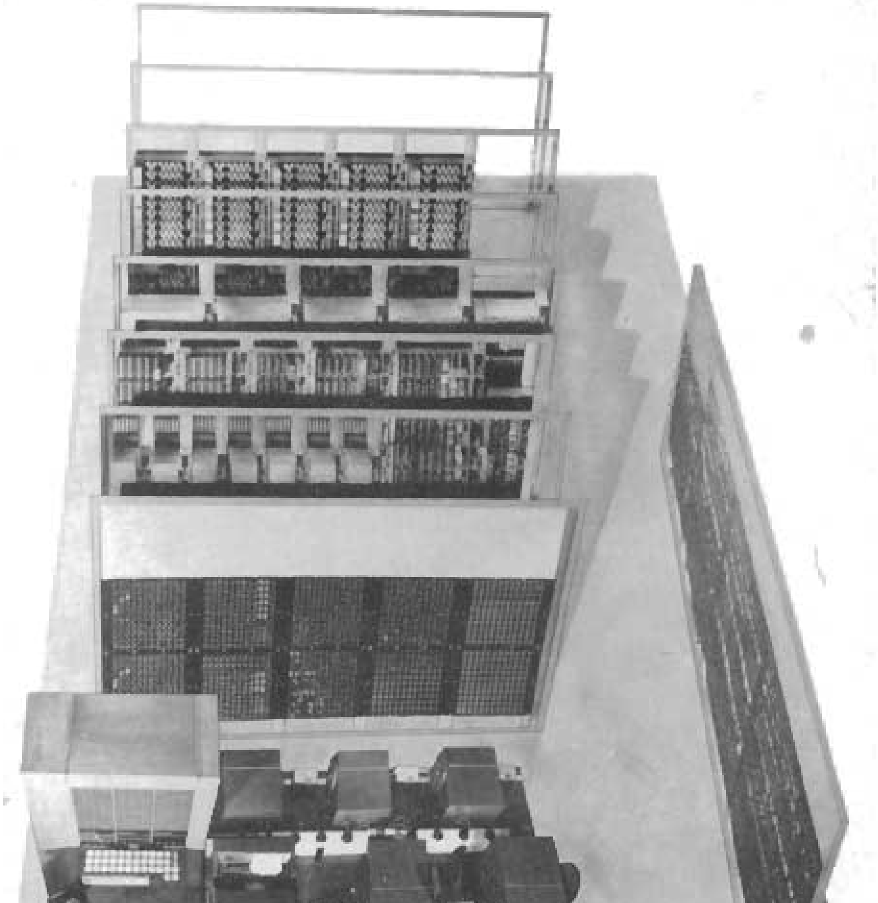
BARK

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The BARK, A Swedish General Purpose Relay Computer

Introduction.—In December 1948 The Swedish Board for Computing Machinery decided to build a relay digital computer for which plans and cost estimates had been drawn up by DR. CONNY PALM. Design work started almost immediately under the direction of Dr. Palm. The machine was completed in February 1950 and, after a testing period, was inaugurated on April 28, 1950. The machine is called BARK, standing for "Binär Automatisk Relä Kalkylator." The main characteristics of the computer are listed below.

Numbers are represented by absolute value and sign in the form $2^p \cdot q$, where p is a 6-digit binary number with algebraic sign and q is a 24-digit binary fraction with algebraic sign. Thus, 32 binary characters are required for the representation of one number. In the decimal system this corresponds to a range between 10^{-19} and 10^{+19} with a precision of slightly better than seven decimal digits.

In the number representation, q plus the sign is referred to as the "numerical part" of the number, while the remaining places are called the "exponential part." Similarly, in the following, the 25 places of a register which store the digits and sign of the fraction q will be referred to as the "numerical part" of the register, while the remaining places will be called the "exponential part." Within each part we use the terms "first" or "left(most)" to designate the most significant positions or digits, while "last" or "right(most)" describe the least significant positions.

Storage and Arithmetic Circuits.—The storage consists of 50 relay registers and 100 constant registers, each storing 32 binary characters. In the near future the memory capacity will be increased to 100 relay registers and 200 constant registers. The original design enables this enlargement to be made without difficulty. The constant registers are set manually by means of one 4-position switch for the signs and ten 8-position switches, each one taking care of three binary digits; conversion to binary form is thus necessary before a number is put in a constant register.

