A survey of ICT: evolution of architectures, models and layers

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Abstract—The development of computer architecture seems to have halted in the past 15 years compared to the earlier times of the computer era. There is an obvious trend of miniaturization, significantly increased processing speed, however, there are no significant novelties in either architecture or operation. This paper offers a short overview of computer development over the generations, as well as the new usage models that have arisen since the deceleration of the development in architecture. Further, this work presents the various fields where new advancements of computer architecture, operation and ICT in general are expected in the foreseeable future.

Keywords – computer generations, cloud computing, Internet of Things, fog computing, quantum computing, biocomputing, cognitive computing

I. INTRODUCTION

The beginning of the computer era is usually dated from the appearance of the first electronic computer in the early 1940s. At the very beginning of the computer age, these machines were slow, using an enormous amount of electrical energy due to the technological requirements of the age for electronic tubes and the necessary cooling. There was no communication between the user and the computer in the current sense of the word, it all happened over the operator console. Later, terminal networks appeared on large hosts, followed by their appearance on mini (third generation computers) computers. The arrival of the PC computer resulted in the replacement of the old terminal clients into computer networks. They functioned in a client-server environment, where the more powerful mini computers or smaller host computers took the role of servers. Since the early stages, computers have been becoming more and more powerful, smaller and even more affordable.

In 2006 a new ‘usage’ model of computers emerged, combining server farms, network environments, and the Internet: this was Cloud Computing. Formulation of the idea on intelligent sensors and actuators came up in 1999 and their intensive implementation in practice started in 2013. This made the usage architecture of info-communication technologies even more complex. Different user models and levels have appeared in the architecture, as well as in the usage models of today’s information communication technologies (ICT).

The aim of this work is to present an overview of the development of computer architecture and usage models, information and communication technologies. Thereby to highlight the cause-effect relationship between research, technologies, market demand and the need for computer resources on the one hand, and the architecture and models of ICT technologies on the other hand.

II. COMPUTER GENERATIONS AND THEIR ARCHITECTURE

The first generation of computers consisted of vacuum tubes which generated a large amount of heat, and thus were often subject to overheating. These computers had programs written in low level programming languages, they were unreliable and required a huge amount of electrical energy, as they could not operate without air conditioning. The weight of these computers was close to ten tons. They contained magnetic core memory and external memory in the form of punch cards. Their architecture is shown in Figure 1.

The computers of the second generation were built using transistors, which made them significantly lighter from their predecessors. They used less energy, and accordingly, had less heat dissipation, though this did not mean they could operate without air conditioning, only the cooling requirements were smaller. Given the transistors, they worked faster compared to the first generation. Apart from the Assembly language, they used Fortran and Cobol. The internal (main) memory was still magnetic, whereas the external memory took the form of magnetic tapes, drums and discs (the magnetic card readers are still not expelled). The first I/O processors (channels) appeared to remove the burden of executing input/output operations of the CPU. At the second generation IBM 7094 computers, the fast storage devices (magnetic- drums and -disc storages) were controlled by a joint I/O processor. The slow I/O entities, like card readers, printers and magnetic tape storages had their own I/O processor for their operation. The first operative system was developed, and later, the time-sharing processing technique appeared. Figure 2 presents the architecture of the second generation (IBM 7094).

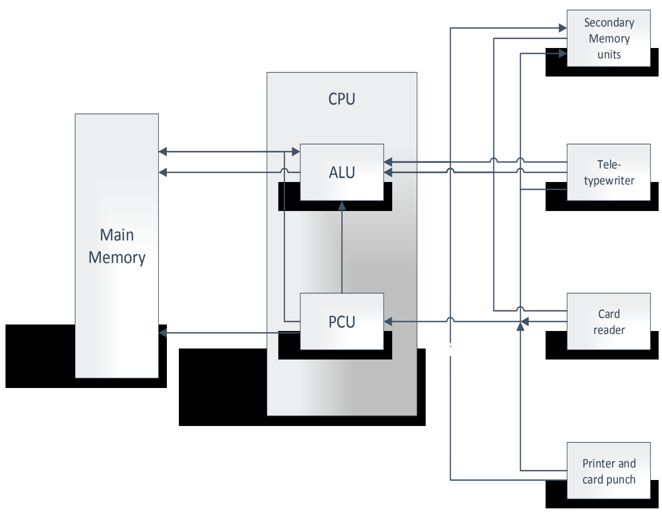

Figure 1. Architecture of first generation computer [2]

