TC 97

International Standard 1538

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Programming languages — ALGOL 60

Langages de programmation ALGOL 60

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 1538 was prepared by Technical Committee ISO/TC 97, *Information processing systems.*

This International Standard replaces ISO/R 1538 (withdrawn in 1977), of which it constitutes a revision.

ISO Recommendation 1538 was a compilation of several source documents. The basic one [developed under the auspices of the International Federation for Information Processing (IFIP), whose contributions are acknowledged] was the Revised Report on the Algorithmic Language ALGOL 60.

The text presented in this International Standard is based on the Modified Report on the Algorithmic Language ALGOL 60, which is a minor technical revision and a textual clarification of the Revised Report, as established by IFIP. For reasons of ISO editorial policy the original introduction which is irrelevant to an International Standard has been deleted and some introductory clauses have been added instead.

Programming Languages — ALGOL 60

0 Introduction

In this International Standard consistent use is made of ALGOL 60 as the name of the language, rather than just ALGOL, in order to avoid confusion with ALGOL 68 which is a completely different language. It is recommended that the language defined in this International Standard be referred to as STANDARD ALGOL 60.

Whenever the name ALGOL is used in this International Standard it is to mean ALGOL 60, not ALGOL 68, unless it is clear from the context that no specific language is indicated.

1 Scope and field of application

This International Standard defines the algorithmic programming language ALGOL 60. Its purpose is to facilitate interchange and promote portability of ALGOL 60 programs between data processing systems.

ALGOL 60 is intended for expressing a large class of numerical processes in a form sufficiently concise for direct automatic translation into the language of programmed automatic computers.

This International Standard specifies:

a) the syntax and semantics of ALGOL 60;

b) characteristics of programs written in ALGOL 60, and of implementations of that language, required for conformance to this International Standard.

This International Standard does not specify:

a) results of processes or other issues, that are, explicitly, left undefined or said to be undefined;

b) questions of hardware representation (these may be the subject of another International Standard), or of implementation;

c) the way non-valid programs are to be rejected, and how this will be reported;

d) requirements and rules for executing programs on an actual data processing system.

2 Reference

ISO/TR 1672, *Hardware representation of ALGOL basic symbols in the ISO 7-bit coded character set for information processing interchange.*

3 Definitions

For the purpose of this International Standard the following definitions apply:

3.1 valid program: A text written in the ALGOL 60 language that conforms to the rules for a program defined in this International Standard.

3.2 non-valid program: A text that does not conform, but was intended to be a program.

3.3 processor: A compiler, translator or interpreter, in combination with a data processing system, that accepts an intended program, transcribed in a form that can be processed by that data processing system, reports whether the intended program is valid or not, and if valid executes it, if that is being requested.

3.4 implementation: A processor, accompanied with documents that describe

a) its purpose, and the environment (hardware and software) in which it will work;

b) its intended properties, including

- the particular hardware representation of the language, as chosen;
- the actions taken, when results or issues occur that are undefined in this International Standard;
- conventions for issues said to be a question of implementation;

c) with regard to the implemented language, all differences from, restrictions to, or extensions to the language defined in this International Standard;

d) its logical structure;

e) the way to put it into use.

3.5 conforming implementation: An implementation conforming to this International Standard by accepting valid programs as being valid, by rejecting non-valid programs as being non-valid and by executing valid programs in accordance with the given rules.

3.6 implemented language: The version of the language as defined by the implementation.

3.7 conforming language version: A version of the language, defined by a conforming implementation that

a) does not contain any rule conflicting with those defined in this International Standard;

b) does not contain any rule not provided for in this International Standard, except such rules as either said to be intentionally and explicitly a question of implementation, or otherwise being outside the scope of this International Standard.

3.8 extension: A rule in the implemented language that

a) is not given in this International Standard;

b) does not cause any ambiguity when added to this International Standard (but may serve to remove a restriction);

c) is within the scope of this International Standard.

4 Conformance

4.1 Requirements

Conformance to this International Standard requires

a) for a program, that it shall be a valid program;

b) for an implementation, that it shall be a conforming implementation;

c) for the implemented language, that it shall be a conforming language version.

4.2 Quantitative restrictions

The requirements specified in 4.1 shall allow for quantitative restrictions to rules stated or implied as having no such restriction in this International Standard, but only if they are fully described in the documents with the implementation.

