METHODOLOGICAL NOTES

General computer workshop for physics students of the Moscow State University

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We describe in this note the general mathematics workshop for students taking lower-level courses at the Physics Department of the Moscow State University. The purpose of the workshop is to teach them how to apply computer procedures in research. The need for such organized instruction became pressing with introduction of computer techniques in science. In particular, there has been a continuously increasing number of undergraduate and graduate physics students using the computer facilities of the Computation Center of the University. On the other hand, the progress in computer techniques and particularly the development of high-level computer languages, which greatly facilitate the programming, have created a demand for large scale teaching of programming.

Of course, a physicist who is not too narrow a specialist does not resort to computers, frequently enough even now, to make programming an important tool for his research; it does represent, as is customarily stated, an element of mathematical culture. Familiarity with computers and with programming makes it possible to assess the possibility of using the computer in the appropriate field, and in addition, makes it possible to perform various calculations independently and effectively.

The scope and curriculum of programming instruction are connected mainly with the number of computers it is proposed to use, or with the produced assortment of computers and the prospect for their acquisition. It seems that the most suitable for teaching is a time-sharing system with terminals feeding a rather large computer system. (A terminal is a device connected to the computer and intended for the input and output of the information, having a keyboard for the information input and the instructions, sometimes a buffer memory, and either a typewriter or a cathode-ray screen for an output). The terminals can be located quite far from the computer; the time-sharing system makes possible simultaneous operation with several terminals connected to one computer). Of course, programming can be taught also by the so called "parcel-post" reduction, wherein the student never sees the computer, and addresses it via intermediaries. During the initial stages of group instruction, however, the clarity and the psychological effect of personal use of the computer are of tremendous importance. In many cases it is therefore most expedient to use for teaching purposes small computers with a sufficiently developed high-level language; such computers can be regarded, with certain limitations, as equivalents of terminals of larger computers operating in the time-sharing mode.

The use of computers in physics research should also be divided into two classes; a) calculations and mathematical simulation, b) the reduction of the results of physical experiment, wherein the computer becomes, as it were, part of the experimental setup. Each of these uses should be taught separately with the second during the later stages. Both forms are realizable in principle with a large or medium computer, but in the case of a small computer, which is usually more specialized, it becomes necessary to give preference to one of these classes. The discussion that follows concerns teaching how to use computers for calculations, i.e., the first stage of the general study.

The choice of the computer for teaching should be governed by the following main premises. The input language must be simple enought to be mastered in a short period by students without special preparation. At the same time, the language must have the main features of modern algorithmic languages. The computer construction must be suitable to permit its direct operation and the control board and the operating procedures should be simple enough. Great importance attaches also to the operating features of the computer, its reliability in operation, small dimensions, compactness. On the other hand, the volume of the main memory and the speed are not essential parameters, at least during the initial stage of instruction.

The computer "Mir-1" chosen by us satisfies on the whole the requirements formulated above. This computer was developed by the Cybernetics Institute of the Ukrainian Academy of Sciences under the direction of V. M. Glushkov[1]. The input language is reminescent in general outline of the modern ALGOL-60 language. A feature of the computer is the internal interpretation of the language, which is incorporated in the logic (microprogram) circuit, which makes it possible to dispense with cumbersome external memory devices. Information between man and computer is exchanged with an electric typewriter (to introduce the program, it is sufficient to type it out). The computer operates in the decimal system with an arbitrary number of digits, limited only by the volume of the memory. When operating with six digits, the computer speed is on the average 200—300 arithmetic operations per second. The volume of the main memory with this number of digit is 200—300 numbers. As an example of the capability of the computer, we indicate that the maximum order of a system of linear algebraic equations that can be solved (by the Gauss method) with the "Mir" computer in six digits is fifteen. The solution time is then about 7 minutes. The computer is easy to operate, is sufficiently reliable, and compact.

A computer having parameters close to those of "Mir" is "Nairi," it has two languages at different levels, so that it permits if necessary compilation of a more detailed and economical program designed for repeated use. In addition, the "Nairi" has a somewhat larger effective memory volume (the number of digits in the computer is fixed). However, even the high-language, called automatic programming, seems to us less convenient and more difficult to grasp at first. The same pertains also to the practical use of the computer. It is therefore preferable to use the "Nairi" for scientific computations, although it can be used for instruction purposes. When it comes to systematic reduction of experimental results, the "Nairi" offers definite advantages over the "Mir."

