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ALGOL 60 Translation for Everybody

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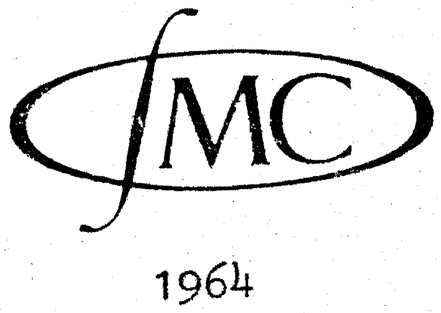

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ALGOL 60 Translation for Everybody

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Summary: It is the purpose of this article to sketch an ALGOL-Compiler structure that is expected to be comprehensible by everyone. So doing it has been abstracted as much as possible from any specific machine, and there are put forward only the essential features of translation. An example program for the translation of arithmetic expressions is given for illustration.

Zusammenfassung: Ziel des vorliegenden Artikels ist es, die Struktur eines ALGOL-Compilers in einer Weise darzulegen, von der erwartet werden kann, daß sie für jedermann verständlich ist. Dabei wird soweit als möglich von jeder spezifischen Maschine abgesehen, und es werden nur die wesentlichen Eigenschaften der Übersetzung hervorgehoben. Ein ausgearbeitetes Beispielprogramm für die Übersetzung von arithmetischen Ausdrücken veranschaulicht die Ausführungen.

1. Introduction

Ever since the appearance of the first official publication on ALGOL 60 [1], there has been a worldwide effort directed toward the implementation of this problem-oriented programming language for several specific machines. Some of these investigations have been reported to a limited extent [2, 3, 4], or even in minute detail, while in some other cases only a few insiders have had the privilege of being initiated into the often masterly techniques used therein.
Although there has been communication between the several designers about their work, and, consequently, common methods have been devised, nevertheless the various ALGOL 60 compilers diverge strongly, due, amongst other things, to:
1. differences in the machines;
2. differences with respect to the requirements and wishes posed for an ALGOL system by the various groups. To indicate the differences between machines, we mention here only such things as hardware stacking orders, indirect addressing, the size of the main store, and possible backing stores, whereas, on the other hand, the notions of efficient object program, of the detection of errors, and the size of translator and running system play an important role.

Hence, it is difficult for the uninitiated to gain an impression of how ALGOL translators actually do generate their object programs, and it is the purpose of this paper to sketch a translator structure that is, hopefully, comprehensible to everyone. So doing, we will abstract ourselves as much as possible from any specific machine, and will put forward only the essential features of translation. Therefore, no concession has been made to efficiency; everything has been sacrificed in the interests of readability. As an example, a program for the translation of arithmetic expressions has been worked out and is given here.

2. Macros

The simplest way to design a largely machine-independent ALGOL compiler seems to be to entrust the two logically distinguishable compiler tasks, namely:
1. analysis of the given program, and
2. construction of an equivalent machine code program,
to two separate parts of the translator, namely:
1. the ALGOL-processor, and
2. the Macro-processor, respectively.
The first of these, then, will have to recognise the constructions used in the ALGOL source text, and represent

[1]) Mathematical Centre, Amsterdam.

them in terms of a series of macro orders, possibly provided with one or more "metaparameters". These macros are independent, sharply described, small tasks, defined apart from any specific machine and capable of being suitably interpreted on any given machine.

The Macro-processor must generate a piece of object program for each such macro. This can be one hardware order, a series of orders, a subroutine call for a piece of running system, etc. Moreover, it is quite possible that a Macro-processor will replace a set of consecutive macros by another, more efficient one, and in this way will do quite a lot of optimizing. In any case, the Macro-processor will be strongly machine-dependent, but in principle can be a simple, straightforward program.

3. The language for our ALGOL compiler

Naturally, our machine-independent ALGOL translator will itself be formulated in a machine-independent programming language. As a side remark, we notice here that such a description would have some big advantages for any translator:
1. apart from the motivation, the translator would be its own description, and no documentation problems would arise afterwards; as soon as the translator has been finished, there exits a report, the translator text itself, which is accessible to anyone;
2. due to the greater readability, maintenance of the translator would be relatively simple, and, moreover, it would be fairly easy for customers to adapt the translator to specific requirements of their own.

If we then have to make a choice from the great variety of problem-oriented programming languages, we shall have to choose one that is really suitable for the problem. The most important property of ALGOL 60 that matters in this respect, seems to the author to be the essential recursivity in the definitions of the official report. Therefore, the translator must have a recursive structure, and our programming language will have to lend itself to recursive processes. Good examples of such languages are LISP [5] and ALGOL 60 itself. Although LISP, being a recursive list-processing language, seems to be highly suitable for the formulation of compilers, we have preferred ALGOL 60 for the purposes of this paper.