4.3 Extensions

An implementation that allows for extensions in the implemented language is considered to conform to this International Standard, notwithstanding 4.1, if

a) it would conform when the extensions were omitted;

b) the extensions are clearly described with the implementation;

c) while accepting programs that are non-valid according to the rules given in clause 6 of this International Standard, it provides means for indicating which part, or parts, of a program would have led to its rejection, had no extension been allowed.

Valid programs using extensions shall be described as "conforming to ISO 1538 but for the following indicated parts".

4.4 Subsets

Conformance to a subset specified in this International Standard means conformance to the subset rules as if they were the only rules in the language.

5 Tests

Whether an implementation is a conforming implementation or the implemented language is a conforming language version may be decided by a sequence of test programs. If there is any uncertainty or doubt regarding acceptance of these programs then the conclusions drawn from the actual behaviour of the processor will prevail over those derived from its accompanying documents.

6 Description of the reference language

The detailed description of the reference language given herein reproduces, without modification, the text taken from the Modified Report (see the foreword), the contents of which are the following:

1 Structure of the language

1.1 Formalism for syntactic description

2 Basic symbols, identifiers, numbers, and strings. Basic concepts

2.1 Letters

2.2 Digits and logical values

2.3 Delimiters

2.4 Identifiers

2.5 Numbers

2.6 Strings

2.7 Quantities, kinds and scopes

2.8 Values and types

1. *Structure of the language*

The algorithmic language has two different kinds of representation—reference and hardware—and the development described in the sequel is in terms of the reference representation. This means that all objects defined within the language are represented by a given set of symbols—and it is only in the choice of symbols that other representations may differ. Structure and content must be the same for all representations.

Reference language

1. It is the defining language.
2. The characters are determined by ease of mutual understanding and not by any computer limitations, coder's notation, or pure mathematical notation.
3. It is the basic reference and guide for compiler builders.
4. It is the guide for all hardware representations.

Hardware representations

Each one of these:

1. is a condensation of the reference language enforced by the limited number of characters on standard input equipment;
2. uses the character set of a particular computer and is the language accepted by a translator for that computer;
3. must be accompanied by a special set of rules for transliterating to or from reference language.

It should be particularly noted that throughout the reference language underlining in typescript or manuscript, or boldface type in printed copy, is used to represent certain basic symbols (see Sections 2.2.2 and 2.3). These are understood to have no relation to the individual letters of which they are composed. In the reference language underlining or boldface is used for no other purpose.

The purpose of the algorithmic language is to describe computational processes. The basic concept used for the description of calculating rules is the well-known arithmetic expression containing as constituents numbers, variables, and functions. From such expressions are compounded, by applying rules of arithmetic composition, self-contained units of the language—explicit formulae—called assignment statements.

To show the flow of computational processes, certain non-arithmetic statements and statement clauses are added which may describe, e.g. alternatives, or iterative repetitions of computing statements. Since it is sometimes necessary for the function of these statements that one statement refers to another, statements may be provided with labels. A sequence of statements may be enclosed between the statement brackets **begin** and **end** to form a compound statement.

Statements are supported by declarations which are not themselves computing instructions, but inform the translator of the existence and certain properties of objects appearing in statements, such as the class of numbers taken on as values by a variable, the dimension of an array of numbers, or even the set of rules defining a function. A sequence of declarations followed by a sequence of statements and enclosed between **begin** and **end** constitutes a block. Every declaration appears in a block in this way and is valid only for that block.

A program is a block or a compound statement that is contained only within a fictitious block (always assumed to be present and called the environmental block), and that makes no use of statements or declarations not contained within itself, except that it may invoke such procedure identifiers and function designators as may be assumed to be declared in the environmental block.

The environmental block contains procedure declarations of standard functions, input and output operations, and possibly other

operations to be made available without declaration within the program. It also contains the fictitious declaration, and initialisation, of **own** variables (see Section 5).

In the sequel the syntax and semantics of the language will be given.

Whenever the precision of arithmetic is stated as being in general not specified, or the outcome of a certain process is left undefined or said to be undefined, this is to be interpreted in the sense that a program only fully defines a computational process if the accompanying information specifies the precision assumed, the kind of arithmetic assumed, and the course of action to be taken in all such cases as may occur during the execution of the computation.