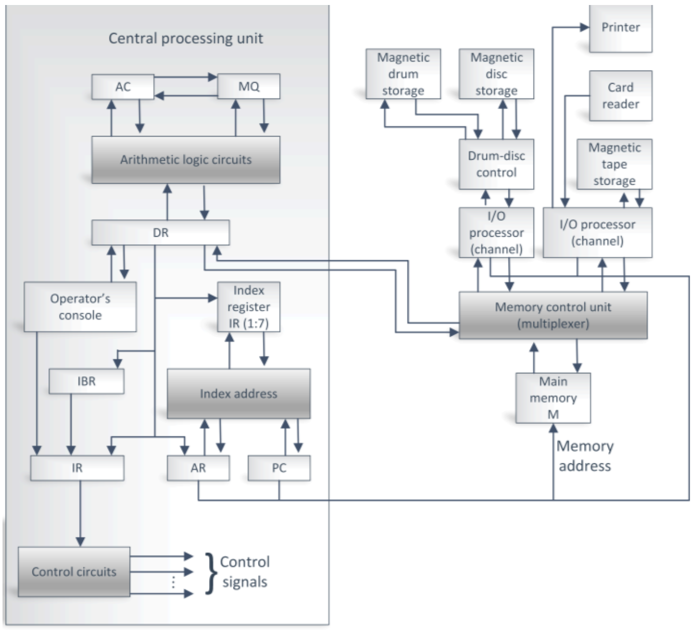

Figure 2. Architecture of the second generation

The third generation of computers featured integrated circuits (silicon chips) which were reliable, cheap, compact, and did not have considerable cooling requirements. Time-sharing was implemented in all the models of the new generation. These included mini and super mini computers, whose (VAX-11/780) architecture is shown in Figure 3 [28].

The fourth generation of computers (mostly referred to as Personal Computers (PCs)) use microprocessors integrated into a single chip. The trend of miniaturization continues, the rate of reliability increases, the need for electrical energy decreases, along with the price of personal computers, and these devices do not need any form of cooling (Figure 4 [7]).

The development towards the fifth generation of computers includes several course lines, including quantum-, biological- and cognitive computing. Their planned characteristics will include high speed [22], low power usage [21, 35], artificial intelligence (the comprehension of human speech, logical thinking and human reasoning), as well as real time problem solving [24].

