Building Computers in Serbia:
The First Half of the Digital Century

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Abstract. In this paper, we describe the early development of CER-10, the first digital computer built in Serbia, honor its inventors, and follow the professional path of its chief designers, prof. Rajko Tomovic and prof. Tihomir Aleksic, who became the first university professor of computer engineering in Serbia. We also give a short overview of CER family of computers that were developed after the CER-10 till mid-seventies. In the early eighties, computer revolution continued with personal computers, so we show the early attempts to produce this kind of computers in Serbia, from "build it yourself" campaigns to the industrial production, and we analyze implications of these attempts to the development of user community and evolution to the information society.

Keywords: history of computing, CER family, personal computers, computer industry.

1. Introduction

During the Second World War, the interest to speed up computation was driven by the need to decipher codes and to run ballistics calculations. A group of women called "human computers" were employed to use differential analyzer, a mechanical analogue computer designed to solve differential equations at The Moore School of the University of Pennsylvania in Philadelphia. But on the backstage, John W. Mauchly and J. Presper Eckert were developing ENIAC, the first computer that could perform ballistics calculations faster by a factor of 1,440. ENIAC was composed of 18,000 vacuum tubes, 70,000 resistors and 10,000 capacitors. It had 40 panels, weighed 30 tons, and it was powered by 150 kilowatts. The first operators of the machine were six women [1].

In 1996, ENIAC turned 50, as well as the leading organization of computer professionals and scientists ACM, which organized a year-long celebration, with multiple conferences and activities which honored the first 50 years of technological accomplishments that lead to today's information society [2]. The celebration took place in the USA 14 years before the anniversary in honor of the first half-century of digital computers in Serbia. For many IT professionals half-younger then CER-10, the first computer developed and built in Serbia, it was a perfect occasion to find out about computing pioneers, the first electrical computing machinery, the first programmers and professors who set the foundations of computer science and engineering in Serbia.

The central event of the celebration organized by Informatics Society of Serbia, Institute "Mihajlo Pupin", University of Belgrade-School of Electrical Engineering, Ministry of Telecommunications and Information Society, and Chamber of Commerce of Serbia, was the exhibition set in the hall of National bank of Serbia [3]. About 70 exhibits, such as old computers, peripherals, photos, panels and publications from early sixties to the present time, helped the older visitors to remember, and the young students to research the roots of our profession and its impact on the technological development and industrial productivity of Serbia. It also demonstrated the enormous changes in our everyday life in which not only the vision of a computer on every desk and in every home, but also a smart device in every pocket, transformed the way how we live, teach and learn.

In the following chapters we will examine the roots of computing in Serbia, present CER-10 computer, honor its inventors, and provide the overview of the whole CER family. The second part of the paper is devoted to the personal computers of the 1980s that were produced in Serbia: Galaksija (Galaxy), Lola 8, TIM computers, and Pecom 32/64. Finally, we will elaborate on the process of choosing school computer, and the transition to the production of PC compatible computers in 1990s.

2.   Before the Beginning: The Roots of Computing between Electrical Engineering and Mathematics

The transition from mechanical computing devices to electrical computers required the knowledge and experience in electrical engineering and mathematics. The first university level lecture in the area of electrical engineering in Serbia was held in 1894 by Professor Stevan Marković, the first lecturer and founder of Electrical Engineering Chair at the Great school in Belgrade, which was the third of that kind in Europe [4]. Telegrams about this event were sent to already famous electrical engineers living abroad: Nikola Tesla and Mihajlo Pupin in New York and Vojislav Marinković in Paris. Only four years later, Professor Marković also founded electrical engineering laboratory at the basement of Kapetan Miša's Palace (now the building of the University of Belgrade). Since then, electrical engineering has been studied

in the Great School, and later at the University of Belgrade which developed from it. The first diplomas in electrical engineering were issued in 1922.

One of the best friends of Professor Marković and his son's best man was the famous mathematician, Mihajlo Petrović Alas. The beginning of the story about "Computing in Serbia" and the exhibit number one (Figure 1) at the exhibition [3] is Petrović's hydro integrator that he constructed, and presented at the Exposition Universelle in Paris in 1900, and received the Gold Medal for it. The hydro integrator was based on the principle of hydraulic analogy, and it could solve two classes of differential equations. In addition, it was a kind of predecessor of the plotters, because calculation data was written automatically with a pen on the paper rolled around the cylinder [5].

Fig. 1. Mihajlo Petrović's hydro integrator

3.   Beginning of the Digital Century: CER-10

Until the early sixties, only six countries in Europe succeeded in developing their own electronic computers: Great Britain, France, Germany, Poland, Russia and Yugoslavia. The Yugoslav product CER-10 (in Serbian: Cifarski Elektronski Računar – Digital Electronic Computer) was a vacuum tube, transistor and relays based computer [6][9]. From 1956 till 1960, a team of 70 engineers, programmers, technicians and specialists were involved in its construction at the Institute Boris Kidrič - Vinča in Belgrade. The project was initiated by academician Dušan Mitrović. The machine was designed by professor dr Tihomir Aleksić, academician Rajko Tomović and their associates: Ahmed Mandžić, Petar Vrbavac, Vukašin Masnikosa, Dušan Hristović, and Milojko Marić [37].