4. Some remarks on the storage-allocation problem

A consequence of the recursive structure of ALGOL 60 is that a block may sometimes be activated while it is already active. Then the values of the local variables of so-far incompleted activations must be preserved; thus, several values may correspond to each variable at any given time. As a rule this excludes a static form of addressing variables (something that could be done during translation). The commonly used way out of this so-called storage-allocation problem is the use of the memory organization now known as a stack [6], for a dynamic allocation of the variables. The stack then consists of a set of block cells, each belonging to just one activation of a block.

Each cell contains, besides the local variables and anonymous intermediate results of the evaluation of expressions, a set of administrative data, by means of which it is possible to find this and other block cells in the stack. Each variable can now be characterized by a dynamic address, consisting of a combination of two data: one for block identification and one for positioning inside the block cell concerned. It is a task of a block introduction macro to touch up the cell administration, and of the block exit macro to delete one or more cells out of the stack.
The top of the stack can be used for the evaluation of expressions. A so-called stackpointer refers to the first free position (this pointer might be an index register, but a pseudoregister can be used instead).
For the rest, all allocation problems are problems for the design of a running system. They have hardly any influence upon the writing of an ALGOL compiler.

5. The macros for the translation of arithmetic expressions

Since it goes far beyond the framework of this paper to sketch a complete ALGOL processor, we will restrict ourselves to a specific example. The simplest case is the translation of arithmetic expressions, and therefore in section 7, a number of procedures are given which are capable of converting an arithmetic expression into a series of macros. In this section, we will discuss what these macros are supposed to do, whereas in section 6 the basic functioning of the procedures will be elucidated.
We will assume that the running system has at its disposal two registers, called F and C. These may be real hardware registers, or programmed pseudoregisters. F is the register for floating point arithmetic, and for the sake of simplicity we will assume that F is also able to work with integers, which are distinguished from floating numbers only by means of an exponential part equal to zero (this is e.g. the case for the Grau representation [7] of floating numbers). C is a two-valued register, with value true or false. There exists a macro COJU, for conditional jump, which will continue the program from a different point only if C has the value false.

Furthermore, the running system will operate on the stack, and in principle, all binary arithmetic operations will take place with the top of the stack as the first operand and F as the second, the result being delivered in F. Examples are:

ADD	addition with result	F:= stack[stackpointer - 1] + F;
SUB	subtraction	F:= stack[stackpointer - 1] - F;
MUL	multiplication	F:= stack[stackpointer - 1] × F;
DIV	division	F:= stack[stackpointer - 1] / F;
IDI	integer division	F:= stack[stackpointer - 1] ÷ F;
TTP	to the power	F:= stack[stackpointer - 1] ↑ F;

all with the side effect that:
stackpointer:= stackpointer - 1;
The content of F can be saved in the stack by means of the macro:

```
STACK        stack[stackpointer]:= F;
             stackpointer:= stackpointer + 1;
```

Inversion of F is done by:

```
NEG          F:= - F;
```

To obtain the value of a simple variable, we introduce the macro:
TAV(<dynamic variable address>),
which will transform the given dynamic address (block identification number and position in the block cell) into a

memory address, and will copy the value of the variable into F. Dealing with subscripted variables, the value of each index is evaluated and put into the stack, after which:

TSAV(<dynamic array address>)

carries out the indexing and delivers the required value in F.

The treatment of formals, called by name, is done by the dynamic insertion of a piece of object program belonging to the corresponding actual parameter. This insertion is carried out by means of the macro:

DO(<dynamic parameter address>),

which causes execution of an order contained in the stack. Finally we mention here the macros:

JU(<program address>) goto address;

COJU(<program address>) if ¬C then goto address;

that play a role in the translation of if-then-else-constructions.

6. The basic functioning of the procedures Arithexp, et seq.

In the next section a number of procedures will be declared, the effect of which is to translate arithmetic expressions. The fundamental idea of almost all of them is that the first basic symbol of the syntactical unit to be processed by that procedure has been read already (its value being assigned to "last symbol"); the procedure considers itself to have finished its task after reading the first symbol that can no longer belong to that unit syntactically. In the mean time, the translation of that unit has been produced.

For example we take here the procedure Factor. According to the definition in the Revised Report:

<factor> ::= <primary> | <factor>↑<primary>.

Therefore, a factor certainly must start with a primary, and so Factor begins with a call for Primary. On returning into Factor a set of macros has been produced, which, on execution, will deliver the value of the primary in F. If now the primary is followed by a symbol ↑, then we have to save F in the stack, deliver the following primary in F and carry out the exponentiation. The procedure to produce the macros doing this is Next Primary. On completion of these three tasks a new test for the occurrence of a ↑ is necessary due to the recursivity in the definition of <factor>. This is carried out by Next Primary also, which, in case of absence of a ↑, has no effect at all.