Within the machine numbers are transferred along three number transfer busses, each of which contains 32 wires or digit channels. Voltage on a digit channel represents the digit one or a plus-sign; no voltage represents the digit zero or a minus-sign. The A- and the B-busses transmit numbers from the storage to the arithmetic circuits, and the C-bus transmits numbers in the opposite direction.

The arithmetic circuits carry out transfer, addition, and multiplication with arbitrary signs for the numbers involved.

Transfers include transfer with opposite sign, transfer of absolute value and negative absolute value, and logical addition (i.e., the transfer of the logical sum of two numbers). Technically a transfer is accomplished when corresponding digit channels in each of the three busses are interconnected. From this it follows that the ordinary transfer is a special case of logical addition, where one of the two numbers consists of zeros (or minus signs) on all wires.

The adder shifts the number having the smaller exponent to its proper position and then forms the arithmetically correct sum or difference of the two numbers. The shifted number is not rounded off. If the sum of the numerical parts of the two numbers should exceed one, the result is shifted one position to the right and its exponent increased by one. In this case the

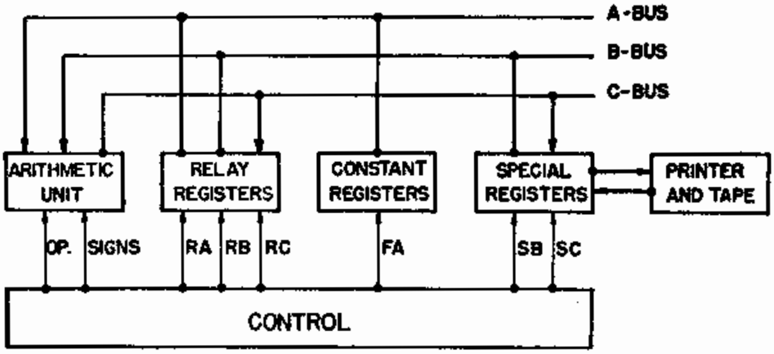

Fig. 1.

result is rounded off before the shift is made. If, on the other hand, the sum or difference should be less than one-half, the result is not shifted. The first digit of the result is therefore not necessarily a one.

The adder contains 232 relays. Addition is carried out in five successive steps. First, exponents and signs are compared. Second, the difference is taken between the two exponents and simultaneously the number to be shifted is selected. Third, the shift is carried out and the number not shifted is inverted, if necessary. (Nines complements are used.) Fourth, the addition of the two numerical parts is carried out. Fifth, the sum is shifted one position to the right, or inverted, or left unchanged, whichever the case may be. Simultaneously the exponent of the result is increased by one if the sum was shifted, and the sign of the numerical part is formed. A chain of slower relays controls the timing, so that no step is started before the previous one is completed.

Multiplication is carried out in the following way: The two numbers coming in are first "normalized," that is, shifted to the left until the first binary one occupies the leftmost position. [This operation is called a "zero-shift" in the report on the BTL Relay Computers (*MTAC*, v. 3, p. 1–13; 69–84).] The exponents are modified accordingly. In the rest of the multiplication the numerical parts of multiplier (MR) and multiplicand (MD) are treated as 8-digit numbers in the octal number system, since a group of three binary digits forms one octal digit. Multiples of MD with the integers 1, 2, $\cdots$, 7 are formed and selected simultaneously by the eight octal digits of MR. The multiples are added together in seven adders in such a way that only 30 binary digits, or ten octal digits, are retained for the final result. In order to compensate for the digits that are dropped an octal three is added in the tenth octal position. When the whole product is formed, a binary one is added into the twenty-fifth binary position and the 24 first digits retained. The multiplier thus delivers a correctly rounded 24-digit product, where, however, the first digit may be a zero. No provision has been made for computation with double accuracy. Such computation can still be done by a coded sequence of instructions but turns out to be extremely cumbersome and is therefore in most cases impracticable. Altogether the multiplier contains 923 relays.

Normalization of a single number can also be carried out. One of the two normalizing circuits in the multiplier is then connected to the A- and the C-bus. The rest of the multiplier is not affected by this operation.

