 memory caches, superscalarity (multipipeline), branch prediction unit in Intel Pentium, AMD Am5x86, Cyrix 5x86 and NexGen Nx586.

II. *The principle of direct addressing* of random access memory (PDA). PDA means that random access memory, as the second most important device of any computer, is addressable, i.e. any cell (field) of RAM has its own number (address). Therefore, the processor reads (writes) data from the RAM to its registers (more precisely, the cache memory) almost instantly, indicating the address of the RAM field.

A modern computer uses many different memory devices that are not in the processor crystal, but faster than random access memory, storage devices does not exist. For example, HDD, which is not formally classified as a storage device, since one of the basic characteristics of any hard disk is the search and positioning time of magnetic heads, reaching 2 - 20 milliseconds, which slows down the speed of writing and reading by hundreds of millions of times compared to the RAM. In speed of working with the RAM, the ROM (storage device - read only memory), which is also on the motherboard, can be compared, but the ROM is used only read only and for other purposes.

III. The principle of *stored* program and data (PSPD). PSPD means that the program under which the control computer is currently operating (i.e., the processor) and the data that this program processes (uses) must be in the RAM.

PSPD laid the foundation for the development of new directions in information technology. Such as programming technology, operating systems, theory of compilers and translators, etc. For example, PCPD underlies the multiprogram and multiprocess modes of operation of modern computing systems and, in particular, desktop computers, laptops, tablets and even smartphones. In fact, PSPD means which (from an infinite sets) program we will download into the RAM, this *work* will be performed by the computer - singing, performing an operation, welding a car body, cooking dinner, etc. Of course, if you have the appropriate peripheral devices (hardware). And this means that the computer is the most universal invention of mankind at all times.

John von Neumann and his colleagues considered PSPD (i.e, the principle of program control and the principle of memory homogeneity, in the original) as the basic principle for computers in the "*John von Neumann Architecture*". Therefore, all modern computers fundamentally based on the John von Neumann architecture, even despite their various modifications and improvements.

To create computers with completely different architecture from John von Neumann did not bring success. For example, the creation in 2015 of a prototype meme processor (memprocessor[1]) by scientists from the United States and Italy was unsuccessful.

IV. *The principle of duality (PD). PD* means that any information that *creates, stores and processes* by computer must encoded in a binary number system (NS).

The principle of *duality* is the most controversial of all those proposed by John von Neumann, since the ternary NS is much more efficient and optimal for storing and processing information. For example, ternary logic, which is a classical mathematical logic, unlike bivalent logic, would make it possible to reduce the number of logical ventels in a processor crystal by a factor of thousands. As an example, we can cite the serial ternary computer *SETUN*[2] created in the former USSR under the leadership of N.P. Brusentsov [5]. It is noteworthy that future quantum computers, in principle, are also ternary.

However, the ternary NS is physically much more difficult to implement than the binary one, therefore computer science

[1] special processors that write and store data

[2] A small computer based on ternary logic, developed in the computing center of Moscow State University in 1959.

and information technologies are completely based on binary NS and binary logic.

III. CONCLUSION

The basic concepts of John von Neumann architecture and its basic principles should lay the methodological and methodological basis for Informatics and ICT. At the same time, almost any element of modern information technologies should take into account two aspects in the design and implementation of technologies: first - physical (hardware), 2 - logical (software).

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