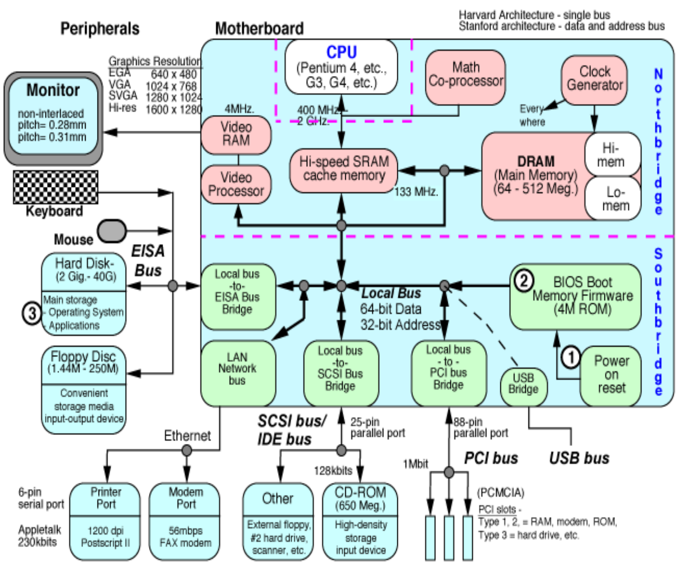

Figure 4. The architecture of personal computers

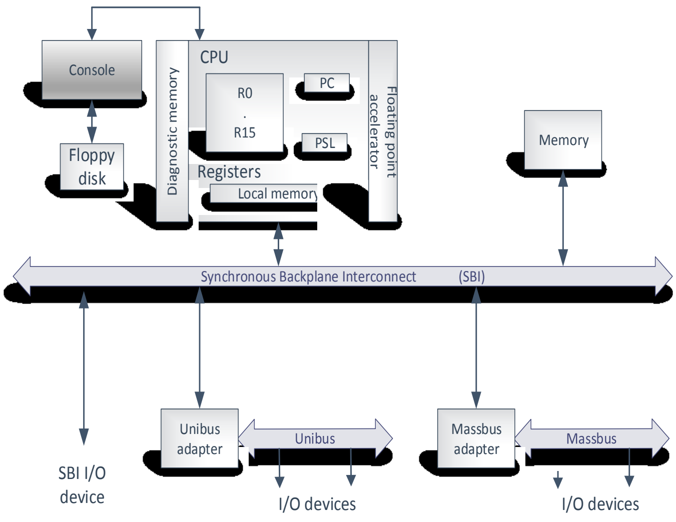

Figure 3. Architecture of VAX-11/780

III. MODELS AND LAYERS OF INFORMATION ANC COMMUNCICATION TECHNOLOGY

A. USAGE MODELS

While the fifth generation of computers has not yet arrived, but implementing state-of-the-art hardware and software components, some highly innovative data collecting and processing models were created. The operation of these usage models include cheap- and renewable sources of electrical energy. The new computer usage models are mainly associated with the appearance of cloud computing – CC – and intelligent sensors and actuators (Internet of Things – IoT). Widespread use-cases of CC and IoT result in complex architectures of those usage systems.

The Internet of Things, i.e. the smart sensors and actuators only add to the complexity of the previously presented model of CC. They undoubtedly contribute qualitative and quantitative advantages in terms of collecting data (sensors) and executing elementary activities (actuators) [9]. The model of the value network of CC-supported data processing, extended with services by IoT devices is shown in Figure 5.

The value network in the CC ecosystem shows the actors and their value exchange relationships. Organizations, actors in the CC service ecosystem can play various roles (providers, buyers, competitors) in this environment. Simply put, in a value network actors exchange services for money: they buy services from each other, add value to these services (by converting, modifying, refining, enriching) and offer, provide

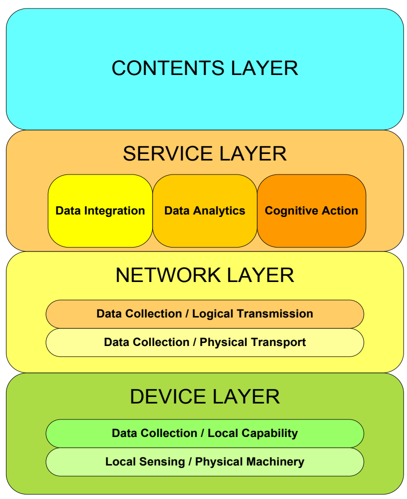

Figure 5. Aggregated functional and activity layers

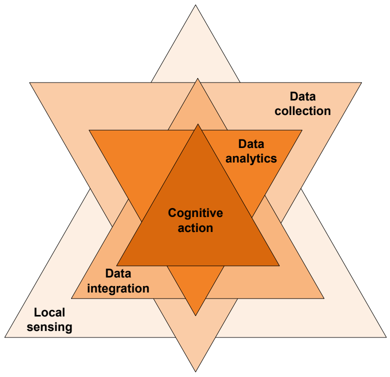

Figure 6. Activity layers of IoT

or sell them to other actors [8]. It must be emphasized that in order to provide/use the services of CC and IoT, Internet connection has to be ubiquitous.

