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Organization of Address-free Computer B-100

by

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The present paper contains the description of a small computer destined for engineering calculations. The organization of this machine is based on quite new mathematical principles, formulation of which one may find in the papers [1]—[3].

The mathematical basis for the machine was worked out at the Institute of Mathematics of the Polish Academy of Sciences; its simplified model was designed at the Warsaw Technical University.

Assumptions

The computer is destined to calculations of arithmetical formulae, containing about 30 independent variables and operations of adding, subtraction, multiplication and division.

The computer B-100 is to work in a decimal system. (Nine-figure numbers with arbitrary location of decimal point). Computation of iterative formulae is also envisaged in this device.

Drum memory and electronic valve circuits are used.

As output the standard teletype is used, input — on perforated tape with 30 symbols reading velocity per second. A formula once introduced into the computer may be many times computed (e.g. thousand times) for various values of independent variables and parameters. From analysis of the problems, which are to be computed it follows that computation of one value of a function ought to last from several to some dozen seconds.

This "time" consists of:

1. "introduction time" of formula into memory T_f,
2. "introduction time" of data into memory T_d,
3. "computation time" of the value of formula T_c,
4. and of "printing time" of result T_r.

Since this machine does not require too high speed, these operations can be made successively step by step and not concurrently, as it would be necessary if a high speed of computation were assumed.*)

Assuming that a formula once introduced into the memory may be computed manifoldly, T_f, in relation to the other aforementioned "times" may well be disregarded. "Introduction time" of data into the memory T_d (30 nine-figure numbers) amounts to *c.* 9 sec.; the "printing time" of the result amounts to *c.* 3 sec. (nine-figure number); "computation time" of the value of the formula may thus take several seconds.

Assuming that the drum has 1,800 revolutions per 1 min., we simultaneously assume that one arithmetical operation is carried out during one drum revolution (1/30 sec.), and thus the computation of the formula is performed during 1 sec., approximately.

Thus the effective speed of operation of the machine depends mainly upon the speed of introduction of the data into the machine.

Internal language of the computer

This internal language has been selected so that it can be used at the same time as external language.

In the case of application of another kind of external language, the machine must be equipped with a translating device.

Numbers. As mentioned in the preliminary part of the paper the machine operates in the decimal system with arbitrary decimal point location. Zeros are not written at the beginning.

Variables. We may distinguish the following variables in the machine:

1) a — different variables,
2) x, y, z — "uni-shaped" variables,
3) c — partial result,
4) p, g, r, s, t, u, w — parameters,
5) b — substitutional variable,
6) i — inductive variable,
7) n — recursive variable.

Operations. Let us assume the following operations:

1) $+$ which denotes adding,
2) $-$ — subtraction,
3) $\cdot$ — multiplication,
4) $/$ — division,
5) , — printing,
6) π — repetition of the computation.

* One may easily observe that, if time of performing of one dyadic arithmetical operation amounts to t and all operations require the same time, then the computation of the value of formula, containing n dyadic symbols of operations, cannot be performed in the time shorter than $t_{\min}$, where $t_{\min} = t \cdot \log_2 n$.

Formulae. In the computer we assumed a somewhat modified parenthesis-free symbolism with blank spaces [3]. The formulae are defined in a recursive way:

i. $\Delta\alpha\beta$ is a formula, where Δ is one of the symbols $+$, $-$, $\cdot$, $/$

whereas α and β — any arbitrary letter out of the following: $a, x, y, z, p, q, r, s, t, u, w, b, i$.

ii. If α and β are formulae, then the expression $\alpha\beta(c)$ is also a formula, with $\beta(c)$ denoting the expression obtained by substitution in β of an arbitrary letter different from c by the letter c;

iii. If α is a formula containing at least one letter i, then $\alpha\pi n$ is a formula.

iv. If α is a formula, then $\alpha,$ is also a formula.

Examples of formulae. $+xy$, $+aa-xa/cc$, $\cdot xy/aa-cp+cc$, $\cdot ix\pi y$ denote, $(x+y)$, $(a+a)/(x-a)$, $((a/a)+((x\cdot y)-p))$, and raising to power x^y, respectively.

In the language given a comma written after a formula denotes printing of the result. Every variable, occurring only once in the formula, is indicated by letter a. Such a solution greatly simplifies the construction of the machine. Outside the machine symbol a may be eventually used with subscripts, to avoid equivocations. If in the formula any variable occurs at least twice, we denote it by one letter from among the letters x, y, z. Symbol n denotes the number of iterations. For symbol i we always substitute the result of the last computation. The substitutive variable will be discussed in the section pertaining to organization of the machine. Reading of the formula starts from right towards left. The arguments of each operation are the two nearest variables at the right-hand side. Location of the nearest letter c, at the right-hand side — into which no partial result was written — is replaced by the result of computation of each operation. The procedure of translation from parenthesis symbolism into formalized language, just given, is very simple. A detailed description of this translation will be presented in a separate paper.

Organization of the machine

A simplified scheme of the machine is given in the Figure. This machine consists of the following elements:

D — drum memory,
H_1 — reading head,
H_2 — writing head,
H_3 — head checking "blank spaces" in the memory,
L — argument counter,
A — arithmometer,
C — control unit,
O — operation register,
V — variable register,
N — iteration register,
W_1 — output register,
W_2 — input register of the data and of the formulae,
W_3 — input register of partial results.

