Computers in Russia: Science, Education, and Industry

SERGEI P. PROKHOROV

The history of Russian computer development is described from the first experiments in 1948 to modern times.

Introduction

The period covered here is divided into four stages of 10–15 years. These stages correspond to the changing generations of Russian computers.

Initial Period (1948–1962)

The initial period in the development of Russian computing had results that were important for further development. In the Soviet Union, the domestic computers were developed for the solution of computing problems of the major state programs: nuclear physics, space research, and defense. The industrial production of computers of the first generation was established in several different centers: Moscow, Minsk (in Belarus), Penza (in Russia), Kazan (in the Tatar Republic), Ulyanovsk (in Russia), and Yerevan (in Armenia). Scientific schools for the development of computers, computational mathematics, and programming were created in these major centers, and several major achievements were accomplished that will be described below. Unfortunately, it is impossible to give much in the way of detail about each, but interested readers should be able to locate more details from the ever-growing number of publications available in languages other than Russian.

The history of Russian computers began in the end of 1940, when I.S. Brouk and S.A. Lebedev developed, independently from Western scientists, the main principles of the architecture of electronic digital computers. On 4 December 1948, Brouk and B.I. Rameev received the certificate for the invention of "The Automated Digital Computers." It is the first certificate registered in Soviet documents concerning electronic computers. This marks the beginning of the computer era in Russia.

BESM-1

Developed in the Institute for Precise Mechanics and Computer Engineering (IPM CE) under the management of Lebedev, the High-Speed Electronic Accounting Machine of the Academy of Sciences of the Soviet Union (BESM-1) was a major stage in the development of Russian computer science. Started in operation in 1953, BESM-1 had 5,000 electronic vacuum tubes, had a speed of 8,000–10,000 operations per second, and was, at that time, the fastest computer in Europe and one of the fastest in the world.

BESM-1 was a parallel computer with an advanced architecture and organization of its internal communications. The principles of its organization and design were embodied and improved in subsequent computers developed in the Soviet Union. An important feature of BESM-1 was that it could perform operations on numbers "with a floating point," with values having a large range (from -2^{32} up to 2^{32}). High accuracy could be obtained because the standard word size permitted the retention of about 10 decimal digits, and operations with double-length numbers were possible at a reduced speed. The production of BESM-1 allowed, for the first time, the solution of large scientific and industrial problems.

BESM-1 had three types of main memory in various versions of the machine. The memory size was 1,024 39-bit words, and it was first constructed from mercury delay lines. Later, memory systems were constructed from electron-beam tubes ("potentialoscopes" or "Williams tubes") and ferrite magnetic cores. Beginning in 1958, serial production (at the Ulyanovsk factory) of the BESM-2, which was compatible with BESM-1, used ferrite core memory. There was also a read-only memory fabricated out of semiconductor diodes. The main memory of the machine was supplemented by two-level secondary storage (magnetic drums and magnetic tapes).

Development of BESM was under the general management of Lebedev, who was assisted by K.S. Neslukhovsky, P.P. Golovistikov, V.A. Melnikov, B.S. Burtsev, A.G. Laut, A.N. Zimarev, V.P. Smiryagin, V.N. Laut, I.D. Vizun, A.A. Sokolov, M.V. Tyapkin, V.Y. Alekseev, A.S. Fedorov, and others (see Fig. 1).

Lebedev made the first widely distributed report about the BESM-1 at the *International Conference on Electronic Machines* in Darmstadt, Germany, in 1955. The report was published in four separate brochures in Russian, English, German, and French. Earlier, Lebedev had published a book in Russian, *The High-Speed Electronic Accounting Machine of the Academy of Sciences of USSR.*

Strela

In 1953, an experimental version of the computer known as Strela, developed by Special Engineering Bureau SKB-245, was tested. Strela had a three-address system of instructions, a speed of 2,000 operations per second, and a memory constructed from potentialoscopes of a capacity of 2,048 43-bit words. Two of the main players in the development of the Strela computer were Y.I. Bazilevsky and Rameev.

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Less than a year later, the Moscow factory of Accounting-Analytical Machines had produced the first production model of Strela, and it was in operation in 1954 in the Institute of Applied Mathematics of the Academy of Sciences (IAM AS) of the Soviet Union. It was on this computer, under the direction of M.R. Shoura-Boura, that the first large industrial program of modeling a nuclear explosion was developed. The calculations took several years. The resources of the Strela computer were rather modest for such a difficult problem, and this resulted in very high demands as to the quality of the development of these programs. It was necessary:

Fig. 1. Outstanding computer designer S.A. Lebedev (right) and his pupil V.A. Melnikov (also a famous computer designer). Lebedev was the designer of the first Soviet computer: MESM. He was the designer of computer series BESM and the director of the Institute of Precise Mechanics and Computer Technology. Lebedev is a recipient of the IEEE Computer Pioneer Award.

- to use extreme economy in both instructions and memory;
- to have carefully thought out the modular decomposition of the programs and overlay structure;
- to have careful organization of control points; and
- to repeat calculations every 10–15 minutes with an automatic check of the results.

All this transformed the development of the programs into a difficult scientific problem and promoted the establishment of a highly qualified school of programming.

All together, seven copies of the Strela computer were made in the period 1954–1958. They were installed in computer centers of organizations and were used for problems related to the major state programs. Strela was the first computer produced by an industrial firm in the Soviet Union. It was an important resource in that it performed the calculations necessary for the successful launch of the first rockets and satellites and for building the first nuclear plant.

M-20

The beginning of the development of the computer industry in the Soviet Union dates to 1958, when the production of the M-20 computer started in Kazan. This machine was developed in a joint effort between IPM CE and SKB-245. Lebedev was appointed as the main designer of M-20, and his deputies were M.K. Sulim and Shoura-Boura.

The M-20 computer was one of the fastest and most reliable machines of the first generation. Its speed was 20,000 operations per second, the operating memory (ferrite cores) had 4,096 words, and the external memory was composed of magnetic drums and tapes. The computer received wide recognition and distribution in the Soviet Union and was used for the solution of problems in many areas of science and engineering.

The high speed of the M-20 was the result of a number of new architectural decisions related to the processor, including overlapping the executions of parts of operations, accelerating the execution of operations of addition and multiplication, and being able to multiply two digits at the same time. The improvement of overall computer performance was also reached with the help of new decisions:

- to use index arithmetic, thus allowing one to get rid of having to modify instructions during program execution;
- to introduce new logic operations; and
- to overlap printing and processing operations.

The use of a pulsing principle (dynamic triggers) for construction of the systems circuits resulted in a reduction of the number of vacuum tubes required to 1,600 (logic circuits were almost totally constructed from diodes). That principle—in combination with the no-load mode of circuit operation, which was a consequence of the application of a pulsing principle of circuit design—ensured an increased reliability of the computer as a whole.

It was on this computer, under the direction of M.R. Shoura-Boura, that the first large industrial program of modeling a nuclear explosion was developed. The calculations took several years.