1.1. *Formalism for syntactic description*

The syntax will be described with the aid of metalinguistic formulae (Backus, 1959). Their interpretation is best explained by an example:

⟨ab⟩ ::= (| [| ⟨ab⟩(| ⟨ab⟩⟨d⟩

Sequences of characters enclosed in the brackets ⟨⟩ represent metalinguistic variables whose values are sequences of symbols. The marks ::= and | (the latter with the meaning of 'or') are metalinguistic connectives. Any mark in a formula, which is not a variable or a connective, denotes itself (or the class of marks which are similar to it). Juxtaposition of marks and/or variables in a formula signifies juxtaposition of the sequences denoted. Thus the formula above gives a recursive rule for the formation of values of the variable ⟨ab⟩. It indicates that ⟨ab⟩ may have the value (or [or that given some legitimate value of ⟨ab⟩, another may be formed by following it with the character (or by following it with some value of the variable ⟨d⟩. If the values of ⟨d⟩ are the decimal digits, some values of ⟨ab⟩ are:

[(((1(37(
(12345(
(((
[86

In order to facilitate the study, the symbols used for distinguishing the metalinguistic variables (i.e. the sequences of characters appearing within the brackets ⟨⟩ as ab in the above example) have been chosen to be words describing approximately the nature of the corresponding variable. Where words which have appeared in this manner are used elsewhere in the text they will refer to the corresponding syntactic definition. In addition some formulae have been given in more than one place.

Definition:
⟨empty⟩ ::=
(i.e. the null string of symbols).

2. *Basic symbols, identifiers, numbers, and strings. Basic concepts*

The reference language is built up from the following basic symbols:
⟨basic symbol⟩ ::= ⟨letter⟩|⟨digit⟩|⟨logical value⟩|⟨delimiter⟩

2.1. *Letters*

⟨letter⟩ ::= *a*|*b*|*c*|*d*|*e*|*f*|*g*|*h*|*i*|*j*|*k*|*l*|*m*|*n*|*o*|*p*|*q*|*r*|*s*|*t*|*u*|*v*|*w*|*x*|*y*|*z* |*A*|*B*|*C*|*D*|*E*|*F*|*G*|*H*|*I*|*J*|*K*|*L*|*M*|*N*|*O*|*P*|*Q*|*R*|*S*|*T*|*U*|*V*|*W*| *X*|*Y*|*Z*

This alphabet may arbitrarily be restricted, or extended with any other distinctive character (i.e. character not coinciding with any digit, logical value or delimiter).

Letters do not have individual meaning. They are used for forming identifiers and strings (see Sections 2.4 Identifiers, 2.6 Strings). Within this report the letters (from an extended alphabet) Γ, θ, Σ and Ω are sometimes used and are understood as not being available to the programmer. If an extended alphabet is in use, that does include any of these letters, then their uses within this report must be systematically changed to other letters that the extended alphabet does not include.

2.2. *Digits and logical values*

2.2.1. *Digits*

⟨digit⟩ ::= 0|1|2|3|4|5|6|7|8|9
Digits are used for forming numbers, identifiers, and strings.

2.2.2. *Logical values*

⟨logical value⟩ ::= **true**|**false**
The logical values have a fixed obvious meaning.

2.3. *Delimiters*

⟨delimiter⟩ ::= ⟨operator⟩|⟨separator⟩|⟨bracket⟩|⟨declarator⟩| ⟨specificator⟩
⟨operator⟩ ::= ⟨arithmetic operator⟩|⟨relational operator⟩| ⟨logical operator⟩|⟨sequential operator⟩
⟨arithmetic operator⟩ ::= +|−|×|/|÷|↑
⟨relational operator⟩ ::= <|≤|=|≥|>|≠
⟨logical operator⟩ ::= ≡|⊃|∧|∨|¬
⟨sequential operator⟩ ::= **go to**|**if**|**then**|**else**|**for**|**do**
⟨separator⟩ ::= ,|.|$_{10}$|:|;|:=|**step**|**until**|**while**|**comment**
⟨bracket⟩ ::= (|)|[|]|⌜|⌝|**begin**|**end**
⟨declarator⟩ ::= **own**|**Boolean**|**integer**|**real**|**array**|**switch**|**procedure**
⟨specificator⟩ ::= **string**|**label**|**value**

Delimiters have a fixed meaning which for the most part is obvious or else will be given at the appropriate place in the sequel.