7. The procedures

```
procedure  Arithexp;
      begin   integer  future1, future2;
              future1:= future2:= 0;
              if  last symbol = if then begin  next symbol; Boolexp;
                  if last symbol ≠ then then  ERRORMESSAGE (AE1);
                  MACRO2 (COJU, future1);
                  next symbol; Simple Arithexp;
                  if last symbol ≠ else then ERRORMESSAGE (AE2)
                  else   begin     MACRO2 (JU, future2);
                                   SUBSTITUTE (future1);
                                   next symbol; Arithexp;
                                   SUBSTITUTE (future2)
                         end
              end
      else Simple  Arithexp
end Arithexp;
```

If an arithmetic expression begins with an if-clause, first a procedure Boolexp is called for, to produce a piece of program to assign the value of the Boolean expression to C. Next, the macro COJU is produced. However, since it is still unknown to which point of the program the jump must go, a provisional address part of zero is given to it. It is a task of the Macro-processor, to assign in this case the value of the order counter to future1so as to make possible a later address substitution. This last is done by the procedure SUBSTITUTE, which must substitute the current value of the order counter into the address part of the macro COJU. An analogous construction occurs somewhat further on, just after encountering the else (future2 then contains the location of the macro JU to be completed later on).

The function procedure "next symbol" assigns both to itself and to last symbol, the value of the next basic symbol of the source program. The function procedure "Identifier" reads an identifier, looks it up in the name list, and assigns to itself a code word containing information about the identifier, e.g. its type, its address, etc., or it assigns to itself an address in the name list, from which such information can be obtained. In a manner analogous to this, the procedure "Unsigned number" has to read a number, and look it up in the constant list. Moreover, it has to produce a macro TCV, take constant value, with the appropriate address. The procedures subscrvar, formal, function, and arithmetic must answer questions about the identifier concerned, on the basis of knowledge supplied by declaration or occurrence.

There are two points in which the definition of an arithmetic expression goes beyond its own borders: the first is the if-clause, in which a Boolean expression occurs; the other is the function designator, in which actual parameters of all kinds may occur. We shall not go into this, and the procedures Boolexp and Function Designator will be present in the program only as black boxes.

Besides being translated, the ALGOL expression presented is also checked for syntactical correctness. In general, we have strived for a construction such that after detecting an error and producing a message about it, the translation process can be continued as a syntactical test with some chance of success (albeit that the translation then produced is worthless). A good example of this strategy is the reaction to a missing else-part after an if-then-construction (see Arithexp), and also to the absence of a closing parenthesis (see Primary).

```
procedure Simple Arithexp;
        begin   if last symbol = minus   then   begin   next symbol; Term;
                                                       MACRO (NEG)
                                                 end
                                         else    begin   if last symbol = plus then next symbol;
                                                       Term
                                                 end;
                Next Term
        end Simple Arithexp;

procedure Next Term;
        begin   if last symbol = plus    then   begin   MACRO (STACK);
                                                       next symbol; Term;
                                                       MACRO (ADD); Next Term
                                                 end
                else
                if last symbol = minus   then   begin   MACRO (STACK);
                                                       next symbol; Term;
                                                       MACRO (SUB); Next Term
                                                 end
        end Next Term;

procedure Term; begin Factor; Next Factor end Term;

procedure Next Factor;
        begin   if last symbol = mul     then   begin   MACRO (STACK);
                                                       next symbol; Factor;
                                                       MACRO (MUL); Next Factor
                                                 end
                else
                if last symbol = div     then   begin   MACRO (STACK);
                                                       next symbol; Factor;
                                                       MACRO (DIV); Next Factor
                                                 end
                else
                if last symbol = idi     then   begin   MACRO (STACK);
                                                       next symbol; Factor;
                                                       MACRO (IDI); Next Factor
                                                 end
        end Next Factor;

procedure Factor; begin Primary; Next Primary end Factor;

procedure Next Primary;
        begin   if last symbol = ttp     then   begin   MACRO (STACK);
                                                       next symbol; Primary;
                                                       MACRO (TTP); Next Primary
                                                 end
        end Next Primary;

procedure Primary;
        begin   integer n;
                if last symbol = open    then   begin   next symbol; Arithexp;
                                                       if last symbol = close then next symbol
                                                       else ERRORMESSAGE (P1)
                                                 end
                else    if digit last symbol     then   Unsigned number
                else    if letter last symbol    then   begin   n:= identifier;
                                                               if ¬ arithmetic (n) then ERRORMESSAGE (P2);
                                                               Arithname (n)
                                                       end
                else    ERRORMESSAGE (P3)
        end Primary;
```

```
procedure Arithname (n); integer n;
        begin   if subscrvar (n) ∨ formal (n) ∧ last symbol = sub then Subscrvar (n)
                else   if function (n) ∨ formal (n) ∧ last symbol = open then Function Designator (n)
                else   if formal (n) then MACRO2 (DO, n) else MACRO2 (TAV, n)
        end Arithname;

procedure Subscrvar (n); integer n;
        begin   if last symbol = sub      then   begin   next symbol; Subscript list;
                                                         if last symbol = bus then next symbol
                                                         else ERRORMESSAGE (SV1);
                                                         if formal (n) then MACRO2 (DO, n)
                                                         else MACRO2 (TSAV, n)
                                                 end
                else ERRORMESSAGE (SV2)
        end Subscrvar;

procedure Subscript list;
        begin   Arithexp; MACRO (STACK);
                if last symbol = comma then   begin   next symbol; Subscript list end
        end Subscript list;
```