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After initial prototype's testing in Vinča, the construction continued in the Institute "Mihailo Pupin" in Belgrade, where the machine was extended with the so-called Statistical Unit, so by the end of 1962 the project was finished and CER-10 could be moved to the SKNE-DSUP (The Federal Commission for Nuclear Energy-State Secretariat for Internal Affairs) building, which later belonged to TANJUG (Telegraph Agency of the new Yugoslavia). CER-10 was used for statistical cryptologic processing of information for the Yugoslav Federal Government, including SSUP (Federal Secretariat for Internal Affairs) and TANJUG, as well as for mathematical problems solving, related to the scientific projects in SKNE (The Federal Commission for Nuclear Energy) in Vinča.

Fig. 2. CER-10 at the Belgrade Technical Fair, August 21-31 1960, Belgrade

CER-10 [9] was the universal one-address machine with the average processing speed of about 50,000 simple operations per second and about 1,600 additions per second. Data in CER-10 was represented in multiples of 5-bit binary groups, so the operations could be performed on 5-bit, 15-bit or 30-bit binary words. Instruction was composed of 25 binary digits. A 5-bit opcode, which could potentially code 32 instructions, was used for only 17 codes of regular instructions (Table 1) and additional 7 instructions which were later introduced by building a statistical unit. Index field was used to determine if the operation should be performed on 5-bit, 15-bit or 30-bit binary words. 15-bit address field determined the address of the lowest 5-bit group of the operand.

The main memory was organized in two subsystems of matrix ferrite memory cores Philips 6D3 pfi 2mm and switching cores 6E2. The memory word was 30+1 bits, and it could store up to 6 characters: numbers, letters or symbols coded with 5 bits each. Access time for the ferrite memory was 10 microseconds.

The control unit of the CER-10, and its arithmetic unit were composed using the standard logic circuitry modules made of electronic vacuum tubes,

transistors, Ge-diodes and R, L, C discrete components. As an input unit, the machine used Photoelectric Reader of the punched paper tapes Ferranti type TR 2B (the speed was 300 char/sec). For output, it used the Paper tape Puncher Creed type 25 (max. 100 char/sec). The Siemens teletype T-100 with printing speed of 8-10 char/sec was also used.

The Power Supply system was an independent motor generator with the nominal power 20/15,5 KVA, produced by the Rade Končar company, Zagreb. The rectifiers with three phase circuitry had Si-diodes, types 14R2 and 10R2 (Th. Houston). There was the automatic regulation, the relay protection and the signalizations for all power units. The size of computer room in the TANJUG building was 80 m^2, with double flooring and air conditioning. The metal rack dimensions were 2 * 2 * 0,70 meters for each of the seven rack units.

In building the CER-10, the following components were used: Philips electronic tubes of types ECC 81, EL 83 etc. (approx. 1.750 pieces); Transistors 2N396, OC 76, OC 44 (1.500 pieces); Ge-diodes OA 85 Philips, for logic circuitry, (approx. 14.000 pieces); Electronic relays type Schrack (approx. 650 pieces); Pulse transformer core D25 (approx. 1.700 pieces); Delay pulse Lines (approx. 850 pieces), etc.

Table 1. Instruction set of CER-10 [9]. The first letter defines the statement, **n** represents the memory address, **Z** represents the index (Z, X or Y) which determines the size of operand, A stands for accumulator, B and C are special registers, and **n** should be interpreted together with the index. s/X/ represents the value stored in X.

Statement	Functionality	Comment
AnZ	s/A/→n without delete of s/A/	Store A to n
RnZ	s/A/→n with delete of s/A/	Store A, Delete A
CnZ	logical and of s/A and s/n→A	A and n→A
JnZ	s/B/→n without delete of s/B/	Store B to n
K	end of program execution	Stop
Nn	if s/A/>0 go to n	Conditional jump
On	if s/A/<0 go to n	Conditional jump
Pn	if s/A/≥0 go to n	Conditional jump
RnZ	s/A/- s/n/→A	A-n→A
SnZ	s/A/+s/n/→A	A+n→A
TnZ	s/n/→C	Load C from n
DnZ	s/A/ x 2^{-a}; a= s/n/	Shift right A,n
LnZ	s/A/ x 2^a; a= s/n/	Shift left A,n
MnZ	s/C/ x s/n/→A and B	Mul AB,C,n,
QnZ	s/C/ / s/n/→ B	Div B,C,n
I	Output the lowest 5 bits of s/A	Out A
U	One character from the tape+s/A→A	Add A, Input

In the interview [12], Vukašin Masnikosa, the member of the team that developed CER-10, explained that the programming was done in machine

language and that the CER-10 proved its usability by decoding an important radio-message sent to Egypt from Israel, so President Josip Broz Tito sent the messenger who traveled by airplane to deliver the message personally to President Nasser.