Other elementary operations where only one number is involved at a time are handled by special circuits. These operations are:

1. Transfer of an exponent to the last six places of the numerical part of a register
2. Transfer of the last six digits of a numerical part into the exponential part of a register
3. Transfer of the numerical part only
4. Transfer of the fractional part of a number (for example, in 23.67 the fractional part is 0.67)
5. Shift one step to the left (or to the right) of the numerical part without modification of the exponent.

Integral numbers are normally represented with the exponent +24, whereby the rightmost digit of the number falls into the last place of the numerical part of a register.

No built-in operation is needed to extract the integral part of a number (53 is the integral part of 53.67), as this may be done by adding to the number a zero with the exponent +24 (an "integral zero"); for in an addition the number having the smaller exponent is shifted to the right until both exponents are equal to +24, and a number with the exponent 24 is an integral number.

Sequencing and Coding.—Instructions for the machine are written in the form: *n* A op. signs B C D, where A and B are the addresses of the two numbers that are combined by the operation "op," which may be T (transfer), A (addition), M (multiplication), or E (special operations on one number only). The "signs" symbol indicates which one of the four possible combinations of signs should be attached to the numbers A and B. The different types of transfers are also distinguished by means of the "signs" symbol, whereas the different E-operations are distinguished by means of the B-address. The letter C is the address where the result should be sent, while *n* is the number, or index, of this particular instruction and D is the number of the next instruction.

Instructions of this type are executed automatically by means of the control system, which has three parts: the central control unit (built into the control table), the "order chain," and the five "order panels." The order chain contains 840 relays (later it will contain 1200) connected in such a way that one and only one relay can be operated at a time. In order to start the machine on a problem, one of these relays is operated from the control table, and the machine then proceeds to operate automatically. The central control unit now supplies voltages on five lines which pass through contacts on the operated relay of the order chain to plug holes on four of the order panels. On the order panels plugged connections are made so that the voltages reach their destinations. Three of them, coming from the A-, B-, and C-panels, operate relays in the proper registers to connect these registers to the respective busses. The two remaining voltages from the operations panel give the sign-combination and initiate the operation. When the arithmetic unit gives a back-signal to the central control unit indicating that the operation is finished, the five voltages are removed, the relay in the order chain is released, and the next relay is operated. Then the whole procedure is repeated automatically.

Normally the central control unit steps the order chain from relay n to relay $n + 1$. It is possible, however, to break this sequence by means of plugged connections on the sequence panel. This is called a jump in the program. Jumps can be made from any even instruction to any odd instruction. With this restriction only, the whole of the 840 available instructions may be divided into an arbitrary number of subsequences of arbitrary length. These may constitute one or several independent computing programs. Conditional jumps are obtained by means of the selectors which will be discussed below.

The even-odd rule makes it sometimes necessary to insert meaningless instructions in the program. For instance, at the end of a subsequence that would otherwise contain an odd number of instructions, a special phony instruction is available to permit the jump.

No instructions are given to the machine from tapes or similar devices; all programs are physically realized by the plugged connections. For every instruction, normally one such connection must be made on each panel. The principle of the arrangement is similar to the subsequence mechanisms used with Mark I at Harvard and to the corresponding equipment in the BTL computer, Model VI.

Flexibility in the coding is obtained by the use of "selectors" or relay pyramid circuits. There are four 64-selectors (pyramids with 64 exits) and 125 two-way selectors. By letting the path of the corresponding plugged connection go through such a pyramid, any part of an instruction may be subject to a choice of up to 64 different possibilities. The choice is then dependent on some control number previously sent from the arithmetic circuits to the controlling relays of the pyramid. This technique greatly reduces the number of instructions needed in a program. For instance, the multiplication of two square matrices of unspecified order n (where $n < 50$) may be programmed with only 18 instructions.

Other Equipment.—Input and output devices make use of standard teletype equipment. Five tape readers, five tape punches, and one page printer are available. This equipment may also be used as external storage, although with limited flexibility, as no provisions have been made for "hunting" on the tapes. Numbers may be read or punched in binary or decimal notation and printed in octal or decimal notation. Printing in octal form is used for checking, especially for checking of the setting of the constant registers. Conversion from binary to decimal notation, or inversely, is done by the computer itself and is programmed by ordinary means.