8. Final considerations

He who would analyse the procedures presented in the last section will find that arithmetic expressions are transformed into a macro program which corresponds to the so-called Reversed Polish Form [8]. This is carried out, however, without any need to give to the arithmetic operators and to the other delimiters any priority number, or to program a stack for operators, such as is described e.g. by Dijkstra [9]. The priority rules are taken into account automatically by the sub- and side-ordering of the appropriate procedures. Likewise, there is no need for a separate "future list" for the provision of the "anonymous jumps", like those occurring in if-then-else-constructions. The only list that is assumed to exist, apparently, is a name list.

Furthermore, it will be clear how close the procedures are to the syntactical definitions, given in 3.3. of the Revised Report. As a matter of fact, they are just a straightforward transformation thereof, and this fact almost excludes errors during the writing of such procedures. No far-reaching conclusions have been drawn from the report; no attempt has been made to short circuit certain chains of thought; and in general such attempts may be the cause of errors.

Perhaps it is useful to say something about some difficulties which one encounters when trying to extend the process, followed in Arithexp, to other syntactical structures in the language. It is a property of arithmetic expressions that at any moment we know what type of structure has to be processed next during a sequential scan. This is no longer true for Boolean expressions, where e.g., after an opening parenthesis, either a Boolean expression or an arithmetic one (namely as part of a relation) can follow. Here we have to create a procedure that can read both types of expressions and that itself investigates what kind is presented to it. Moreover, such a procedure must notify the results of that investigation to its surroundings; even the answer: "yet undecided", may not be excluded. Still more general procedures will be necessary for the translation of actual parameters - which can be anything -.

A case analogous to the foregoing arises in the assignment statement, where, after '<left part>:=', we don't know whether an '<expression>' or again a '<left part>' follows. Just as before, we need procedures that can handle both situations. It is important here to have at our disposal a number of macros, suitable for both cases, such that the translation process can continue even before the discrimination between the two possibilities has been made.

It has been the purpose of this paper to give some insight into a plausible structure for an ALGOL 60 translator. In fact, the real problems arise during the design of the running system that has to see to it that the macros to be defined work properly. The design of the translator is a relatively easy job.

This paper would not have been possible without continuous contacts with the collaborators of the Mathematical Centre, especially within the group preparing the ALGOL 60 implementation for our future Electrologica X 8 computer. The author would like to mention here separately the cooperation with J. Nederkoorn in the definition of a macro system for that machine. Furthermore, the author thanks B. Mailloux, who was helpful in the final formulation of the text.

In appendix A a program is given, with which the procedures given in section 7 have been tested using the MC-I ALGOL implementation on the X 1. In appendix B some examples of input and output of this program are reproduced.

9. References

[1] see: Naur, P. (ed.), Revised Report on the Algorithmic Language ALGOL 60, Regnecentralen, Copenhagen, 1960.

[2] Dijkstra, E.W., ALGOL 60 Translation, ALGOL Bull. Suppl. no. 10.

[3] Naur, P., The design of the GIER ALGOL compiler, BIT, 2, 1963, 124 and BIT, 2, 1963, 145.

[4] Randell, B. and Russell, L.J., ALGOL 60 Implementation, APIC studies in Data Processing no. 5, Academic Press, London, New York, 1964.

[5] McCarthy, J., Recursive Functions of Symbolic Expressions and Their Computation by Machine, Comm. ACM, 3, 1960, 184.
[6] Dijkstra, E.W., Recursive Programming, Num. Math., 2, 1960, 312.
[7] Grau, A.A., On a Floating-point Number Representation for Use with Automatic Languages, Comm. ACM, 5, 1962, 160.
[8] Samelson, K. and Bauer, F.L., Sequentielle Formelübersetzung, Elektronische Rech., 1, 1959, 176.
[9] Dijkstra, E.W., Making a Translator for ALGOL 60, APIC Bull., 7, 1961, 3.

Appendix A

The program given below was written for the purpose of testing the procedures Arithexp, et seq. It is based on the following restricted definitions:

A1: <Boolean expression>::=<variable identifier>
A2: <unsigned number>::=<unsigned integer>
A3: <function designator>::=<procedure identifier>|
<procedure identifier> (<arithmetic expression>).

Moreover, due to the absence of declarations for the identifiers present in the expressions that are processed, the questions: "arithmetic?", "formal?", "subscrvar?", and "function?" are answered either stereotypedly or on the basis of the delimiter following the identifier concerned. As a consequence, some constructions and some macros are not shown to full advantage.