Shoura-Boura took a large role in the development of the M-20 computer. He, together with Lebedev, developed the instruction set, and Golovistikov developed the circuits of the arithmetic-logic unit and the control systems based on dynamic elements. Alekseev, V.V. Bardizh, V.N. Laut, Sokolov, Tyapkin, and Fedorov also had an active role in the machine's development.

The successful introduction of the M-20 stimulated the production, beginning in 1965, of a series of computers compatible with the original M-20: the M-220 and the M-222 (in Kazan), with a speed of up to 200,000 operations per second.

Statement Scheme of a Program

In 1954, having introduced the concept of a program's *statement scheme*, A.A. Lyapunov (see Fig. 2) laid the foundation for the direction of one section of Russian computer science research—the theory of programming. A statement scheme is a formal description of a program in the form of a string of symbols, each of them denoting a statement of one of three types:

1) a statement that changes contents of memory (an assignment statement);
2) a statement that changes an order of execution, depending on the values of predicates on the contents of memory (a conditional statement); or
3) a statement that modifies other statements in order to apply them to new areas of memory (a shift statement).

The concept that Lyapunov introduced turned out to be very productive. It is used all over the world in the formal research of such properties of programs as termination, equivalence, and use of memory. Designers of compilers use a statement scheme of a program to carry out a global optimization of object code. In 1954, Lyapunov organized an urban seminar on programming at the IAM RAS (Keldysh institute). All leading Moscow programmers were present. They discussed questions of the theory and methodology of programming, adjacent questions of cybernetics and genetics, the problems of artificial intelligence, the future of computers and their role in society, new books, and translations.

Later, U.L. Janov, R.L. Podlovchenko, A.P. Ershov, S.S. Lavrov, V.V. Martynjuk, and others researched several refinements and modifications of statement schemes.

Fig. 2. Outstanding mathematician A.A. Lyapunov. He is a recipient of the IEEE Computer Pioneer Award for his outstanding work in the theory of programming. He is the founder of the Soviet school of programming.

Programming Programs

During the early years, Soviet programmers used the statement schemes of Lyapunov as flow diagrams for the development and documentation of programs. A program was represented by its statement scheme and by a set of texts that specified each of its statements. That was exactly the source language for the first Soviet compiler. With S.S. Kamynin and E.Z. Lioubimsky's creation of this compiler in 1954, automation of programming began in the Soviet Union. In 1954, they created the prototype of the compiler for the computer Strela; it was referred to as a *programming program* (PP-1). In the spring of 1955, a group of programmers from the Keldysh institute (IAM of the AS) under the supervision of Kamynin, Lioubimsky, and Shoura-Boura created an industrial version of this compiler (PP-2). Arithmetic expressions in PP-2 were programmed on the basis of convolution. Each program statement with its operands was replaced in a text of an expression with a symbol of a working cell where the result of this operation was placed. Then, according to a statement scheme, a complete lookup of all expressions up to the nearest entry or exit point was carried out. At every point where there was a similar operation (associatively, commutativity and priorities were taken into consideration), it was also replaced by a symbol of this work cell. Boolean expressions were used only for conditional jumps and were optimized locally. Great care was paid to the optimization of expensive shift statements, because there were no index registers in the Strela computer at that time.

The main means of optimization was to find indexed variables, which appeared repeatedly in a sequential block, and to remove them so that they were fetched in advance into fixed temporary-memory locations. The object code obtained was, in practice, just as efficient as "manually" developed programs. That made it possible to use PP-2 as the main programming tool for the Strela computer for several years.

Three Algol Compilers

The experience of working on automation of programming that had accumulated in previous years allowed Soviet computer scientists to begin development of an Algol-60 compiler as soon as the IFIP Committee had produced its completed specification. In the Soviet Union, there were three simultaneous projects to produce an Algol-60 compiler for the M-20 computer, each of which used system IS-2 for reference to standard subroutines. The compiler TA-1 (Lavrov was the chief developer) had a compact and fast scheme of compilation (without optimization) at the expense of eliminating the use of recursive procedures and had a number of other restrictions.

The compiler TA-2 (developed by Shoura-Boura and Lioubimsky) was a practically complete implementation of Algol-60. In TA-2, a method of table-controlled generation of machine language instructions was systematically applied for the first time, a new algorithm for implementing recursive procedures was employed, and the concept of a field of *mathematical memory* with continuous addressing through all types of memory was implemented.

The compiler Alpha (developed by Ershov, G.L. Kozhukhin, and I.V. Pottosin) was an extension of Algol-60 (without recursive procedures). The language Alpha contained a number of important innovations, for example: variable initialization and the introduction of complex and multivariate variables as arguments and results of main operations. The implementation of the Alpha system demonstrated the practical possibility for the development of compilers for languages more complex than Fortran, with acceptable efficiency of object codes. The work on the Alpha system produced a number of essential results on methodology of compilation with optimization. The multipass compilation scheme, oriented to optimization, was introduced. The transformation of an intermediate representation of the program was used for optimization and the global saving of memory. This work was based on Lavrov and Ershov's previous theoretical works.

The Users Association of the M-20 Computer

In 1961, by the decision of the Presidium of the Academy of Sciences, the Users Association of the M-20 Computer was authorized as an interdepartmental coordinating organ under this name: Commission on Operation of Computers M-20. It was the first professional association of computer specialists in the Soviet Union. The chairman of the Users Association was Shoura-Boura. The tasks of the Users Association were:

- organization of a regular information exchange on the operation of machines by participants of the Users Association;
- development of the recommendations and organization of consultations;
- development of the unified programming language;
- organization of an algorithm and program exchange;
- organization of work on the creation of standard programs;
- realization of work on automation of programming; and
- organization of conferences devoted to the questions of operation of M-20 machines.

The activity of the Users Association was important not only for establishing a precedent—which formed the pattern for similar associations for BESM-2, the Ural and Minsk series, and later the BESM-6 computer—but also for accelerating the development of the concept of computer software.

Computers of the Second Generation (1962–1975)

The change brought about by the introduction of second-generation computers allowed the creation of much more powerful computing means for scientific calculations, which, in the first half of the 1960s, were conducted mostly on the M-20 and M-220 computers. By the end of the decade, scientific calculations were already being carried out on the BESM-6, which had many architectural features of computers of the third generation (see Fig. 3).

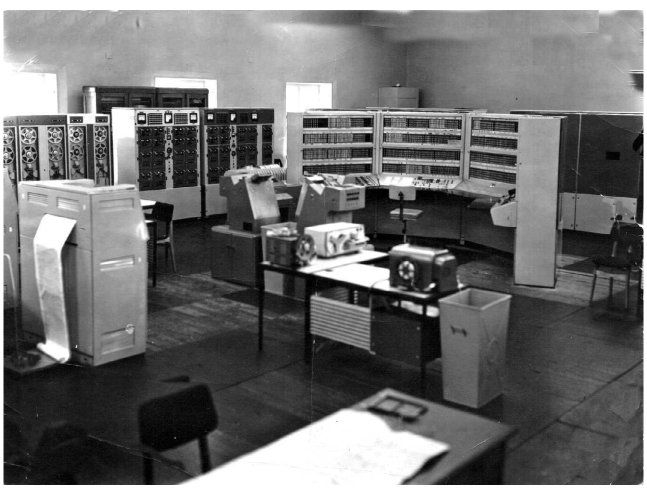

Fig. 3. BESM-6, the main computer for scientific research. It was a very stable and unpretentious computer. These computers were produced during 18 years, from 1967 until 1985.