In March 2006 the Institute Mihailo Pupin donated the case and parts of the CER-10 to the Museum of Science and Technology in Belgrade, where it will be displayed as a valuable exhibit.

4. Designers of CER-10 and their Heritage in Serbian Computing Education

The CER-10 implementation was based on the design of Professor Tihomir Aleksić and academician Rajko Tomović, who worked with a group of 70 associates, programmers and technicians. The two of them later became professors at the Faculty of Electrical Engineering in Belgrade, and set the foundations of computer engineering studies in Serbia. Professor Rajko Tomović (1919-2001) greatly contributed to the design of the first analog and hybrid computers built in the Vinča Institute from 1950 till 1960. After that, he joined the Institute Mihajlo Pupin, where he started the Laboratory for Robotics. In 1962 he became associate professor, and in 1964 full professor of automatic control at the Faculty of Electrical Engineering. He was the member of Serbian Academy of Sciences and Arts (SANU), and the designer of multifunctional hand prosthesis, so-called Belgrade hand, exhibited in the Museum of Robotics in Boston [7][8].

Professor Tihomir Aleksić (1922-2004) was the first elected university professor of computer engineering in Serbia. He got his Ph.D. in the field of switching theory in 1958, and started his research at the Mathematical Laboratory of the Vinča Institute, where he worked till 1960, when he transferred to the newly founded Institute for Automation and Telecommunications, Belgrade, the predecessor of the Mihajlo Pupin Institute. Professor Aleksić designed the laboratory prototype of a bookkeeping computer, a prototype of electronic printer, the electronic teleprinter, the telephone switching system, and other devices that have announced the digital age in this region [7].

His academic career started by the promotion to invited full professor at the Technical Faculty of Niš in 1967. After the establishment of the Faculty of Electronics in Niš, he became its first Dean. During the same year, the Faculty of Electrical Engineering of the University of Belgrade started the major changes in its study programs, by introducing integrated 5-year engineering studies. The curriculum contained a new module called Data Processing, and professor Aleksić's course Systems for Data Processing was one of the major subjects. In 1971, he became a full professor at the Faculty of Electrical Engineering in Belgrade, and the founder of the Department of Data Processing, which was the nucleus that started the development of the present Department of Computer Engineering and Informatics, today's

teaching bases of two major curricula in computing: Computer Engineering and Informatics as well as the Software Engineering.
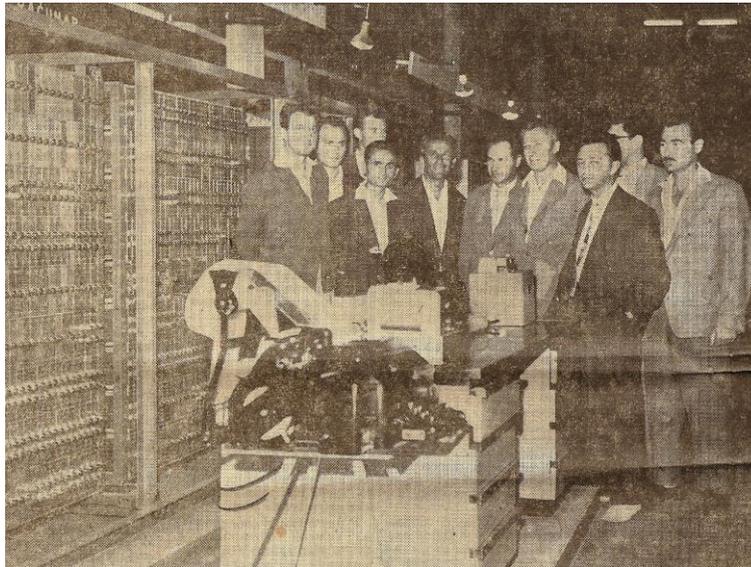

Fig. 3. The CER-10 Team, in "Borba" newspaper from September 6, 1960, and photos of professors Rajko Tomović and Tihomir Aleksić

5.   CER and HRS families: the Successors of CER-10

After the construction of CER-10, Institute Mihajlo Pupin developed and produced the whole family of CER computers (CER-11, CER-22, CER-200 CER-12), which have been applied for data processing in multiple enterprises, banks and federal agencies [10][11]. They also developed specialized CER computers for the Yugoslav Army from 1965 to 1989. The last CER computer remained functional in the Vojvođanska Bank-Zrenjanin until the late 1980s, when it was replaced by the VAX minicomputer. An overview of CER family is summarized in Table 2.

While CER-12, CER-22 and CER-200 were mainly used for bookkeeping and banking applications, CER-30, described in [29] was something completely different. It was a predecessor of programmable electronic calculators, designed by professor Nedeljko Parezanović, who made an original multiplication and division algorithms, dr Milojko Marić, and dr Bogdan Janković. Due to the lack of components, the building of this machine was delayed, but the problem was solved when Professor Tihomir Aleksić provided germanium transistors produced in Ei-Niš. Instead of a display, CER-30 used 15 light indicators, and the keyboard was replaced by doorbell switches. However, the machine was used for a long time for financial computations at the institute.