Identifiers and numbers are stored upon occurrence in a name list for later use in the output as metaparameters of macros. In fact, this list is a first in - last out list, but this is by no means essential; if we omit the last statement before the label EX in the procedure MACRO2 the program still works the same - the only effect then would be that the names are needlessly preserved in the list.

The internal representation of the basic symbols is chosen to be close to that of the input/output medium, i.e. paper tape punched in MC-Flexowriter code. The input/output routines are slightly code-dependent, but care has been taken to make them comprehensible without any knowledge of the code itself.

Those procedure identifiers that do occur in the program without having been declared are library routines, which, in the MC-I ALGOL implementation, are considered as standard functions, just like entier, abs, sqrt, etc. They are:

RE7BIT: a function procedure assigning to its identifier the value of the next heptad on the input paper tape;
PU7BIT (n): a procedure, punching the value of n ($0 \leq n \leq 127$) as a heptad on the output paper tape;
PUNLCR: a procedure, punching a new line carriage return symbol on the output paper tape;
PUSPACE (n): a procedure, punching n space symbols on the output paper tape;
PUTEXT1 (string): a procedure, punching the actual string on the output paper tape (⊄ and ⊅ are the MC hardware representations of string quotes);
ABSFIXP (n, 0, x): a procedure, punching the absolute value of x rounded to an integer, in n figures, replacing leading zeroes by space symbols;
stop: a procedure that stops the execution of the program until the operator pushes the button "continue" on the machine console.

The program translates a set of expressions on the input tape, separated by semicolons, and closed by a semicolon followed by a stopcode symbol (this last symbol corresponds to a punching but has no visible mark on the typewriter sheet). In Backus Normal Form we could define the job as:

A4: <job> ::= <arithmetic expression> ; stopcode |
<arithmetic expression> ; <job>

Any set of basic symbols comment <any sequence not containing ; > ; is skipped on the input tape. The program starts with the reading of a small tape, containing some of the basic symbols in hardware representation, to define the internal representation thereof. This is just a preparation of the input procedures. The small tape consists of the symbols:

: = | _ comment ;

not separated by other (lay out) symbols, followed by the symbols:

, ( ) [ ] if then else + - × / ÷ ↑

which can be punched using spaces etc.

```
begin comment   Test program for Arithexp.
                programmed by F. E. J. Kruseman Aretz.
                identification: R989 / Arithexp;

integer         last symbol, pointer, macrocounter, stock, empty, symbol,
                blank, erase, case, lower case, upper case,
                tab, space, new line, stopcode,
                colon, equal, bar, underlining, comment, semicolon, comma,
                open, close, sub, bus, if, then, else,
                plus, minus, mul, div, idi, ttp,
                AE1, AE2, P1, P2, P3, SV1, SV2, FD1, MP1, STOP,
                NEG, ADD, SUB, MUL, DIV, IDI, TTP, STACK, ENTER, RET,
                JU, COJU, TAV, TCV, TBV, TSAV, DO, FDES;

integer         array   list[0 : 200];
```

```
procedure   Initialization;
            begin  AE1:= NEG:= JU:= 1;     AE2:= ADD:= COJU:= 2;
                   P1:= SUB:= TAV:= 3;     P2:= MUL:= TCV:= 4;
                   P3:= DIV:= TBV:= 5;     SV1:= IDI:= TSAV:= 6;
                   SV2:= TTP:= DO:= 7;     FD1:= STACK:= FDES:= 8;
                   MP1:= ENTER:= 9;        STOP:= RET:= 10;
                   blank:= 0;  erase:= 127;  case:= lower case:= 122;
                   upper case:= 124;  tab:= 62;  space:= 16;  new line:= 26;
                   stopcode:= 11;  stock:= empty:= 1;
                   colon:= next tape symbol;          equal:= next tape symbol;
                   bar:= next tape symbol;            underlining:= next tape symbol;
                   comment:= next string symbol;      semicolon:= next string symbol;
                   comma:= next symbol;  open:= next symbol;      close:= next symbol;
                   sub:= next symbol;    bus:= next symbol;       if:= next symbol;
                   then:= next symbol;   else:= next symbol;      plus:= next symbol;
                   minus:= next symbol;  mul:= next symbol;       div:= next symbol;
                   idi:= next symbol;    ttp:= next symbol
            end  Initialization;

comment  input procedures;

integer     procedure  next tape symbol;
            begin  integer  n;
                   n:= RE7BIT;
                   if  n = blank ∨ n = erase then next tape symbol:= next tape symbol
                   else  if  n = lower case ∨n = upper case then
                            begin  case:= n;  next tape symbol:= next tape symbol end
                   else  next tape symbol:= if  n = tab ∨ n = space ∨ n = new line ∨
                            n = stopcode ∨ case = lower case then  n  else  n + 128
            end  next tape symbol;

integer     procedure  next string symbol;
            begin  integer  n, m;
                   if  stock < 0 then n:= stock:= - stock else  n:= next tape symbol;
                   if  n = colon  then  begin  m:= next tape symbol;
                                               if  m = equal then  n:= 256 else  stock:= - m
                                        end  :=
                   else  if  n = bar  then  n:= next tape symbol + 256
                   else  if  n = underlining  then  begin  n:= next tape symbol + 512;
                                                           m:= next tape symbol;
                                                           if  m = underlining then
                                                           begin  n:= 512 × n + next tape symbol;
                                                           AA:    stock:= - next tape symbol;
                                                                  if  stock = - underlining then
                                                                  begin  next tape symbol;  goto  AA  end
                                                           end  worddelimiter
                                                           else  stock:= - m
                                                    end  underlining;
                    next string symbol:= n
             end  next string symbol;

integer     procedure  next symbol;
            begin  integer  n;
                   n:= next string symbol;
                   if  n = tab ∨ n = space ∨ n = new line then  next symbol:= next symbol
                   else  if  n = comment  then  begin  for  n:= next string symbol while  n ≠ semicolon do ;
                                                       next symbol:= next symbol
                                                end  comment
                   else  next symbol:= last symbol:= n
            end  next symbol;
```

```
Boolean  procedure  digit last symbol;
         digit last symbol:= (0 < last symbol ∧ last symbol < 9) ∨ (18 < last symbol ∧ last symbol < 26) ∨ last symbol = 32;

Boolean  procedure  letter last symbol;
         begin  integer  n;
                n:= if  last symbol < 128 then  last symbol else  last symbol - 128;
                letter last symbol:= (34 < n ∧ n < 42) ∨ (49 < n ∧ n < 57) ∨ (66 < n ∧ n < 74) ∨
                                     (80 < n ∧ n < 89) ∨ (96 < n ∧ n < 105) ∨ (114 < n ∧ n < 122)
         end  letter last symbol;

comment  output procedures;

procedure  ERRORMESSAGE (n);  integer  n;
         begin  switch  S:= AE1, AE2, P1, P2, P3, SV1, SV2, FD1, MP1, STOP;
                PUNLCR; PUTEXT1 (‹ERROR›); goto  S[n];
         AE1:  PUTEXT1 (‹AE1›); goto  EX;   AE2:  PUTEXT1 (‹AE2›); goto  EX;