Computers in this period were also applied in the sphere of data processing for the solution of economic and stock-taking problems—this required development of alphabetic input-output systems and a machine architecture oriented to the processing of alphanumeric information. Real-time computers for the control of industrial technological systems processes and objects were also developed during this period.

Between 1962 and 1975, important results in the field of automation of programming were obtained. Compilers for variants of Algol-60 and Fortran—to be used for programs for industrial purposes—were created, and integrated multilanguage programming systems were developed. Multiprogram operating systems—providing modes for batch processing, time-sharing, and real-time work—were created. A theory of program schemes, making a nucleus of theoretical programming, was advanced.

Research and development of dialog systems was carried out that related mainly to the BESM-6 computer (the systems were Pult, Dimon, Multidostup, and others), which gave the users opportunities to edit program texts and processing of the task in a batch mode. A number of objective circumstances led to the fact that, up to middle of the 1960s, programming in the Soviet Union was developed to some extent independently from the West. Many areas of programming, including general methodology and theory plus the methods of compilation, were developed in the Soviet Union under the effect of our own powerful creative pulses.

In the middle of the 1960s, the isolation of the Soviet Union had, in effect, weakened. Integration processes had begun to have an appreciable influence on the character of work in the field of computer science and programming. First of all, it should be noted that there was collaboration with international organizations engaged in nuclear research, in particular the collaboration between the Joint Institute of Nuclear Research (JINR) and the European Center for Nuclear Research (called CERN). The exchange of programs and data resulted in more unification of the software and data media. In 1966 in Prague and in 1967 in Moscow, international computer exhibitions were held, and there was an opportunity for the legal purchase of computing equipment and software from Western firms. At the same time, information on the architecture of the IBM 360 family of computers and its operating system was rather aggressively distributed.

Serial production of the BESM-6 computer began in 1966, which for the whole decade remained a high-performance machine in the Soviet Union—in many respects, this defined the direction and character of work in Soviet programming.

The representative All-Union Conferences on Programming were held in 1968 in Kiev (in the Ukraine) and in 1970 in Novosibirsk (in Russia)—important events in Soviet programming. During these conferences, various aspects of system and applied programming were widely discussed.

Ural Series 11, 14, and 16

In the beginning of the 1960s, Rameev had formulated the principles of construction of a line (family) of computers that were unified from the point of view of design, circuitry, technology of production, structure, source languages, systems of automation of programming, and operating conditions. These principles were embodied in a family of second-generation Ural computers (Ural 11, 14, and 16) that replaced the earlier vacuum tube Ural models. The three models of this family covered productivity ranges from 10,000 to 80,000 operations per second, with memory sizes from 4 K up to 524 K words (48 bits each). The uniform set of 300 instructions included instructions to operate on words of variable length (one, two, ..., 48 bits), symbols, and numbers with fixed or floating point (variable word length) represented in binary or decimal form. The instruction set was a single-address format, with relative addressing and the opportunity of step addressing for data arrays. An advanced system of interrupts and hardware protection of memory allowed the simultaneous processing of several tasks (Ural 11 and 14 were single-program computers, the Ural 16 was a multiprogram computer). Organization of multimachine complexes on the basis of identical or different computers of the family, the interface with communication channels, and the reservation of separate devices and machines to increase reliability were all part of the development. All models of the family were constructed on unified circuit elements using domestic semiconductor devices that were in wide use in other computer and automation projects.

The software of the family included:

- a universal supervisor program, executing functions of the operating system;
- an autocode (assembly language), ensuring complete upward program compatibility;
- compilers for Algol-60 and ALGAMS (a language developed in the Soviet Union for the solution of economic problems); and
- a library of the standard programs in these languages.

The development of the Ural family was done by Rameev (main designer), who was assisted by his deputies V.L. Burkov (software), A.S. Gorshkov, G.S. Gorshkov, V.L. Mukhin, and A.N. Nevsky.

The Penza factory VEM began serial production of the Ural 11 and Ural 14 in 1964 and the Ural 16 starting in 1969. They were widely applied in Soviet Union in computing centers and automated control systems of industry, construction, etc.

BESM-6

The BESM-6 computer, developed in 1967 by IPM CE's group under Lebedev's supervision (see Fig. 4), takes an especially important place in the development and use of computer technology in the Soviet Union. It was the first supercomputer in the Soviet Union, with a power of 1 million operations per second. The new principles incorporated in the architecture and organization of the computer and its software had an influence on the development of many other computers and computer complexes of the following generations.

Fig. 4. The team of BESM-6 designers. (Second from the right) The general designer, S.A. Lebedev. (Third from the right) The deputy general designer, V.A. Melnikov. (Third from the left) The designer of system software, L.N. Korolev.

BESM-6 was constructed mainly with current switching transistors and diode resistors and core memory (in the 1980s, in IPM CE, BESM-6 compatible computers were designed using integrated circuits). A high-frequency system (for the first time in the Soviet Union, a clock frequency of 10 MHz was reached) and a compact construction with short links between circuit blocks were used. The pipeline principle of control organization ("water pipe," as Lebedev called it) permitted it to combine execution of up to 14 machine instructions in different stages of execution. In addition, thanks to the availability of buffer units of intermediate instructions and data storage, the operation of internal memory modules, the control unit, and the arithmetic and logical unit were carried out in parallel and asynchronously. For acceleration of the pipeline execution of instructions, a separate index register storage and a separate address arithmetic module were incorporated in the control unit. The associative memory on fast registers (like a cache) allowed it to automatically save the most frequently used operands and thus to reduce the number of internal memory references. The internal memory "interleaving" provided the opportunity for simultaneous reference to its different modules from different computer units.

In the arithmetic and logical unit, high-speed algorithms for multiplication and division were realized (multiplication by four digits of the multiplier and computation of four digits of the quotient within one step). The multiply unit used a redundant adder that avoided carry propagation. The redundant adder accepted three inputs and produced two outputs.

The BESM-6 had an advanced system of interrupts, a paged organization of memory with hardware transformation of mathematical (virtual) addresses in the physical address space (paging mechanism), a hardware mechanism of memory protection that provided the possibility of multiprogram mode of operation, dynamic memory allocation in the operating system, the possibility of many units of external memory and input-output units working in parallel with computations.