The students are taught in the mathematics workshop in the following manner. During the first semester, they perform three computations intended for familiarization with the computer language and the simplest procedures of programming and operating the computer. In one of the first lectures and in the first seminar project, the students receive the basic information on the computer, the general outlines of the algorithm and methods of recording the simplest algorithms with the aid of the input language of the computer. They are then assigned problems which they are to solve independently within a prescribed time. During this time the students use the published instructions ("Description of the input language and instructions for the use of the Mir-1 computer") to compile the program in the input language of the computer. They turn for advice to the mathematics instructor and to the workshop instructor on duty. The student is allowed to solve his problem with the computer only after the program and the student's knowledge are tested by the workshop instructor. This test can conveniently be held in the form of a colloquium in which the entire group or a smaller number take part. After he passes the test, the student is assigned computer time. He is allowed 30 minutes for each problem; thus, the student operates the computer for an hour and a half during the first semester. The work is performed as a rule independently, without the help of the laboratory attendant.

The problems assigned in the first semester include the following main features. The first assignment calls for an acquaintance with the main construction of the language—the arithmetic expressions, standard functions, simplest operators, and the sequence and distinctive features of operating the control board.

Examples. 1. Calculate

a) $\frac{4-0.0186^2}{\sqrt{0,1}-\sqrt{10}}$ to six digits

b) $(1+\sqrt[3]{\lg 3})^4$ to seven digits

c) $\sum_{n=1}^{24} \frac{\sin n}{n\sqrt{n}}$ to five digits

2. Find the root of a transcendental equation $F(x) = 0$ with the aid of a standard (previously compiled) program that uses a method in which the interval is divided in half. To this end, it is necessary to become acquainted with the program and specify, in addition to the other parameters, the form of the function $F(x)$. In this assignment, the standard program is introduced from a punched tape.

In the second assignment there is developed the concept of an algorithm (simplest cyclic programs, arbitrary operators).

Example. Given the sequence $a_n = n/2^n$. Find the smallest number satisfying the condition $a_n < 10^{-6}$.

In the third assignment the students consider, besides the foregoing, also work with large masses of numbers.

Examples. a) Find the coefficients p and q of the straight line $px + q$ having the smallest mean-squared deviation from specified points x_i, y_i, $i = 1, 2, \ldots, N$, on a plane (the formulas are given).

b) Given the coordinates of points on a plane, x_i, y_i, $i = 1, 2, \ldots, N$. Find the point whose distance form a given straight line is minimal. N is taken equal to 10–20.

In addition, the students solve in the second semester problems in approximate methods of calculations, as taught in the course of higher mathematics, viz., calculation of definite integrals with quadrature formulas and solution of transcendental equations.

In the second, third, and fourth semesters the students use the computer to reduce experimental results obtained in the general physics course. The automatization of the experimental data reduction is relative in this case, since it is very difficult to feed directly information from the experimental setup into the "Mir" computer, and all that is involved is automatization of the computations on the basis of results obtained in the usual manner. In addition, this automatization is partial, since each student solves during the semester two or three problems with computer reduction. The reduction itself is performed with standard programs compiled beforehand on the basis of simple algorithms. A typical example is the problem of determining certain physical parameters by least squares. The programming of such problems is not complicated in principle, but the entire task, including the checking of the program, is quite laborious and it is not advantageous to assign it to all the students. To teach students how to use computers for data reduction seems to require the formulation of special problems, and this should be taken into account when practical physical experiments are reviewed and modernized.

To realize the described teaching program, it was necessary to have at least one "Mir" computer per 200 students of the first course. The computer operation was scheduled in two shifts from 9 AM to 10 PM, calling for several personnel shifts. In the main, the students work with the computer during hours when no academic courses are scheduled. The remainder of the time can be used to perform various scientific calculations. In the Physics Department of the Moscow State University, the "Mir" computer was used not only by the students of the first and second courses, but also by staff members, graduate students, and undergraduates from practically all other departments.

From the very beginning, the mathematics workshop was received by the students with great enthusiasm. The process of "live" communication with the computer greatly increases the instruction efficiency. Absences or latenesses were very rare. Many students expressed independently a desire to apply the acquired knowledge to the reduction of their practical results at the very beginning of their study of programming. Some assumed duties in the computer room and voluntarily helped the operators, so as to be able to work with the computer. In the students' general opinion, the programming and computer-operation course is not complicated. Most errors committed by the students are more readily due to slips of the pen than to failure to understand the gist of the matter.