The will to improve efficiency, reduce the amount of data need to be transferred through the Internet and to maintain security led to the new computational model by the name of 'FOG' or 'Edge Computing'. The term FOG (shortening for 'From the cOre to the edGe') was coined by Ginny Nichols of CISCO in 2012. This concept extends CC and IoT models (e.g. their services) to the edge of the network to provide data, computation, storage, and application services [11]. Although, FOG computing has been written about for quite some time [13, 14, 15, 29], the OpenFog consortium has published the description of the open FOG architecture only this year [12]. A similar concept was announced in the paper published in late 2013 by Wang et al. [16]. Currently they are actively searching for business application possibilities for this data collecting and computational model.

B. LAYERS OF THE ICT USAGE MODELS

They rarely define for layers of usage for the classic computer configurations, i.e. the typical representatives of the generations due to their simplicity (of their usage model). The newly introduced models (CC, IoT, FOG) for providing ICT services are quite complex, thus there are suggested schemes of layers. The majority of constructed layer models start from the first model of layer architecture suggested for digital technology [17, 18] which is aimed at its functionality/use. More recently, layer activities appeared for the above-mentioned models of ICT usage [10]. The activity layers for IoT are shown in Figure 6. Based on the names of the layers, the events taking place in each of them can be clearly identified, and so can the order, in which these events take place during IoT operation.

The activity- and functional layers' contraction gives a deeper insight to the operation of the ICT usage model. Thus, we present the aggregation of IoT functional- and layer activities in Figure 7. We also highlight the interconnectivity of these functional and activity layers: which activities should be realized in which functional layer in our sight.

IV. DISCUSSION

The presented tendency of computer development shows a continuous decrease in price, dimension, and energy consumption on the one hand, and a continuous increase in both hardware and software complexity, performance, and intelligence. This statement is widely known, and primarily refers to the first four generations of computers.

In the field of hardware, a good example of this line of development is the operative memory: from mercury delay line memory, magnetic drum-, magnetic core-, magnetostrictive delay line-, thinfilm-, semiconductor-, dynamic random access-, magnetic bubble memory et cetera. This line leads up to today's DRAM memory units and VLSI technologies of 16 nanometers [20] and, most recently, the IBM-developed 7 nanometer technology. Latter is not yet on the market, it will go to quantity production in around 7-10 years [34]. There are some significant novelties around memory units lately, taking their technology to the nanometer-level [36]. For extra long-term data storage purposes, Microsoft bought ten million artificial DNA molecules from a startup company, named Twist Bioscience [37].

In one cubic millimeter of DNA it is possible to store data of exabyte-scale, which is unique by itself. On top of that, it can safely store this enormous amount of data for 2000 years, however the data access speed can take from 10 seconds up to