The main participants in the creation of BESM-6 were:

- Lebedev (the main designer),
- Melnikov (an assistant of the main designer),
- L.N. Korolev (an assistant of the main designer),
- L.A. Zak,
- V.N. Laut,
- V.L. Smirnov,
- Sokolov,
- A.N. Tomilin, and
- Tyapkin.

Other contributors who played a major role were:

- A.V. Avaev,
- Alekseev,
- O.A. Bolshakov,
- V.F. Girov,
- V.A. Zhukovsky,
- Y.N. Znamensky,
- V.L. Lee,
- Y.L. Mitropolsky,
- V.S. Chekhlov,
- Fedorov, and
- O.K. Tsherbakov.

Leading developers of software for BESM-6 were:

- V.P. Ivannikov,
- Lioubimsky,
- N.N. Govorun,
- V.P. Shirikov,
- I.N. Silin,
- V.N. Kurochkin,
- D.B. Podshivalov,
- M.G. Tchaikovsky,
- V.S. Shtarkman,
- Y.M. Bayakovsky, and
- V.F. Tyurin.

The development of BESM-6 was a vivid example, peculiar to the Lebedev school, of the creative approach to the design of computers that used all opportunities presented by the technical base, mathematical modeling of structural decisions, and possibilities of industry to achieve the best computer characteristics possible.

The development of BESM-6 was also an example of successful joint work of the engineers and mathematicians on creation of computing systems. During the development of BESM-6, the main principles of computer-aided design systems were incorporated. The compact documentation of the computer's internal circuits, Boolean algebra formulae, was the basis of its maintenance and installation documentation. The documentation for assembly was presented in the form of tables that were produced from the computer-aided design computer.

Moscow's Accounting-Analytical Machines factory put the BESM-6 into serial production starting in 1967. For the next 17 years, various models of this machine equipped the main computer centers of the Soviet Union. During more than 25 years of active use of BESM-6 and its successors, a large and extremely important software library had been accumulated.

In the 1971–1973 period, multimachine systems with variable components, known as the AS-6, were produced (mainly for space flight management problems) with the help of BESM-6.

Supervisor-68

A big influence on development of research, and development of the field of operating systems for computers, was the creation, in 1967 at IPM CE under the supervision of Korolev, of the first multiprogram operating system for the BESM-6 computer, later called Supervisor-68. The basic developers were Korolev, Ivannikov, and Tomilin.

This operating system provided:

- multiprogram execution of tasks;
- control of simultaneous data transfer on all communication channels with external memory units and all input/output devices;
- a combination of processing of all tasks with a parallel work of external memory units and input/output devices;
- organization of joint dynamic sharing of resources of two-level memory (operating and external), based on replacing pages in operating memory;
- sharing units between tasks;
- input/output buffering;
- well-developed communication with the operator for control of running jobs and of external devices; and
- the possibility of multiterminal work in a dialog mode.

Besides these main functions, Supervisor-68 also, of course, supported the interrupt calls from compilers and autocodes.

Supervisor-68 was a precursor of future, more-refined operating systems for BESM-6: Dubna (by Govorun and Silin) and Dispac (by Tyurin), the latter being a disk operating system, oriented to batch processing, and used later on most BESM-6 computers. Supervisor-68 also exerted a great influence on the development, at IPM CE, of a real-time operating system for BESM-6—the ND-70 (by Ivannikov).

Once a reasonable operating system for the BESM-6 had been created, a number of leading scientific-research and industrial organizations and some of the state's brightest mathematicians were able, for the first time in the Soviet Union, to supply a complete software system (operating system and programming systems libraries) to the customer base.

Operating System IAM

In 1967, I.B. Zadykhailo, Kamynin, and Lioubimsky developed the operating system IAM RAS (OS IAM) for the BESM-6 computer. This system was created by a group of programmers from IAM RAS and a number of other institutes under Lioubimsky's management. The OS IAM project was an interesting interaction mechanism for the organization of tasks and processes. All tasks were considered as being members of a community in various relations with each other—from total isolation to complete division of all resources. Each resource (memory, file, unit) had an owner, who could give it back or lend it to any other task, stipulating appropriate rights of use, including the right to lend it further. In particular, the owner could separate himself/herself, or not, from a resource lent to another task. That ability was supported by a wide spectrum of synchronization processes. The exchange of messages between tasks had all the features of the post office, including obtaining receipts for various actions from other tasks.

Each task could contain up to eight processes, including two special high-priority ones for processing messages and internal interrupts. Some tasks could create others, thus forming trees of any depth. By a call to an offspring task, it was possible to set up a control mode that would give the main task access to any resources of the offspring and control of its processes. When an offspring task could not manage the processing of its emergency interrupts, the main task received the appropriate message and could undertake debugging actions—this allowed, for example, the development of programs such as interactive debuggers.

OS IAM had been developed simultaneously with its programming system, and that allowed such properties as incremental compilation and debugging in terms of source language. The majority of compilers were written in the language ALMO (an analog of the language C). It allowed the software to be first bootstrapped, and then debugged, on the M-220 computer and later to be transferred to the BESM-6 under the OS IAM environment. The software was ported to the BESM-6 in 1969 and was stable enough that an industrial version of OS IAM was developed in 1970.

The Monitoring System Dubna

The first Fortran translator for BESM-6 was developed in 1969 by Govorun, Shirikov, and others at JINR in Dubna (in Russia). That translator was then included in a monitoring system known as Dubna in 1970. This multilanguage monitoring system supported a job supervisor and the development and use of multilevel libraries of programs. The system included a library of general-purpose programs compatible with the library of CERN. The monitoring system Dubna could be used with its own operating system, also known as Dubna, as well as with other BESM-6 systems. The monitoring system Dubna consisted of the following components:

- a translator (assembler) from "Madlen" autocode to a load language;
- a translator from Fortran to a load language;
- static and dynamic loaders;
- a librarian and common libraries of standard programs;
- a text editor; and
- system programs for input/output.

Later, other translators and systems were also included, in particular:

- Algol-DDR;
- Fortran-DDR;
- Forex—an optimizing translator from a language close to Fortran 77;
- a translator for the language Pascal;
- Grafor—a package of graphical programs; and
- Poplan—a translator for the language POP-2.

The Dubna monitoring system was created by a group of employees of JINR with the participation of experts from the Kurchatov Institute of Atomic Energy and from participant countries of the JINR (East Germany, Hungary, and North Korea). The employers of the Institute for Cybernetics of the Academy of Sciences of Ukraine (IC AS UkrSSR), the Institute for Automation and Control Processes of AS (known as IAPU) in Vladivostok (in Maritime Territory), the Institute for High Energy Physics, and other organizations also took part in further development of the system. Govorun was the overall supervisor of this project. Other leading developers were Silin, Shirikov, A.L. Volkov, and R.N. Fedorova.