         P1:   PUTEXT1 (‹P1›); goto  EX;    P2:   PUTEXT1 (‹P2›); goto  EX;
         P3:   PUTEXT1 (‹P3›); goto  EX;
         SV1:  PUTEXT1 (‹SV1›); goto  EX;   SV2:  PUTEXT1 (‹SV2›); goto  EX;
         FD1:  PUTEXT1 (‹FD1›); goto  EX;   MP1:  PUTEXT1 (‹MP1›); goto  EX;
         STOP: PUTEXT1 (‹STOP›);
         EX:
         end  ERRORMESSAGE;

procedure  MACRO (n);  integer  n;
         begin  switch  S:= NEG, ADD, SUB, MUL, DIV, IDI, TTP, STACK, ENTER, RET;
                PUNLCR; ABSFIXP (3, 0, macrocounter);  PUSPACE (3); goto  S[n];
         NEG:  PUTEXT1 (‹NEG›); goto  EX;   ADD:  PUTEXT1 (‹ADD›); goto  EX;
         SUB:  PUTEXT1 (‹SUB›); goto  EX;   MUL:  PUTEXT1 (‹MUL›); goto  EX;
         DIV:  PUTEXT1 (‹DIV›); goto  EX;   IDI:  PUTEXT1 (‹IDI›); goto  EX;
         TTP:  PUTEXT1 (‹TTP›); goto  EX;   STACK: PUTEXT1 (‹STACK›); goto  EX;
         ENTER:PUTEXT1 (‹ENTER›); goto  EX; RET:  PUTEXT1 (‹RET›);
         EX:   macrocounter:= macrocounter + 1
         end  MACRO;

procedure  MACRO2 (i, n);  integer  i, n;
         begin  integer  k, last case;
                switch  S:= JU, COJU, TAV, TCV, TBV, TSAV, DO, FDES;
                PUNLCR;  ABSFIXP (3, 0 macrocounter);  PUSPACE (3);  goto  S[i];
         COJU: PUTEXT1 (‹CO›);
         JU:   PUTEXT1 (‹JU (›);  ABSFIXP (3, 0, n);  n:= macrocounter;  goto  EX;
         TAV:  PUTEXT1 (‹TAV (›);  goto  NAME;
         TCV:  PUTEXT1 (‹TCV (›);  goto  NAME;
         TBV:  PUTEXT1 (‹TBV (›);  goto  NAME;
         TSAV: PUTEXT1 (‹TSAV (›); goto  NAME;
         DO:   PUTEXT1 (‹DO (›);  goto  NAME;
         FDES: PUTEXT1 (‹FDES (›);
         NAME: last case:= 0;  for  k:= n step  1 until  pointer - 1 do
                begin  if  list[k]>127  then  begin  if  last case ≠ 2 then  begin  last case:= 2;  PU7BIT (upper case) end;
                                                     PU7BIT (list[k] - 128)
                                              end
                       else  begin  if  last case ≠ 1 then  begin  last case:= 1;  PU7BIT (lower case) end;
                                    PU7BIT (list[k])
                             end
                end;
                pointer:= n;
         EX:   PUTEXT1 (‹)›);  macrocounter:= macrocounter + 1
         end  MACRO2;

procedure  SUBSTITUTE (n);  integer  n;
         begin  PUTEXT1 ( ‹          substitute›);  ABSFIXP (3, 0, macrocounter);
                PUTEXT1 (‹in addresspart of macro›);  ABSFIXP (3, 0, n)
         end  SUBSTITUTE;
```

```
comment  supplementary translating procedures;

procedure  Boolexp;
           begin  integer  n;
                  n:= identifier;  MACRO2 (TBV, n)
           end  Boolexp;

procedure  Unsigned number;
           begin  integer  n;
                  n:= number;  MACRO2 (TCV, n)
           end  Unsigned number;

procedure  Function Designator (n);  integer  n;
           begin  integer  future;
                  future:= 0;
                  MACRO2 (FDES, n);
                  if  last symbol = open  then  begin  MACRO2 (JU, future);  MACRO (ENTER);
                                                       next symbol;  Arithexp;
                                                       MACRO (RET);  SUBSTITUTE (future);
                                                       if  last symbol = close  then  next symbol
                                                       else  ERRORMESSAGE (FD1)
                                                end
           end  Function Designator;

integer  procedure  number;
           begin  number:= pointer;  list[pointer]:= last symbol;  pointer:= pointer + 1;
                  next symbol;  if  digit last symbol  then  number
           end  number;

integer  procedure  identifier;
           begin  identifier:= pointer;  list[pointer]:= last symbol;  pointer:= pointer + 1;
                  next symbol;  if  letter last symbol V digit last symbol  then  identifier
           end  identifier;

comment  informative procedures;

Boolean  procedure  arithmetic (n);  integer  n;  arithmetic:= true;

Boolean  procedure  subscrvar (n);  integer  n;  subscrvar:= last symbol = sub;

Boolean  procedure  function (n);  integer  n;  function:= last symbol = open;

Boolean  procedure  formal (n);  integer  n;  formal:= false;

procedure  Arithexp;  < body of Arithexp > ;
procedure  Simple Arithexp;  < body of Simple Arithexp > ;
procedure  Next Term;  < body of Next Term > ;
procedure  Term;  < body of Term > ;
procedure  Next Factor;  < body of Next Factor > ;
procedure  Factor;  < body of Factor > ;
procedure  Next Primary;  < body of Next Primary > ;
procedure  Primary;  < body of Primary > ;
procedure  Arithname (n);  integer  n;  < body of Arithname > ;
procedure  Subscrvar (n);  integer  n;  < body of Subscrvar > ;
procedure  Subscript list;  < body of Subscript list > ;
```

```
Main Program :
        Initialization; stop; stock:= empty; case:= lower case;
        next symbol;
Expression:
        pointer:= macrocounter:= 0;
        Arithexp;
        if  last symbol ≠ semicolon then begin  ERRORMESSAGE (MP1);
                                                for  symbol:= next symbol
                                                while  symbol ≠ semicolon do
                                            end ;
        PUNLCR; PUNLCR;
        if  next symbol = stopcode  then  ERRORMESSAGE (STOP)
                                    else goto  Expression
end
```