The period from late 1960 until 1970 was marked by the design, development and production of hybrid computer systems HRS-100, intended for scientific and technical research, modeling of complex dynamic systems in real and accelerated time scale, and to effectively solve a wide range of scientific tasks in the following fields: power engineering, space industry, medicine, chemical technology, electronics and process automation.

The HRS-100 was ordered by and made in cooperation with the Institute for problems management of the USSR Academy of Sciences. Bringing together the world's achievements in the field of analog and digital computer technology with a range of original solutions, this system achieved the capabilities and performance of the world's top-class computers of the time. The HRS-100 has been implemented in 1971 in the VLSI technology and represented the modern system of the third generation with many original solutions (the electronic control of coefficients for hybrid computing, the system of interrupts, a hybrid loop for graphics, the dynamic order of priorities, the link device with the high precision AD and DA convertors, etc.).

The main program orientation continued from 1974 until 1990, which brought an expansion of the development program to the special purpose computer systems, as well as the design of real-time control applications. It was the time of intensive development and implementation of hybrid computer systems. Three HRS-100 systems were delivered to the institutes in USSR in Moscow and Novosibirsk. Another six hybrid mini-computers were also produced for faculty laboratories in Sarajevo, Skopje, Belgrade, Zagreb, Split and Subotica.

Table 2. An overview of CER family [11]

Model	Designed (End of exploitation)	User companies	Remarks
CER-10	1956/1960 (1966)	SSUP, TANJUG, ETŠ	the first electronic computer constructed in Serbia
CER-11	1965/1966 (1988)	JNA-DSNO	the mobile military computer
CER-20 CER-30	1963/1965 (prototypes)	IMP, Ei, RIZ(TRS)	CER-30 was the programmable electronic calculator, using original algorithms for multiplication and division designed by Nedeljko Parezanović
CER-22	1966/1968 (1975)	Beobanka, Jugopetrol, Belgrade Watersupply and Wastewater	production run: 3 printed circuits with transistors
CER-200/ 202/ 203	1966/1971 (1985)	Planika-Kranj, PIK-Tamiš, GIK-Banat, Kanal DTD-Novi Sad, Mehano-grafija, Jugopetrol, VMA, EI Poljobanka, IMP	production run: 15 printed circuits with transistors
CER-12	1969/1971 (1997)	Cred. Bank Zrenjanin, ERC-IMP	production run: 2 third generation 57 machine instructions, CDC disks, AMPEX magnetic tape unit, VLSI circuits, wire-wrapped Augat boards
CER-101-Kosmos	1972/1973 (1988)	JNA-VTI	the mobile military computer, third generation VLSI circuits, wire-wraped Augat boards, magnetic drum VERMONT 1004
CER-111	1974/1975 (1988)	JNA-DSNO	the mobile military computer third generation 57 machine instructions VLSI circuits, wire-wraped Augat boards

6. Personal Computers of the 80s

The CER project, however fascinating it was, could not retain the momentum necessary to keep up with the developments of the global computer industry. During the sixties and the seventies, Serbian companies bought and utilized computer systems produced by IBM, Honeywell, and DEC. In the early eighties, another computer revolution was approaching - home computers were ready for their big time [38]. So the creativity of Serbian engineers aroused once again.

"We can achieve the Computing Revolution only if we have a domestic computer" [15]. This sentence from an editorial of the first publication about personal computers released in the former Yugoslavia "Computers in your home," sounded logical at the time, at least as much as today it sounds funny. But in the early 80s it was important to produce a domestic TV, domestic appliances, a domestic airplane and, why not, a domestic home computer.

Fortunately, in the early eighties the domestic computer design was not a mission impossible. The computer hardware and software were simple enough that they could be designed, produced and tested by small teams, without expensive resources, on a moderate budget. In global terms, the first home computers were created in garages and constructed by the young people, who did not always have formal qualifications.

There were many garage built computers, but only some of them, due to the inventive design, quality software, and a bit of good fortune, could eventually reach the market. The situation on the global market at the time was strange: a dozen of mutually incompatible computers competed for customers, ready to invest endless time, enthusiasm, and a lot of money into the machines which could not do a really useful job.

At the time, Yugoslav economic system was inert, new products development was slow and often dependent on political decisions. The private companies were not only discouraged, but prohibited by the law. Production of computers required imported chips, and the possibility to import them was limited, as a person entering the country could only import small items worth about 50 Deutschmarks. Companies had to prove that their imports were covered by their exports, and to buy foreign currency at a rate significantly higher than the official.

But every cloud has its good: the unreasonable policies, along with many other factors, resulted in an incredible event - a "build it yourself" computer was assembled by approximately ten thousand people. This, of course, was not exactly the first home computer, as a few iterations were necessary to reach the winning concept.