The memory, as a rule, consists of a single "path" (not taking into account auxiliary "paths", e.g. clock "paths") comprising sixty 48-bit words. The path is used to record the computed formulae.

The word is divided into twelve 4-bit groups marked by symbols from G_1 to G_{12}. Symbol G_1 denotes operation, G_2 — variable, G_3 — the last bit (sign of the number), the second one at the left-hand side denoting whether the given word is occupied

or free. Other G-groups denote number. Thus, the word consists of 5 groups of $OVFSN$ symbols:

O — symbol of operation, V — symbol of variable,
F — symbol of occupation, S — sign, and N denoting number.

The meaning of symbol F will be explained in the course of discussion of the operation cycle of the machine. The graph of the word is given below (Fig. 1):

Fig. 1

The arithmometer performs, as a rule, four basic arithmetical operations, which are set from the register of operation O. This arithmometer disposes of three registers (not shown in the Figure 2), which fulfil both the role of accumulator and of register of multiplicand and multiplier (or dividend and divisor).

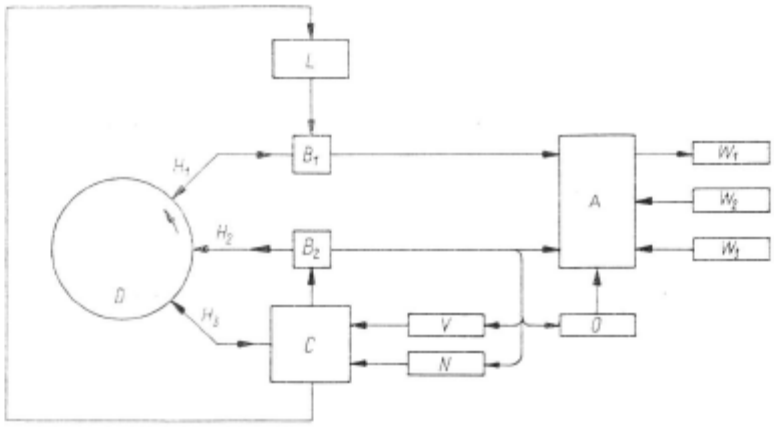

Fig. 2. Simplified scheme of organization of address-free computer B-100

Cycle of operation. The cycle contains the following "steps":

1) input of formula,
2) input of parameters,
3) input of data,
4) computation,
5) printing of results.

Formula, parameters, and data are, as a rule, introduced from tape through input W_2. Manual input from the keyboard is also possible. Introduction of the formula consists in recording by means of corresponding words of suitable symbols of operations and variables.

Introduction of parameters and data consists in the substitution of variables and parameters by numbers.

It should be noticed that in the symbolism applied substitution of the value of variable consists not in the substitution of the variable by a number but in record-

ing a number, which is the value of the variable beside the corresponding variable (i.e. N, in the word denoted by a given variable, should be replaced by the value of a given variable).

Thus, in the "course" of substituting the formula does not undergo any "destruction", and may be used over again for computation of function values for new values of parameters. After introduction of the formula, all words containing the variable c have $F = 0$, others have $F = 1$.

On introducing the formula each symbol is brought in during the time of one drum revolution.

The words in the memory are numbered from 0 to 59. Argument counter L points out to which word the given symbol of operation — variable or number — should be introduced.

The numbers are first completed in the accumulator, then they are introduced into appropriate location in the memory. Each arithmetical operation is carried out in the time of one drum revolution. At every drum rotation the argument counter increases its content by 2.

If in the counter L number k is placed, then the control unit C transfers the operational part of the word of the number k to register O, the variable of the same word — to register V, and the numbers of words k and $k+1$ — to respective registers of arithmometer A.

If the printing operation is located in register O, then the machine interrupts the action of computing and "passes to the next step", i.e. — to printing of the accumulator content by means of output register W_1.

If the iterative operation is put in the register O, then respective number comes into the iterative counter N.

On computing a new value, number 1 is always located by the arithmometer in position F. Before renewed execution of iteration in all words denoted by letter c, number 0 is put in the place F. After performance of the 5th step, the 3rd step is executed, i.e. new values of variables are substituted.

Heads H_1, and H_2 and then H_2 and H_3 are situated at a single-word distance. Head H_3 "searches" in the memory for the nearest blank space, that is the closest place, where $F = 0$ and $V = c$.

When such a place is found, the control unit C, by means of gate B_2 and head H_2, registers the result from the arithmometer in the memory.

Let Φ be a function not contained in the memory of the machine, that is a function comprising more than 30 operation symbols, — such that $\Phi = \text{sub}\left(\begin{matrix}\Psi\\ b\end{matrix}\right)\Psi'$, where Ψ and Ψ' contain, by this time, less than 30 operation symbols. In such a case we compute first the values of function Ψ', all the results of computation Ψ' being perforated on the tape; then the value of function Ψ is computed.

The procedure of substitution of new data into formula Ψ is as follows: the tape with the value of function Ψ' is introduced at the input W_3; when substituting new values of variables, the data are introduced from input W_2, whereas the values of the substitutive variable — from input W_3.

In this way, by means of the computer under consideration, one may also compute formulae longer than those included immediately in the memory of the machine.

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