The Third Period (1970–1985)

At the beginning of the 1970s, the Soviet Union had been producing about 20 different kinds of mainframe computers. These computers were different in architecture and structure, in the types of components on which they were based, and in software. There were also military ground-based and on-board computers that were specialized because of the necessity to satisfy strict requirements as to performance and the use of only domestic components. The existing mainframe and specialized computers demanded rather significant efforts in applications programming because of the differences in architecture. Under these conditions, it was impossible to satisfy the increasing needs of computer technologies for the economy and defense. At the same time, the state foresaw large investments in increasing production capacities for computing devices. Therefore, a question of the creation of systems of computers having a modular structure that would allow a large volume of production became a most important one. For the solution to that problem, it was necessary to develop families of digital computing and control computers of the third generation.

The most significant events of the third period are:

- development and organization of production of the Unified system of computers (ES EVM);
- development and organization of production of the system known as Small computers (SM EVM);
- establishment of multimachine complexes and computing systems that would make rational use of the existing computers; and
- development and wide use of packages of applications and also of methods of software engineering.

The Unified System of Computers (ES-Ryad)

The development of ES (ES is an abbreviation of "Unified System," and Ryad or Riad is a term meaning a row or series) began in 1968. ES was supervised by the specially created Research Center of Computer Technology (directed by S.A. Krutovskikh). In 1969, the Intergovernmental Agreement on Cooperation of Socialist Countries in the Field of Computer Technology was concluded, and the Intergovernmental Commission was created. Various organizations in Bulgaria, Hungary, East Germany, Poland, Romania, and Czechoslovakia were brought into the organization to work on the ES project. More than 46,000 scientists, engineers, and technicians and more than 300,000 workers from more than 100 organizations took part in the program.

Technical and programming tools for ES were developed during the period 1970–1985 for three different lines: Series 1, Series 2, and Series 3, each taking place during the three different five-year intervals. A high level of standardization and unification was typical for ES machines, including:

- program compatibility of different models from a family of computers—implementing a standard set of commands and data representation formats that corresponded to the architecture of the IBM 360/370 families;
- a unified set of peripherals connected through a standard input/output interface; and
- unity of design and production principles.

The first line of ES, whose production was organized in the Soviet Union, included three models of Series 1 (ES 1020, ES 1030, and ES 1050), which differed in performance by a factor of four to five times—from 20,000 to 500,000 operations per second (on a Gibson 3 mixture of instructions). These models were then modernized with about a twofold increase in performance and were produced as ES 1022, ES 1033, and ES 1052.

Four models of Series 2, all produced in the Soviet Union, had a performance that was 2.5 to three times greater than the modernized models of Series 1 (from 200,000 to 5 million operations per second), which were known as the ES 1035, ES 1045, ES 1060, and the ES 1060's variants: the ES 1061 and ES 1065. The emulation of programs from the older Minsk-32 computer was possible on the model ES 1035.

The third line consisted of models of Series 3 (ES 1036, 1046, and 1066), having double the performance when compared with the models of Series 2. In the models of Series 3, there were facilities for dynamic microprogramming with microprogram support of operating system functions and of applications (problem-oriented tuning).

There was the possibility of including special processors (e.g., matrix processors) to increase the performance with certain classes of jobs on models of small and medium computers of Series 1 and Series 3.

The ES models 1030/1035, 1035, 1045, 1050, and 1060/1061 were capable of having two processors with a common area of memory, giving increased reliability and performance. Such complexes were supplied with versions of the operation system OS ES, which included additional components to control the twin-processor configurations. The architecture of ES was also used in special computer complexes for the antiaircraft defense system, developed in the years 1973–1976 under the supervision of Y. Matyuchin.

The upper bound of ES performance was extended in Penza with the production of a multiprocessor "macro-conveyor" computer, the ES 1766, which could have a performance of up to 150 million operations per second. The principles of macro-conveyor organization of computations (developed by V.M. Glushkov in Kiev under the supervision of V.S. Mikhalevich) were implemented in the development of that computer.

Special processors to accelerate the most frequently used computing methods ... allowed them to cope with a large and difficult problem by means of minicomputers instead of supercomputers.

There were 32 different models of these computers—more than 200 kinds of unified peripherals, 12 versions of the operating systems, and thousands of packages of applications—developed and produced in the countries participating in the Agreement on Computer Technology during the 15 years of work on ES.

The Small Computer Family

The Small Computer Family (known as SM) was a second system of computers of the third generation created in the Soviet Union. This second system of computers was developed in cooperation with the countries participating in the Agreement on Computer Technology. This time, the Republic of Cuba also took part. The Institute for Electronic Control Computers AS (IECC), headed by the general designer B.N. Naumov, led the development of the series.

The system included the following models:

- M-4030, compatible with ES (a development of IECC, produced in Kiev);
- M-400, compatible with the Digital Equipment Corporation's PDP-11 (a development of IECC, produced in Kiev);
- M-40, a series of computers for centralized control and regulation of technological processes (a development of IECC, produced in Moscow);
- M-5000, a small computer for data processing, which replaced punched-card-based machines (developed and produced in Vilnius);
- M-6000 and M-7000 minicomputers, compatible with the Hewlett-Packard HP 2116 that composed the core of a system of control computers (developed and produced in Severondonetsk in the Ukraine).

The major de facto architectures of popular minicomputers and microcomputers were accepted as standards for the SM machines. The interface standards, the utilization of common peripheral devices, and a series of common communication devices between computers were developed for the system. ISO standards were strictly adhered to in the creation of this system.

During the period 1974–1985, several more models of the SM (also in three different series) were developed:

- SM 1, SM 2, and SM 1210, compatible with M-6000 and M-7000;
- SM 3, SM 4, SM 1300, SM 1410, and SM 1420, compatible with M-400 and SM 1410, thanks to a second MIR processor;
- SM 1600, compatible with M-5000, thanks to a second processor;
- SM 1700, compatible with a DEC VAX-11 computer; and
- SM 1800, SM 1810, and SM 1820 microcomputers, using microprocessors like Intel 8*86 and control complexes based on them.

Special processors to accelerate the most frequently used computing methods were also implemented in SM computers. A computer complex based on an SM 4 and Fourier processor that was created in IECC and the Institute for Radio Engineering and Electronics AS, for processing radio-location images of the surface of Venus (developed by V.Y. Feldman, G.A. Krylov, and Y.N. Alexandrov) was an example of such a combination. That solution allowed them to cope with a large and difficult problem by means of minicomputers instead of supercomputers.

Areas of mass application of minicomputers, important from the user's point of view, were supported by the creation of problem-oriented complexes of SM computers, which the manufacturers supplied with sufficiently complete software. Such complexes were produced, for example, by:

- the Gomel factory—ARM constructor/technologist, based on an SM 4, for mechanical engineering and radio electronics applications and
- the Vilnius factory—MCC (measuring-computer complexes) based on the SM 3, SM 4 (aggregate complex of electric-measuring technology, known as ASET).