As in many other areas, it is not easy to tell who came first - the construction of a small computer was attempted by many enthusiasts, but no projects were brought to an end. Basically, most of the constructors tried to clone some of the foreign computers, with the possible simplification of hardware, and the use of original system software, namely the BASIC interpreter.

The first home computer that was manufactured in the form of a working prototype, presented at several tradeshows and in the media, was EL-82 [16]. It was designed by Voja Antonić and produced by "Elektronika inženjering" ("Electronics Engineering") in the city of Zemun, at the beginning of 1982. The EL-82 used the Zilog Z80A microprocessor, with user memory of 16 kilobytes (expandable to 64 KB) and ROM of 16 KB. The EL-82 was functionally similar to the TRS-80 Model 1, but it's hardware was completely different, designed with fewer integrated circuits, that made it more suitable for production, but not entirely compatible with the TRS-80. Microsoft Level II BASIC was stored in the ROM, featuring the possibility of operation with numbers in double precision (15 significant digits), alphanumerics, sound generation and low-resolution graphics.

It is interesting to note that the character generator also supported the Cyrillic alphabet (though the keyboard was Latin), so it was possible to enter the Cyrillic text. The ROM also contained monitor program that provided direct access to the computer's memory debugging and working with programs written in the machine language.

The EL-82 was announced as the computer with the ability to expand: the Centronics port was provided for the printer connection, and the possibility of later upgrade with the disc drive (instead of the classic tape recorder used for recording programs) was also mentioned. The other plans included the development of new programming languages for specialized purposes, connecting with industry controllers, etc. The computer was presented to the public during the year 1982 and in the first half of the 1983, after which it quietly disappeared. The company "Electronics Engineering" concluded that the computer production was too expensive - estimated cost of some 250,000 dinars, which was about 6,000 Deutschmarks at the time, was too much for potential customers. But fortunately, there was a better idea...

6.1.   Galaxy (Galaksija)

Galaksija (Galaxy) computer was constructed in 1983 by Voja Antonić, who resigned from the "Elektronika Inženjering" and started his own business. He began to work on the project in July 1983, and the computer was ready for its first presentation in August. Galaksija was based on the Zilog Z80A microprocessor, the top of the 8-bit technology of that time. In the beginning it had 4 KB of RAM (up to the final launch, the memory was extended to 6 KB [18]), 4 KB ROM (with the possibility of extension with additional 4 KB ROM II), and used the monitor or black-and-white TV set that could display 32 * 16 letters and 64 * 48 pixels. The features of Galaksija were comparable to the Sinclair ZX-81 - the price was similar, but the Galaksija had an advantage of the professional keyboard, while the ZX-81 had more peripherals available and a lot of commercial and free software.

Fig. 4. The Galaksija Computer

Galaksija brought two original solutions. One of them was the software support for video, which simplified the hardware, and made the computer cheaper, which was regarded as particularly important. It also allowed for the single-layer printed circuit board, suitable for the "build it yourself" construction. The second characteristic was a BASIC interpreter that Voja Antonić developed by himself, taking some segments (e.g., the floating point arithmetic) of the TRS 80 Level 1 BASIC. The development and optimization of the interpreter took a lot of work, so the 4 KB ROM also contained the software support for video, the line editor, elementary manipulations with strings, a clock, and links for further expansion of the programming language. BASIC commands had shortcuts [19], for example, P. instead of PRINT, for easy typing and memory savings. The intention to unambiguously reduce all the commands to a single letter requested certain changes in the BASIC syntax, so some of the commands were renamed - for example, TAKE instead of READ or BYTE instead of POKE.

The Galaksija computer was offered in the "build it yourself" campaign announced in a special edition "Computers in your home" [20] (December 1983), the first publication on home computers issued in the former Yugoslavia. It happened eight years after the subscribers to Popular Electronics in the USA received the new issue in the mail, with a prototype of the Altair minicomputer on the cover [13]. Altair was named after the star mentioned in the TV show Star Trek [14], and its minicomputer kit was the first one that anybody could obtain for less than $400. Just like in the case of Altair, the magazine also played an important role in introducing Galaksija in Serbia (Figure 5).

It turned out that components for such a computer were affordable for an enthusiastic reader: a microprocessor, memory and other integrated circuits

for Galaksija could legally be imported from abroad by post, and the production of the printed circuit boards, the keyboards, and the case has been organized in Yugoslavia.

Fig. 5. Magazines that promoted "build it yourself" campaigns

In order to succeed in this campaign, it was necessary to spend several months in preparations and publications of articles in the magazine for popularization of science, "Galaksija", so in October 1983 the preliminary order forms appeared in the magazine [21]. The response has surpassed all the expectations: over a thousand readers of "Galaksija" expressed the desire to build their first computer. It motivated the editorial board to further efforts: Voja Antonić spent a lot of time improving computer's hardware and software, and the journal "Galaksija" was looking for the most appropriate way to organize the purchase of components, relying on (as then said) "small businesses". Companies "Mipro" and "Electronics" from Buje (now in Croatia), in collaboration with the Institute of Electronics and Vacuum Technique (Slovenia), supplied printed circuit boards, keyboards and masks, while "Mikrotehnika" from Gratz supplied the chips by mail orders. Editorial board of "Galaksija" collected orders and organized EPROMs burning.