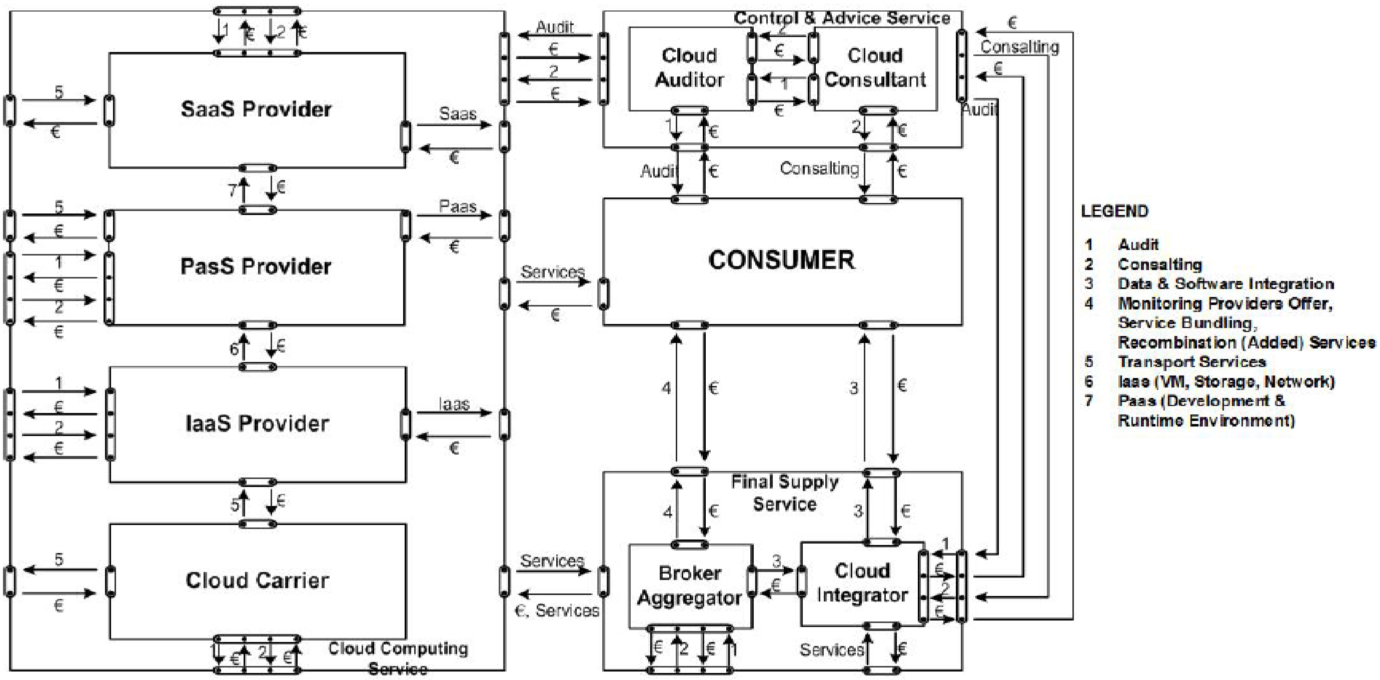

Figure 7. CC-IoT value network

several hours. Scientists from the University of Southampton made a discovery of similarly high significance on expanding the possible amount of data that can be stored in unit volume [38]. They recorded 360 TB of data with 5D laser technology on a small, nanostructured glass plate. Its durability is almost infinite: 13.8 billion years at 190 °C.

However, the most promising research area was brought up a long time ago, and these are the carbon nanotubes. Recently, a mostly clear-out technology was introduced to manufacture its transistors. The technology is similar to that of semiconductors which is also advantageous. Thus, the carbon nanotubes' [35] integration to chip manufacturing could be the most plausible idea, as these nanotubes can be fitted to existing components made with semiconductor technology. Transistors manufactured with carbon nanotube technology can be used at both processor- and memory unit manufacturing.

This line of development is also evident in the field of system (and also user) software: the first developed program languages were Assembler, Fortran, Cobol, then came the first operative systems with real memory, multi-programming, time-sharing system, virtual memory, and transaction processing. In the meantime, software for working in network environment (for terminal and computer networks) appeared, followed by the software prepared for working through the Internet.

The databases appeared in the early 1960s. Their path of development is still impressive today – relational databases, NoSQL databases, Big Data, additional service of data processing such as BI and Analytics or Hadoop.

The development of classic computer architecture (divided into four generations) is the story of advancement of the characteristics of complete computer systems and also in parts of their architecture for data processing.

Recording of big amounts of collected data appeared on the mini computers with the terminal network or with the help of PC computer networks due to the nature of this task. Data recording is a slow process, carried out by people, and it is not worth engaging fast and expensive computers for this purpose. The goal of classic computer development was to speed up the processing, increase the throughput of submitted jobs. The users turned to the computer directly in the process of defining and submitting jobs, being physically close to the computer or the terminal-PC connected to it.