The operation of the machine is supervised from the control table. For checking purposes the order chain may be stepped manually, one instruction at a time, as slowly as desired. Indicator lamps then show at every instant the instruction just carried out, the addresses and operation involved, and the numbers which at that moment occur on the number transfer busses. It is also possible to step the machine manually through arbitrary instructions, not set up on the panels.

No circuits for automatic checking have been built into the machine, but alarms occur for a number of fundamental failures, such as a number exceeding the range of the machine, a dangerous drop in supply voltage, a blown fuse, and, of course, the failure of a coded check.

The machine contains in all some 5000 relays of standard telephone type. The relays are mounted in boxes which can easily be replaced by duplicate units in the case of a breakdown.

A general view of the BARK is shown in the frontispiece. In front is seen the control table and the input and output equipment. At the right and in the first row are the order panels. In succeeding rows are shown the order chain, arithmetic circuits, relay registers, and constant registers. The three empty relay racks provide space for future additions to the machine.

A block diagram of the BARK is shown in Figure 1. Thin vertical lines represent the paths of the signals that initiate operations and effect the connection of the registers to the busses. RA, for example, indicates the path of a signal coming from the A-panel, which connects one of the 50 relay registers to the A-bus.

Operation Times.—The times for elementary operations are:

Transfer	100 milliseconds
Addition	150 milliseconds
Multiplication	250 milliseconds
Printing of one digit	160 milliseconds

The efficiency under realistic conditions may probably be better judged by the following short data from some of the computations which were done during the testing period.

1. Tabulation of four 7th-degree polynomials in two variables (origin: atomic physics). Some 500 values were computed; the machine time was three hours.

2. Tabulation of the specific volume v of water-vapor as a function of the pressure p and temperature $T = 100t$ according to the formula:

$$v = RTp^{-1} - At^{-2.82} - p^2(Bt^{-14} - Ct^{-31.6})$$

R, A, B and C are constants. Some 9000 values were computed: the machine time was 70 hours.

3. Tabulation of irregular solutions of the equation

$$y'' + \left(1 - \frac{2a}{x}\right)y = 0$$

for different values of the parameter a, and $0.05 \leq x \leq 1$ (origin: atomic physics). The equation was solved with step-wise integration, using TAYLOR's series up to and including terms of 7th order, and the result was accurate within one or two units in the 6th decimal place for most values of a. The functions y and y' were computed for about 3000 points. The machine time was 42 hours. The table will be published by C-E. FRÖBERG in *Arkiv för Fysik*.

4. Solution of symmetrical systems of linear equations with the GAUSS' elimination method (origin: surveying). Matrices of orders $n = 8$, 14, 20, and 28 were treated. The machine time for $n = 28$ was 4.8 hours.

5. Inversion of symmetrical and unsymmetrical matrices of orders $n = 8$ and 20 with JORDAN's method (origin: surveying). The machine time for $n = 20$ was 7.5 hours.

Conclusion.—It was found that the coding on BARK is on the whole straightforward and easy. Flow-diagrams, of the type described in the reports on the computing machine under development at the Institute for Advanced Study, Princeton, N. J., are excellently suited for the planning of programs. The plugging of the order panels is time-consuming (the approximate speed being 50 instructions an hour) but may on the other hand be done while the machine is working on some other problem. The greatest advantage of the sequencing system is its flexibility—at any point in a computation the machine may be stopped and the program modified, e.g., by the insertion of a new instruction or subsequence or by skipping another.

The cost of the machine, including planning, designing, construction, and experimental work, does not exceed 100,000 dollars. The main bulk of the design work was done by HARRY FREESE and GÖSTA NEOVIUS. The machine was built by the Swedish Telegraph Administration, which also supplied most of the parts. Under the direction of Dr. Palm, the following persons participated in the general planning, design, and experimental work: C-E. FRÖBERG, O. KARLQVIST, G. KJELLBERG, B. LIND, A. LINDBERGER, P. PETERSSON, and M. WALLMARK.

GÖRAN KJELLBERG
GÖSTA NEOVIUS

Matematikmaskinnämndens Arbetsgrupp
Drottninggatan 95 A
Stockholm, Sweden