As a result of their workshop studies, the students become acquainted with the principles of programming and computer operation, and also with the simplest methods and devices used in computer calculations. They can assess their ability to use computers and thus reveal their bents and select their future scientific activity during the early studies. Experience gained during a long time is very important in programming. Of course, those passing the described course cannot be called experienced programmers, but it can be concluded on the basis of the experience in the mathematics workshop that most students acquire a good knowledge sufficient for further independent work and for further gaining of experience.

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[1]V. M. Glushkov, A. A. Letichevskiĭ, and A. A. Stogniĭ, Kibernetika No. 1, 74 (1965).

Asynchronous excitation of undamped oscillations

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The assumption that oscillations maintained by an external harmonic force always assume the frequency of this force or a multiple of this frequency is widely used in the theory and practice of mechanical oscillations. Yet inertial, thermal, and other effects, frequently not taken into account, introduce time shifts between the driving force and the dynamic functions of the oscillations, and can lead to an asynchronous excitation of undamped oscillations.

The dèlay effect, which is used with tremendous success in microwave electronics, has not yet found application as a operating principle in electromechanical systems. We have developed a number of devices in which definitely prescribed actions applied to oscillations lead to a periodic contribution of energy from an external harmonic source and makes possible generation, amplification, or conversion of oscillations[1]. The oscillatory processes take place at the natural frequency of the oscillations in a damped system with one degree of freedom, acted upon by a harmonically-varying force having a frequency that is not resonant, nor multiple, and in general not even commensurate with the natural frequency. The proposed mechanism permits realization of a self-regulating energy contribution, i.e., it can be used as a mechanism for maintaining undamped oscillations.

We started with the following hypothetical experiment. Let an oscillating electric charge cross during part of its path a parallel-plate capacitor with absolutely permeable electrodes (Fig. 1a), to which an alternating voltage is applied (the time required by the charge to negotiate the gap is of the order of the period of this alternating voltage).

If the amplitude of the field in the capacitor gap reaches a high enough value, then a change in the flight time should occur in the presence of a light charge. Let the time of flight unperturbed by the field be $\tau_0 = 3T/4$ (T is the period of the alternating field). At an initial entry phase $\varphi_1 = 0$ (Fig. 1b), acceleration will take place during the initial half of the period, followed by deceleration. Therefore the real flight time τ_1 is smaller than the unperturbed flight time, and a positive energy contribution proportional to the shaded area in Fig. 1b is produced.

If the initial phase is $\varphi_2 = \pi$, the time of flight is larger than at $\varphi_1 = 0$, and this leads to a large deceleration, i.e., to a negative energy contribution (Fig. 1c).

Comparison of these two swings leads to the conclusion that the resultant energy contribution is positive. If the natural oscillation frequencies of the charge and of the alternating field are not commensurate, all initial entry phases can be regarded as equally probable, and we can reason analogously for all other pairwise-taken flights with initial phases φ and $\varphi + \pi$, so that a predominant energy contribution results (Figs. 1d, 1e).

For any entry phase, the time of flight τ_f can be calculated (if the velocity varies linearly) from the formula

$$\tau_f = \frac{d}{v_0 + \Delta v_0 \cos\varphi_f} = \frac{\tau_0}{1 + (\Delta v/v_0)\cos\varphi_f} = \tau_0(1 - a\cos\varphi_f),$$

where d is the length of the interaction region (width of the capacitor gap), v_0 is the unperturbed flight velocity ($v_0 = d/\tau_0$), and φ_f is the entry phase. It is assumed that $a = \Delta v/v_0$ is small.

It can thus be stated that when the frequency of the oscillating system is not commensurate with that of the alternating external force, a resultant positive energy contribution (averaged over a number of oscillations) is possible if the system alters the time of flight through the interaction space sufficiently strongly.

All the arguments cited above can be repeated for a time of flight equal to T/4, in which case we have predominant deceleration (generator regime).

Understandably, such interactions are possible not only in the particular system considered, but also in any

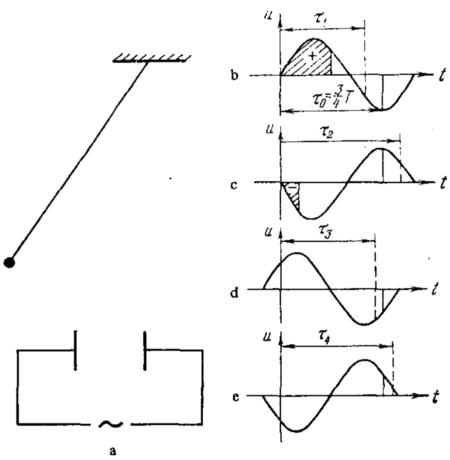

FIG. 1.