Meanwhile, the commercial version of the Galaksija computer was offered, in the joint effort of "Electronics Engineering" and "Institute for learning and teaching resources", that decided to fund (already almost completed) development of Galaksija, in order to put it on the market and offer it to the schools in Yugoslavia. The price of 30,000 dinars was equivalent to about 600 Deutschmarks. After the release of the publication "Computers in your home" in December 1983, over 8,000 readers from all over former Yugoslavia ordered the Galaksija kit; in subsequent months, orders continued to arrive, deliveries were delayed, but finally all eager builders got their packages.

Due to the simple construction of Galaksija, the most of devices that readers built got to work without problems, and for those less fortunate, the service was organized. The commercial model arrived later than promised, but the computer gradually found its way to schools. Perhaps the most important thing was that the media enthusiastically supported the campaign: it was announced and talked about on the radio, television and in magazines, so it can be considered as a milestone that marked the beginning of computer revolution in former Yugoslavia.

In the publication "Computers in your home 2" a scheme for self-building of the memory expansion board, developed by Jovan Regasek, was presented [22], as well as three-channel tone generator and high-resolution graphics, designed by Nenad Dunjić and Milan Tadić [23]. A lot of software was developed for Galaksija, some of which was distributed in an unusual way - via radio waves, in cooperation with Zoran Modli and Radio "Belgrade 202" [24]. "The Institute for learning and teaching resources" distributed programs commercially, so Galaksija even got a chess-playing program - Ivan Gerenčir and Milan Pavićević first adapted a famous Sargon to the memory and graphics of Galaksija. ROM 2 [25] was developed by Voja Antonić - with this 4 KB extension, Galaksija got an assembler program, machine-language monitor program, several new BASIC commands (including floating-point functions), and the printer support.

The subsequent development of the Galaksija computer continued in the magazine "Svet kompjutera" ("Computer World"), where Nenad Balint, Vojislav Mihailović, Bojan Stanojević, and other associates managed to attract the attention of the users. "Computer World" realized the vision of founders of the entire operation: the gathering of the readers who turned into the programmers. They predominantly published games: Diamond Mine, Squash, Light Cycle Race, Blade Alley, Inspector Spiridon, etc. These programs were written in machine language, which used the potentials of Galaksija to its maximum. The crown of the whole project was the construction of Galaksija Plus (Galaxy Plus) [26] by Nenad Dunjić and Milan Tadić. This project was also financed by the "Institute for learning and teaching resources". Galaksija Plus was actually the original computer Galaksija, with 48 KB of RAM, the high-resolution graphics and the three-channel sound generator.

6.2. Lola 8

One of the rare home computers that reached mass production was the Lola 8a, developed as a laboratory project of the IM "Ivo Lola Ribar". The team from their laboratory has worked on the development of hardware for industrial controllers (the project PA 512) built into the machines that "Lola" successfully exported at the time. Their knowledge was applied to a small computer Lola 8. The hardware designer was Radovan Novaković, and the software was written by Nela Radovanović [27]. The project proceeded during 1983 and 1984, so Lola 8 in various stages of development was shown on

local fairs - there was a joke saying that "Lola computer is developed from fair to fair." Visitors particularly remember the games in which, if you collected enough points, you could enjoy the sound of a song "Fijaker stari" (The Old Carriage).

Fig. 6. Lola 8a, project of the IM "Ivo Lola Ribar"

During the summer of 1984, the "final" version of the computer was presented to the public. It was based on Intel 8085 processor with 16 KB ROM and 6 KB of RAM used to store user programs written in BASIC or machine language. The keyboard was non-standard, and 48 keys were not positioned in the usual, "staggered" manner, but one above another, resembling the industrial controllers. The computer had a sound generator with three independent programmable channels, and it used the tape recorder as the external memory. The price of 55,000 dinars was announced, which in mid-1984 was equivalent to 600 Deutschmarks.

Production of the Lola 8a actually started much later - on May 25, 1985. The first "Youth Computer Factory" was opened in Belgrade [28] and it employed thirty workers who had been making Lola 8a. It was substantially revised version of the original Lola 8, with the classic QWERTY keyboard, an Intel 8085 microprocessor working on 4.9 MHz, 24 KB ROM and 16 or 32 KB of RAM. The graphics resolution was 320 * 300 points, and the software was considerably improved, which made the Lola 8a software incompatible with the original model.

During its production cycle, about 2000 units of Lola 8a were made and delivered to primary schools in Belgrade, secondary military schools, and military academies. Publishing company "Nolit" tried to offer the computer on the market, at the price of 125,000 dinars (about 980 Deutschmarks). In the

"Youth Computer Factory" the management tried to organize the team to develop software for the Lola 8a, but the overall software support for this computer was modest, resulting in the decrease of interest and the market for it in the following years.