The new era of using data processing services originates from the disruptiveness of cloud computing (virtualization of computer resources) and, with the rise of speed in wired, but especially wireless communication. CC and IoT, as well as the new usage models of data processing are based on the Internet (on the speed of data transmission) and virtualization.

Virtualization is realized using software (i.e. Hypervisor) over the hardware layer, which makes independent servers, storage and other system resources. Virtualization by itself is a great help in terms of efficient use of one's own hardware and software resources. It represents a precondition for CC providers for ensuring efficient and cheap services (storage, IaaS, PaaS and SaaS) via the Internet.

The development of the new computer usage models (providing data processing services or CC) does not impinge on the classical computer development process in any sense (hardware, software, localization methods and algorithms, analysis or processing of classical and/or multimedia data). This path of development focuses exclusively on efficient organization of operating a great number of servers on server farms. Doing this by using the cheapest possible electrical (and more recently, renewable) energy, as well as on the optimal usage of computer resources with a great degree of utilization. These business models of data processing services are aimed at companies with intensive communication and data processing, and also the huge numbers of mobile users with smartphones.

Mobile devices owners use their devices mainly for communication, entertainment and keeping in touch on social networks, etc. Smartphones with their multiple inbuilt sensors are also capable of large-scale data harvesting within the surroundings of their owners. This method is also an example of IoT, and it is widely known as community- or crowdsensing. This kind of crowd-based data collection and processing is widely used, and thought to be even more widespread in the coming years in Smart Cities [26]. The price of the mobile applications for these devices is cheap, and the great number of downloads ensure a steady profit for the companies operating in the field of communication and service computing. These companies are manufacturers of mobile devices and software, including interesting, necessary, intuitive applications, all easy to use.

Fog computing also falls into this category, and given that it is at the very beginning of its developmental journey, it will be vital to precisely define what makes it different from other CC services and what its possible fields of implementation are. More to the point, the market should decide whether there is a need for this approach as it could be a useful concept to rely on. However, even good ideas can be destroyed by the lack of interest of the developers and decision makers.

The appearance of the fifth generation of computers will be the next real step in this path of computer architecture development. Based on current information, their realization will require more time and investment. Research is intense in various fields, including the most famous areas of quantum computing, bio-computing, and cognitive computing. The quantum computer uses the quantum characteristics of micro particles, instead of bits, it uses qbit, which can take on many different states, as apart from 0 and 1, it can contain an endless number of states of possible quantum superpositions. This condition enables parallel computation, and provide the optimal means for solving some of the existing mathematical problems [22, 23]. The bio-computer uses proteins (Adenosine triphosphate) and a similar strategy to that of quantum computers to perform parallel computation. The consumption of the bio-computer is more than 100 times less than a single transistors', and the realization of this device is expected to happen within the next ten years [21]. Cognitive computing simulates the human thought, acquires knowledge from the data fed into them by self-learning systems (artificial intelligence) and pattern recognition. It involves natural language processing and data mining for self- or deep learning [24, 25].

V. Conclusion

This paper presented the main architectural characteristics of four generations of computers. Following the appearance of the fourth generation, there was no disruptive development in hardware, software of data processing techniques. The breakthrough novelties came up in disruptive usage models of data processing. We summarized these usage models, while also pointing out the directions of hardware, software and computer application development, an also the further research areas that seem to be the most promising.

In short, the generations of computer architectures represent the intensive development of both computer manufacturing technologies and of software development. Secondly, cloud computing model represents a revolution in offering this computation power as a public service. And, thirdly, the IoT model provides an excellent automated data harvesting and computation service relying on CC. All these services are provided in an energy efficient and progressive way. The issues of operational reliability, data safety and privacy, however, are to be dealt with.

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