Minicomputers and microcomputers of the Electronika series (in the same family as models of the SM 3 and SM 4) produced by Minelectronprom in Voronezh, Saratov, Zelenograd, and Kaliningrad (all in Russia) were used in many applications. They were compatible with the DEC PDP-11 and LSI-11

Packages of Application Programs

In the 1970s, work devoted to software for the solution of large applied problems was done. A new direction of research, in which both system and applied programmers participated, received the name "packages of the applied programs." The main purpose of this new direction became research and system support of program configurations to facilitate, and make more reliable, the process of program development. The main advantage to these so-called packages is their openness. Modification or extension of a package occurs, as a rule, by adding new modules to it, and the technology of such additions does not permit any changes in earlier, debugged program texts.

Fig. 5. Two outstanding mathematicians working in computing mathematics: M.A. Lavrentyev and G.A. Marchuk. Academician Lavrentyev was one of the founders of Academgorodok, the scientific town in Siberia near Novosibirsk. It was the first strong scientific center in Siberia, and this town was the "father" of other scientific centers that appeared in Siberia and the European part of the Soviet Union. Lavrentyev made outstanding contributions in the development of numerical methods and computing simulation. He was the first president of the Siberian Branch of the Academy of Sciences. Marchuk also is well-known in computing mathematics. He was the president of the Siberian Branch of the Academy of Sciences (after Lavrentyev). In the 1980s, he was the Minister of Sciences of the Soviet Union.

The key question of the package's design is the structure of the program formed with modules. In the Soviet Union, two different approaches have become popular. The first of them assumes that in the resulting program, modules line up in chains, being executed one after the other. All variations of the problems that the package solves are done by varying the structure and sequence of modules included in the formed chains. The special appeal of the chained approach is that the chain of modules can be assembled simply by giving the initial data and the required result. The second approach fixes a framework of the formed program. The framework has holes that are filled, depending on the needs of a particular task, by various replaceable modules. The framework approach appears to be most fruitful in the area of mathematical modeling, in which the key problem is program support of many different approaches to the research. The characteristic representative of the framework approach was created under the management of A.A. Samarsky and D.A. Koryagin—system Safra, with which a number of important problems of mathematical physics have been resolved (see Fig. 5).

Russian Computer Branch During Recent Years (1986–1996)

During the last few years, computers have been developing in Russia as swiftly as the whole society. Conceptions we used to think to be normal were destroyed, and it became necessary for most Russian software developers and users, who were used to being in an isolated and mostly artificially created atmosphere, to determine their own place in the international world. So what has changed in this area during the last decade?

First, there has been the transition from military and industrial fields into a marketplace, i.e., the field has become commercial. The giants of the military and industrial field, which manufactured domestic computers, have gone out of existence. In their place have appeared a number of smaller companies, with rarely more than 100 employees, that sprang from work going on in university laboratories and research institutes.

Also a number of cooperative companies appeared during the period 1988–1992. The initial attempts at creating computer systems for schools and institutes and also for the consumer market were undertaken during the period 1987–1990 (e.g., Korvet and UK-NC) but have not survived in the competition with their foreign rivals, and essentially nothing from before the early 1990s has survived.

Those companies that continued to assemble PCs and servers have completely changed to using foreign parts and supplies. Russian companies have begun to have much closer cooperation with the large foreign firms. The first Russian PCs made almost totally with foreign components appeared in 1991–1992 from the Moscow and Zelenograd plants of Kvant, Acvarius, IVK, and others. However, because of the barriers to manufacturing in our country, none of these firms (except those that did manage to create a wide retail and services net in 1994–1995) achieved a large volume of sales. Much better results were obtained by foreign firms entering the Russian marketplace. From the end of the 1980s to the beginning of the 1990s, the retailing of various foreign computers was a profitable business. As well as in other spheres (consumer goods, household electronics, film production, etc.), the beginning of the 1990s saw the unskilled dealers begin to disappear and the reorientation of the majority of customers (especially big corporations and banks) to the high quality of well-known brand names, resulting in the introduction of the classical way of getting goods from the manufacturers to the consumers: manufacturer to wholesale distributor to wholesale dealer to retail seller to consumer. In 1994–1995, the annual revenue of the major Russian distributor companies (RSI, Dealine, Merisel, and CIS) was about 100 million U.S. dollars. The total revenue of the computer market exceeds 1 billion U.S. dollars in 1995 and is estimated at about 1.5 billion U.S. dollars in 1996. The same process is occurring with software products, but with some delays. The situation is getting difficult, with a high level of piracy. This piracy is partly caused by the low buying power of the majority of PC users and partly by the low level of technical support and service after purchase.

Besides companies selling computers and software, there appeared, in 1991–1993, firms of system integrators (e.g., IBS, LVS, and Croc) that carry out projects for companies and state organizations and further support and upgrade their systems. These firms are, first of all, occupied with the installation of corporate computer networks of various kinds and with the development and adaptation of the software for specific customer problems. Recently, these firms have carried out a number of large projects, most notably the all-Russian system for the running of the 1995–1996 elections, and a large number of projects in the fields of oil and gas production and bank operations. Among the domestic software developers, some of the notable products have involved the development of the following:

- computer systems for banking and accounting purposes;
- software for dealing with Russian texts (including input and optical character recognition);
- the creation of directory systems; and
- systems for various applied functions (including multimedia).

In the last two to three years, a number of companies have appeared to provide services in connection with the Internet and the World Wide Web. By 1996, more than 100 Internet Service Providers were operating in Russia, and the number of advanced Russian-language Web sites exceeds 1,000. The development of computer publications is also growing. The first publications appeared in 1989–1990 (e.g., *PC World*, *Softmarket*, and *ComputerWeek*), and now more than five weekly and more than 30 monthly editions are publishing translations from Western publishers.

Conclusion

In the past decade, in connection with the change in the general political situation—the disintegration of the Soviet Union into independent states and the economic crisis in Russia—the conditions have changed for scientific research and education in the field of computers. In connection with industrial recession, this branch of science suffered heavy damage, especially in areas associated with the military-industrial complex. Russian enterprises have sharply reduced their development of computers oriented to military-industrial use. The restrictions of the state budget on science have had an effect on scientific activity of state research institutes and higher educational establishments. There have been changes in the system of financing scientific organizations and educational establishments.

Western firms and joint ventures are now actively at work in the market for computer facilities and software in Russia. Many private companies have sprung up that specialize in software and are oriented to both internal and Western markets. System integration firms have also formed. Russian societal needs for the creation and development of information systems have stimulated the creation of large international exhibitions of information technologies as well as scientific conferences and symposia. The quantity of information about computers and software appearing in the world market has also increased.

Easier access to information in Russia, which is one result from Russia's integration into the global community, stimulates work in the methodology and technology of designing information systems, paradigms of modern programming, and new architectures of information and computing systems. The academic and industrial institutes are, of course, also trying to preserve continuity from previous work.

International scientific connections with colleagues from Western countries are also being developed. These are mainly joint research projects between the Russian academic institutes and universities in Western countries. Western industrial firms are also finding that Russia has interesting possibilities for self-directed research and development.

The use of the Internet for the exchange of information has also been a big factor in the Russian integration with world science.