6.3. TIM computers

During the seventies and the early eighties, the engineers at the Institute Mihajlo Pupin designed a number of control and measuring devices, peripheral units, industrial controllers and robots. In 1985 the Institute started manufacturing the equipment for PTT Serbia. The result was a specialized computer TIM-001, and later the TIM-100. A large number of these computers have worked at the post office counters.

The computer offered on the market by the Institute Mihajlo Pupin, TIM 011 [30], has emerged through an alternative channel, sharing only the computer case and the name with the TIM family. In 1987 the Pupin Institute bought the project of CP/M computer that was developed by Nenad Dunjić, Milan Tadić and Ljubiša Gavrilović. The computer was offered to schools, but also in a build-it-yourself campaign, supported by the special edition of the Computers magazine, under the title "Computers in Your School" (April 1988) [31]. Ambition was to repeat the success of the build-it-yourself campaign of the Galaksija computer, and the results were satisfactory, but far from the original.

The TIM 011 was based on the microprocessor Hitachi HD-64180, and the operating system ZCPR 3. However, things were not quite as unusual as these names suggest. The HD 64180 is a hardware and software upgrade of the Zilog Z-80, which, with the built-in MMU, had the ability to address 512 KB or 1 MB of memory divided into 4 KB pages. The speed-up of the processor was based on the two-channel DMA controller built into it, and the construction of the computer was simplified by introducing the embedded interrupt controller, two serial interfaces, and two counters.

In its basic version, the TIM 011 had 256 kilobytes of RAM and additional 32 KB of video memory, located in the I/O map of the microprocessor. In the text mode, it could write 80 characters in each of the 24 rows on the screen, and graphics resolution was 512 * 256 points with four levels of gray. As an external memory, it used the double-sided 80-track floppy 3.5" disk drive, which provided the capacity of 780 kilobytes [30].

The operating System ZCPR 3 (more precisely, the operating system is Z, while ZCPR 3 stands for operating system with command processor - Z80 Command Processor Replacement) is a variation of the CP/M 2.2. ZCPR 3 is an open source operating system, which allowed the authors of the computer to implement the necessary changes. Microsoft CP/M BASIC 5.21 was distributed together with it, and it was extended with instructions that supported graphics and sound. The TIM 011 was a rather fast computer - the PCW speed tests put it at the top of the list, along with then-champion in speed, Acorn BBC B computer [30]. It was an interesting concept that

reached the limits of the 8-bit technology. It was distributed to schools, the attempt was made to sell it on the market and organize the build-it-yourself campaign, but the results were modest, as the companies and individual buyers have already turned to IBM PC compatible computers.

The final representative of the TIM computer family was the TIM 600, introduced in 1988 as the first Yugoslav 32-bit super-microcomputer system. The TIM 600 was based on the (then) top-of-the-line Intel's processor 80386 (with an arithmetic coprocessor Intel 80387), and the original hardware that relied on three system buses: the 32-bit bus between the CPU and the memory, the 16-bit bus for I/O operations and the 8-bit bus for SCSI devices. Unix System V.3 was chosen for the operating system.

Ambitious promotion of the computer TIM 600 at the 32nd International Technical Fair in Belgrade (May 16-20, 1988) included the presentation of the first Serbian aircraft SARIĆ, that flew in 1909, only six years after the Wright Brothers' historic flight (1903), and the part of the CER-10 computer, which was constructed 12 years after the ENIAC. The TIM 600 has continued the tradition, having been promoted barely a year after the first of IBM's 80386 computers [32].

The promotion has attracted considerable media attention, satisfying the expectations of the CEO of the Institute Mihajlo Pupin, Draško Milićević [33], whose ambition was to create the Technology Park at Zvezdara, and stop the brain drain of young and talented engineers. Unfortunately, although the TIM 600 was a fascinating engineering project, it was designed without considering the needs of the market. For the sake of some technologically superior solutions, its designers have given up the PC compatibility, so it became clear that the computer had no chance of commercial success. However, it deserves to be mentioned as one of the few attempts of keeping up with technologically developed countries.

6.4. Pecom 32/64

Elektronska industrija Niš (Electronics Industry Niš) has joined the competition for the school computer at the end of 1985, promoting the Pecom 32, and later the Pecom 64. These computers were looking unusual - rather compact, with the built-in power adapter and the keyboard based on QWERTY scheme, but without special characters and the Serbian letters, and with an unusually short spacebar [34], Figure 7. The CPU was the CDP 1802 working on 2.8 MHz - an advantage of this rather old processor was considerable robustness to low temperatures and other extreme conditions. It was the first microprocessor in space, used in the Voyager mission - one of these processors was used in the craft that leaves the Solar system these days. However, this feature of the Pecom was not overly important for a home computer.