Appendix B

```
comment          testcases for R989/Arithexp. Input tape 5-8-1964 ;
+5 ;
-123 ;
a × b × c ;
a × b + c ;
a × (b + c) ;
a + b × c ;
+ a + (b × c) ;
- a + b × (c - d ↑ e / f) ;
A[i, M[5]] ↑  ( - 3) ;
a × sin(omega × t) ;
if  first then  0 else  if  last then  A[A[0]] else  A[0];
ln(abs(n × (n - 1) / 2)) + (if pos then  sqrt(x)  else  sqrt( - x));
A[( - ( - 13), 15] - i × (i + 1);
- A[if  bool  then  k, i, (j)];
if  operator  then  A[symbol else symbol ;
a ↑  - b × c + if  bool then  x else  y ;
```

testcases for R989/Arithexp. Output tape 5-8-1964.

```
0     TCV (5)

0     TCV (123)
1     NEG

0     TAV (a)
1     STACK
2     TAV (b)
3     MUL
4     STACK
5     TAV (c)
6     MUL
0     TAV (a)
1     STACK
2     TAV (b)
3     STACK
4     TAV (c)
5     ADD
6     MUL

0     TAV (a)
1     STACK
2     TAV (b)
3     STACK
4     TAV (c)
5     MUL
6     ADD

0     TAV (a)
1     STACK
2     TAV (b)
3     STACK
4     TAV (c)
5     MUL
6     ADD

0     TAV (a)
1     NEG
2     STACK
3     TAV (b)
4     STACK
5     TAV (c)
6     STACK
7     TAV (d)
8     STACK
9     TAV (e)
10    TTP
11    STACK
12    TAV (f)
13    DIV
14    SUB
15    MUL
16    ADD

0     TAV (i)
1     STACK
2     TCV (5)
3     STACK
4     TSAV (M)
5     STACK
6     TSAV (A)
7     STACK
8     TCV (3)
9     NEG
10    TTP
```

```
TAV (a)
STACK
FDES (sin)
JU (  0 )
ENTER
TAV (omega)
STACK
TAV (t)
MUL
RET                 substitute  10 in addresspart of macro  3
MUL
TBV (first)
COJU (  0 )
TCV (0)
JU (  0 )           substitute  4 in addresspart of macro  1
TBV (last)
COJU (  0 )
TCV (0)
STACK
TSAV (A)
STACK
TSAV (A)
JU (  0 )           substitute 12 in addresspart of macro 5
TCV (0)
STACK
TSAV (A)            substitute 15 in addresspart of macro 11   substitute 15 in addresspart of macro  3

FDES (ln)
JU (  0 )
ENTER
FDES (abs)
JU (  0 )
ENTER
TAV (n)
STACK
TAV (n)
STACK
TCV (1)
SUB
MUL
STACK
TCV (2)
DIV
RET                 substitute  17 in addresspart of macro  4
RET                 substitute  18 in addresspart of macro  1
STACK
TBV (pos)
COJU (  0 )
FDES (sqrt)
JU (  0 )
ENTER
TAV (x)
RET                 substitute  26 in addresspart of macro 22
JU (  0 )                substitute  27 in addresspart of macro 20
FDES (sqrt)
JU (  0 )
ENTER
TAV (x)
NEG
RET                 substitute  33 in addresspart of macro 28   substitute  33 in addresspart of macro 26
ADD
```

```
    0       TCV (13)
    1       NEG
    2       NEG
ERROR       P1
    3       STACK
    4       TCV (15)
    5       STACK
    6       TSAV (A)
    7       STACK
    8       TAV (i)
    9       STACK
   10       TAV (i)
   11       STACK
   12       TCV (1)
   13       ADD
   14       MUL
   15       SUB

    0       TBV (bool)
    1       COJU (   0 )
    2       TAV (k)
ERROR       AE2
    3       STACK
    4       TAV (i)
    5       STACK
    6       TAV (j)
    7       STACK
    8       TSAV (A)
    9       NEG ──────────┐
                          │
    0       TBV (operator)│
    1       COJU (   0 )  │
    2       TAV (symbol)  │
    3       STACK         │
ERROR       SV1           │
    4       TSAV (A)      │
    5       JU (   0 )    │   substitute   6 in addresspart of macro   1
    6       TAV (symbol)  │   substitute   7 in addresspart of macro   5
                          │
    0       TAV (a)       │
    1       STACK         │
ERROR       P3            │
    2       TTP           │
    3       STACK         │
    4       TAV (b)       │
    5       STACK         │
    6       TAV (c)       │
    7       MUL           │
    8       SUB           │
    9       STACK         │
ERROR       P3            │
   10       ADD           │
ERROR       MP1           │
                          │
ERROR       STOP          │
```

(Eingegangen am 7. 9. 1964)

FORTRAN

D. Sayre, New York/USA [1])

Summary: The development of FORTRAN since its initial appearance is reviewed, especially its growth from an algorithmic to a programming language. Impending developments are indicated.

Zusammenfassung: Die Entwicklung von FORTRAN seit den ersten Anfängen wird besprochen mit besonderer Berücksichtigung der Wandlung von einer algorithmischen zu einer Programmierungssprache. Bevorstehende Veränderungen werden angedeutet.

It is now 7 1/2 years since the first FORTRAN system was issued. The developments which have taken place in FORTRAN itself since that time are of course only a part of the development which has occurred in the field as a whole. Nevertheless they are of considerable interest, as I shall explain in a moment, and it is with them that this paper will be concerned. In these subsequent developments, incidentally, I have had no direct part. I write about them therefore as an interested, but disinterested, onlooker.

What gives these developments their particular interest is the relation of FORTRAN to practical computation. Every programming language and every language processor is inevitably a compromise among factors too numerous and in some cases too ill-defined to mention here. The considerations which should affect the compromise can never be fully known to us, and moreover they are continually subject to the changes that occur in applications, hardware, and computing practice generally. With FORTRAN, probably more than with the other programming languages because its use has been so great and because its users have been so effective in making their experience count in its evolution, the developments reflect in a most interesting way the actual and changing requirements of computation.

The effects of this relation to practice can be noticed in many areas. One could write, for example, a whole article on the development of the method for distributing, maintaining, and

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