Appendix: Chronology of the Main Events in Russian Computing

By the end of the 1940s, Brouk, Lebedev, and U.S. and English scientists independently developed the main principles of architecture and design of general-purpose electronic digital computers.

1947: Lebedev began work for the general-purpose programmed computer, the Small Electronic Computer (MESM).

1948: On 4 December, Brouk and Rameev received the certificate on the invention of "The Automated Digital Computer." The Automated Digital Electronic Computer project started.

1951: The first electronic digital computer in continental Europe, MESM, was developed under the guidance of Lebedev (in Kiev). Lebedev, L.N. Dashevsky, and E.A. Shkabara published their book *Small Electronic Computer*.

1952: Brouk, N.J. Matyukhin, and A.B. Zalkind put into operation the M-1 computer using semiconductor diode logic.

1953: The fastest computer in the Europe at the time—electronic computer of the Academy of Sciences of Soviet Union, BESM-1—was put into operation (in Moscow). The parallel execution of floating-point arithmetic operations was developed. Lebedev published the book *The High-Speed Electronic Computer of the Academy of Sciences of the USSR*.

1953: Brouk and M.A. Kartsev launched the M-2 computer.

1954: The beginning of the manufacture of the Strela computer (seven copies). Bazilevsky and Rameev produced the pilot specimen in 1953.

1956: Brouk, Matyukhin, V.V. Belinsky, G.P. Lopato, B.M. Kagan, V.M. Dolkart, and B.B. Melik-Shahnazarov produced the first specimen of the M-3 computer.

1958: Lebedev and Melnikov began production of the BESM-2 computer (in Ulyanovsk).

1958: The beginning of the production of the M-20 computer (in Kazan). Hardware facilities for loops and ability for parallel operations of the CPU and printer. The design was carried out by the Institute of Precision Mechanics and Computer Engineering (IPM CE) under the guidance of academician Lebedev (deputy leading designers: Sulim and Shoura-Boura).

1958: Melik-Shahnazarov began the manufacture of the Razdan computer (in Yerevan).

1958: Brouk wrote the scientific report *Theory and Principles of Control Computers Design and Application*. This report had a great influence on computer industry development.

1958: Rameev, V.S. Antonov, Mukhin, Nevsky, and A.A. Lazarev develop the first specimen of the Ural-1 computer (Penza).

1958–1959: Lebedev and Burtsev developed the pilot specimens of M-40 and M-50 computers for antimissile defense systems. They are awarded the 1966 Lenin Prize for the creation of the data processing complex for an antimissile defense system based on these computers.

1959: Lopato began production of the Minsk-1 computer (in Minsk).

1959: N.P. Brusentsov began to manufacture the Setun ternary computer (in Kazan).

1959: The first raster display based on a projective TV for picture output from a computer in large-scale format was designed. The authors called this device a "dynamic screen." A magnetic drum on a BESM-1 computer worked as a video buffer. The electronic device development was guided by K.K. Reydik. S.G. Karabutov, V. Alexandrov, and V. Lyzhnikov took part in this project. Tomilin, N.A. Tolmacheva, and N.E. Karabutova designed the software.

1960: The beginning of work on computer logical structures simulation. Lebedev proposed the idea of the simulation. Lebedev, Tomilin, and A.M. Stepanov developed the first programs for mathematical simulation.

1960: The design of the first real-time data processing system. The system was developed on the M-40 computer for an antimissile defense complex. The leaders of the development were Lebedev, Burtsev, and Korolev. A.M. Stepanov, Podshivalov, G.G. Ryabov, and Y.M. Baraboshkin developed the basic programs for receiving ballistic data from communication lines, data processing, and transmission to objects in real-time.

1960: Matyukhin developed the first micro-programmable Tetiva computer (a specialized computer for antimissile defense complex).

1960–1962: A.N. Myamlin developed the pilot specimen of the Vostok computer (magnetic drums with floating heads, command cache, fast registers, and arithmetic unit control).

1961: Rameev began the manufacture of the Ural-4 computer (Penza).

1961: Glushkov and B.N. Malinovsky began production of the Dnepr general-purpose control computer with communication-unit-supplied analog-digital and digital-analog transformers (in Kiev).

1962: Glushkov, E.L. Yuschenko, and Dashevsky developed the Kiev computer.

1963: S.B. Pogrebinsky and V.D. Losev developed the Promin small micro-program-controlled computer for engineering calculations (in Severodonetsk).

1963: The first programs in the field of the computer design technology (the "wave algorithm" for multilayer printed plane trace was developed). Ryabov was the author and main designer of this project. Y.L. Ziman and A.M. Stepanov also took part in this work.

1963: The beginning of the Minsk-2 computer production. V.V. Prjiyalkovsky developed data representation in the form of binary-decimal numbers and alphabetic-numeric words (in Minsk).

1963: Lopato designed the Minsk-222 multicomputer complex.

1963: The beginning of production of the Minsk-32 computer with external replaceable magnetic disk memory developed by V.J. Pikhtin.

1964: The beginning of the Nairy micro-programmable computer production.

1964: Rameev, Burkov, Nevsky, G.S. Gorshkov, A.S. Gorshkov, and Mukhin began production of the Ural computer series (Ural-11, 14, 16) with variable-length operations and structured addressing.

1964: Kartsev began production of the M-4 electronic control computer with a performance of 110,000–220,000 operations/second for control tasks and radio location (in Zagorsk).

1964: The beginning of production of the Vesna computer (300,000 operations/second). The CPU had 32 fast general-purpose registers. The I/0 processor and CPU operated in parallel and were connected through an interrupt system that ensured the individual protection of the separate memory areas (in Minsk). V.S. Polin, B.K. Levin, Shoura-Boura, and Shtarkman developed it.

1965: The manufacture of M-220 and M-222 semiconductor computers with performance of up to 200,000 operations/second (in Kazan).

1965: Glushkov, A.A. Letichevsky, Z.L. Rabinovich, and Pogrebinsky develop the MIR computer family for engineering calculations. The beginning of MIR production (in Kiev). The computers had an architecture with high-level input language (input language Analytic was like Algol-60).

1965: I.J. Akushsky and D.L. Yuditsky design the prototype of a residual class notation computer.

1966: The development of the BESM-6 computer (1 million operations/second) under the guidance of Lebedev. The new architecture solutions developed in this computer were: paged memory, parallel operation of basic units (core memory, control unit, arithmetic/logic unit) through core memory stratification, and introduction of intermediate data storage buffer units. These solutions made it possible to carry out different stages of several sequential command executions simultaneously, i.e., to provide command pipelining. The fast register memory (cache type memory) permitted automated storage of often-used operands and array elements. Fast multiplication and division algorithms were used (multiplication by four digits of a multiplier, and four digits of quotient calculation per clock beat). The multiplication accumulator, without ripple carry, was developed. (At each stage in multiplication, the bit sums and carries were stored separately. Then, at the next stage, a three-input adder incorporated these results into the accumulating product.) A separate accumulator for command address calculation was used. A fast register memory for index (array element numbers) storage was used. Lebedev, Sokolov, Melnikov, V.L. Smirnov, V.N. Laut, Tyapkin, Zak, Korolev, and Tomilin proposed the main ideas.