The Pecom was functionally similar to a home computer COMX-35 [35] which was sold in the Far East by the company COMX World Operations, while in Scandinavian countries it was distributed by West Electronics. There

were a lot of (mostly free) games for COMX-35, and some of them could work on Pecom computers.

Fig. 7. Pecom computer

The Pecom had 32 KB of RAM and 16 KB of ROM. Text could be displayed on TV set using 40 columns * 24 rows of characters, from a character set that could be redesigned in software. This feature could be used for graphics emulation, so a skilled programmer could achieve the resolution of 240 * 216 points in eight colors. The Pecom had a basic sound generator, controlled from BASIC or the machine language program. The BASIC interpreter was unusual, with lots of interesting new commands and the possibility of pseudo-compilation: using the command RUN+, it was possible to store the absolute destination address with each GOTO and GOSUB instruction, thus speeding up the following program executions. Nevertheless, the Pecom was not the speed champion, and work with it was made difficult as the error messages were represented in the form of codes, so the user could not avoid frequent browsing of the user manual [34].

The Pecom computer reached the stage of serial production. It was delivered to schools, and sold on the market, mostly in the bookstores. The production run was not published, but Pecom computers could be seen in the windows of the bookstores a long time after the production cycle was completed. Efforts were made to develop and offer the educational software for it, but the software support remained modest.

6.5.   The choice of school computer

During the mid-1980s it became clear that the computer education was becoming "a new literacy", with the necessity to be seriously studied in the elementary schools. The inevitable consequence was the need to start the first round of the domestic computer industry production. Based on the number of existing schools in the country, and the former centralized decision-making, the producer of the future school computer could count on the reliable market for the large series of machines sold.

From the first days it was clear that the process was complex. The Education Council could not decide between the Galaksija and the Lola 8a, so they found a Solomonic solution to buy both computers for each school in Belgrade. Unfortunately, these computers were completely incompatible, and the development of the educational software for both of them was irrational and expensive.

In the late 1980s it became clear that the school computer could only be a PC clone, but the domestic production of such computers was complicated and expensive, and the authorities constantly insisted that the school computer should be a local product. Thus, in different regions and different times, schools have purchased Galaksija Plus, Pecom, TIM 011, Oric Nova (after the disappearance of computer Oric-1 and Oric Atmos on the British market, the license was purchased through the Slovenian Avtotehna, and the production was initiated in Serbia, so it also become a local computer), EI Lira (interesting PC XT clone), TRS 80 Color Computer, etc.

Even when the computer was selected, its production in larger series has been a serious challenge. Poor supply of components, problems with import, the lack of quality control and related problems have made computers arrive to school in semi-working conditions, so its exploitation depended primarily on the enthusiasm and knowledge of the teachers. The teachers were often not skilled enough, so they felt uncomfortable in front of the students, many of whom had better computers at home, so they already knew a lot about them. That is why many school computers remained unused.

6.6.   PC years

The early production of PC computers was present during eighties in some companies, like NOVKABEL from Novi Sad, which produced ERA family of personal computers from 1979 till 1987. However, serious expansion of the domestic computer market began in 1990, with the establishment of numerous private companies, the introduction of convertible dinars and removal of the import restrictions. PC clones were first imported from Austria and Germany, and then from the Far East, with a steady fall in prices under the pressure of strong competition. In the years of economic sanctions, the computer market was still there, with constant problems with the import, so it turned to the cheapest (and therefore low quality) components. Since the

import of the assembled computers was complicated, the companies started domestic manufacturing of PCs with the components purchased from various sources. Each delivery of components dictated a new configuration of the products, various customers got different models, so the maintenance was difficult, especially with a mass distribution of illegal software.

Expansions of the market lead to the formation of the first brands and the introduction of mass production, with the quality control. Some of the top brands were created by Comtrade, Jugodata, and Pakom, which standardized the equipment to be delivered. After 2000, the foreign brands reached Serbian market, but there are still many successful models that are constructed, configured and assembled in Serbia.

7.   Conclusion

Although the population and the computer market in Serbia are not comparable in size with the population and the markets of the developed countries, computer boom arrived everywhere in a similar way. From the first computers composed of vacuum tubes, inspired by the need to decipher codes, which were huge in size and hard to program, to the first home computers offered in a kit by popular technical magazines, the developments in the computer history of Serbia resembled that of the technological leaders, with several years of delay. It had its own inventors and its own heroes, just like the computer pioneers that Steven Levy called "The Wizards and Their Machines" [14]. Home computers started with several mutually incompatible models that competed for the favor of users. Prohibition on imports of computers, lack of resources and the inert large economic systems in state-ownership has led to significant delays in the introduction of modern technologies, which is still visible nowadays. However, the research and development in the area of computer science and computer engineering, which lead to the production of original computers in Serbia, also influenced the higher education in this area [37], which is nowadays integrated to the European higher education area, using best practices on the bachelor and master level [36]. The history of the last 50 years of digital computing shows that the potential of human talents and creativity can lead to original and competitive solutions in the area of computing in Serbia.

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