1966–1968: Kartsev developed the M-9 multiprocessor computational system with performance of about 10 million operations/second. The operations were performed with functions of two variables.

1967: Glushkov and A.G. Kukharchuk began production of the Dnepr-2 control computer (in Kiev).

1969: Glushkov and Rabinovich develop the Ukraina computer project with advanced interpreting systems.

1970: Ershov, Kozhukhin, G.P. Makarov, M.L. Nechepurenko, and Pottosin develop the Aist-0 multiuser multicomputer system, based on M20 computers under control of a Minsk-32 computer.

1971: The beginning of production (in Minsk) of Prjiyalkovsky's ES-1020 computer (20,000 operations/second). (In 1974, A. Rostovtsev's ES-1022 ran 80,000 operations/second.)

1971: The beginning of the ES-1030 computer production (100,000 operations/second) in Kazan. M. Semiryan developed it at Yerevan.

1971–1973: Melnikov, Sokolov, Ivannikov, Korolev, V.L. Smirnov, Lee, Tyapkin, Zak, Chekhlov, Znamensky, Mitropolsky, Tomilin, Girov, Zhukovsky, Avaev, V.C. Novizentsev, G.V.

Stepanov, and A.L. Zhuravlev contributed to research and development of the AS-6 multicomputer calculating complex (shared memory and functionally oriented calculating units connected through high-speed channels). Hardware facilities were used in the CPU to support program module structure and program modules. This technology provided protected subsystems implementation and dynamic loading of programs.

1971–1985: The development of the Unified Computer Series (Russian abbreviation of Unified Series is ES) in the former socialist countries. Modular organization and unification of devices were used. The Board of Leading Designers (from the Soviet Union) were Krutovskikh and later A.M. Larionov and Prjiyalkovsky.

1972–1976: The development of Matyukhin's ES-like computers (5E76) and computer systems for antimissile defense complexes.

1973: The use of the AS-6 multicomputer calculating complex as a computer pipeline for space-flight data real-time processing. Development of the units for data receiving and for the transfer and mapping through telegraph, telephone, and wide-band communication channels.

1973: The beginning of production of Kartsev's M-10 high-performance computer. A multiformat vector RISC architecture was developed. This computer (in Zagorsk) was used in the missile attack prevention systems and for general-purpose observation of outer space.

1973: The beginning of manufacture of Antonov's ES-1050 computer (in Moscow and Penza).

1974: The beginning of production of A. Gusev's ES-1033 computer (200,000 operations/second) in Kazan.

1974–1985: Naumov (later N.L. Prokhorov) developed the Small Computer Family Series (Russian abbreviation of Small Computer Family is SM), implementing the most widespread international standards for the mini- and microcomputer architectures. The Computer Facilities of Aggregate System based on Microelectronics ASVT-M preceded the development of the SM computers in the Soviet Union (developments at Moscow, Vilnius, and Severodonetsk: the M-4030, M-400, M-40, M-5000, M-6000, and M-7000 computers).

1975: The AS-6 complexes were used for data processing in the USA–Soviet Union *Soyuz–Apollo* joint space flight.

1977: The beginning of production of G.D. Smirnov's ES-1035 in Minsk. (In 1983, R.M. Astsaturov's ES-1036 computer ran 400,000 operations/second.)

1977: The beginning of production (in Moscow and Penza) of Y.F. Lomov's ES-1060 computer—the major model of ES series. Since 1980, the ES-1061 computer ran 1.5 million operations/second.

1977–1978: The development of V.V. Rezanov, V.M. Kostelyansky, G.M. Lekhnova, V.J. Barabanov, and L.A. Sapochkin's SM 1 and SM 2 computer control systems. These systems were M-6000 and M-7000 compatible (in Severodonetsk).

1977–1978: The development of Naumov, M.J. Boyarchenkov, A.N. Kobalevsky, V.P. Semik, Y.N. Glukhov, M.N. Ostrovsky, B.L. Panferov, V.S. Gromov, A.A. Solokhin, E.N. Filinov, and A.V. Filin's SM 3 and SM 4 computer control systems. These systems were M-400 compatible (in Moscow and Kiev).

1978: The beginning of ES-1055 computer production.

1979: The beginning of manufacture of A.T. Kuchukyan's ES-1045 computer (800,000 operations/second) in Yerevan and Kazan.

1980: The development of Naumov, Kobalevsky, Semik, V.S. Zonis, V.V. Rodionov, and A.S. Shumei's two-processor SM 1410 computer system based on the SM 4 processor and special processor for MIR computer language program processing (in Kiev).

1981: The development of Rezanov and Kostelyansky's two-processor SM 1210 computer system. The main command set for SM 2 and scalar and vector operation for PS 3000 computer were implemented (in Severodonetsk).

1981: The beginning of production of Naumov, Kobalevsky, Semik, Shumei, Filinov, T.D. Chernina, Rodionov, V.A. Afanas, and S.S. Zabara's SM 1420 computer control system (in Kiev).

1981: The beginning of production of Naumov, A.N. Shkamarda, N.D. Kabanov, Sokolov, and V.G. Kanevsky's SM 1800, SM 1803, and SM 1804 computer control systems (in Kiev and in Tbilisi, Georgia).

1982: The development of A.M. Nemeikshis's specialized two-processor SM 1600 computer system for business and economics applications. This system was based on the SM 1420 processor and an improved version of the M-5000 processor (in Vilnius).

1984: The beginning of ES-1052 computer production (in Penza).

1984: The beginning of Kuchukyan's ES-1046 computer production (in Yerevan and Kazan) and Lomov's ES-1066 and ES-1068 computers (in Moscow and Penza).

1987: The beginning of production of Chernovt's SM 1810, SM 1814, and SM 1820 computer control systems (in Kiev and Tbilisi).

Sergei P. Prokhorov graduated from the Moscow Institute of Physics and Technology (1972 master's degree in computer science, 1978 doctor's degree in computer science). His thesis was on the investigation of super-high-level dialog programming languages. The writing of the compiler for the dialog language APL was the practical part of the dissertation—it was the first such compiler in the Soviet Union. He has been working in computer science and software engineering since 1970 in the leading Russian scientific institutes, such as the Computer Center of Academy of Sciences, Kurchatov Institute of Atomic Energy, and Moscow State University. Currently, he is deputy director of the Institute for System Programming of the Academy of Sciences. He is also an associate professor at the Moscow Institute of Physics and Technology. His research work has been concerned with programming languages, software, computer simulation, computer system developments (real-time, information systems), and the management of large, complex projects. In 1995, he joined the IEEE Computer Society. He is now a Senior Member of IEEE and coordinator of the Russian subcommittee of the IEEE Computer Society.

The author can be contacted at
email: s.prokhorov@computer.org