Typographical features such as blank space or change to a new line have no significance in the reference language. They may, however, be used freely for facilitating reading.

For the purpose of including text among the symbols of a program the following 'comment' conventions hold:

The sequence	is equivalent to
;**comment** ⟨any sequence of zero or more characters not containing ;⟩;	;
begin comment ⟨any sequence of zero or more characters not containing ;⟩;	**begin**
end ⟨any sequence of zero or more basic symbols not containing **end** or **else** or ;⟩	**end**

By equivalence is here meant that any of the three structures shown in the left hand column may be replaced, in any occurrence outside of strings, by the symbol shown on the same line in the right hand column without any effect on the action of the program. It is further understood that the comment structure encountered first in the text when reading from left to right has precedence in being replaced over later structures contained in the sequence.

2.4. *Identifiers*

2.4.1. *Syntax*

⟨identifier⟩ ::= ⟨letter⟩|⟨identifier⟩⟨letter⟩|⟨identifier⟩⟨digit⟩

2.4.2. *Examples*

q
Soup
V17a
a34kTMNs
MARILYN

2.4.3. *Semantics*

Identifiers have no inherent meaning, but serve for the identification of simple variables, arrays, labels, switches, and procedures. They may be chosen freely. Identifiers also act as formal parameters of procedures, in which capacity they may represent any of the above entities, or a string.

The same identifier cannot be used to denote two different quantities except when these quantities have disjoint scopes as defined by the declarations of the program (see Section 2.7 Quantities, kinds and scopes and Section 5 Declarations). This rule applies also to the formal parameters of procedures, whether representing a quantity or a string.

2.5. *Numbers*

2.5.1. *Syntax*

⟨unsigned integer⟩ ::= ⟨digit⟩|⟨unsigned integer⟩⟨digit⟩
⟨integer⟩ ::= ⟨unsigned integer⟩|+⟨unsigned integer⟩ |−⟨unsigned integer⟩
⟨decimal fraction⟩ ::= .⟨unsigned integer⟩
⟨exponent part⟩ ::= $_{10}$⟨integer⟩
⟨decimal number⟩ ::= ⟨unsigned integer⟩|⟨decimal fraction⟩ |⟨unsigned integer⟩⟨decimal fraction⟩
⟨unsigned number⟩ ::= ⟨decimal number⟩|⟨exponent part⟩ |⟨decimal number⟩⟨exponent part⟩
⟨number⟩ ::= ⟨unsigned number⟩|+⟨unsigned number⟩ |−⟨unsigned number⟩

2.5.2. *Examples*

0	-200.084	$-.083_{10}-02$
177	$+07.43_{10}8$	$-_{10}7$
.5384	$9.34_{10}+10$	$_{10}-4$
$+0.7300$	$2_{10}-4$	$+_{10}+5$

2.5.3. *Semantics*
Decimal numbers have their conventional meaning. The exponent part is a scale factor expressed as an integral power of 10.

2.5.4. *Types*
Integers are of integer type. All other numbers are of real type (see Section 5.1 Type declarations).

2.6. *Strings*
2.6.1. *Syntax*

⟨proper string⟩ ::= ⟨any sequence of characters not containing ⌜ or ⌝⟩|⟨empty⟩
⟨open string⟩ ::= ⟨proper string⟩
|⟨proper string⟩⟨closed string⟩⟨open string⟩
⟨closed string⟩ ::= ⌜⟨open string⟩⌝
⟨string⟩ ::= ⟨closed string⟩|⟨closed string⟩⟨string⟩

2.6.2. *Examples*

⌜5k,, − ⌜[[[⌜∧=/:⌝*Tt*⌝⌝
⌜..*This*␣*is*␣*a*␣⌜*string*⌝⌝
⌜*This*␣*is*␣*all*⌝
⌜␣*one*␣*string*⌝

2.6.3. *Semantics*
In order to enable the language to handle sequences of characters the string quotes ⌜ and ⌝ are introduced.

The characters available within a string are a question of hardware representation, and further rules are not given in the reference language. However, it is recommended that visible characters, other than ␣ and ″, should represent themselves, while invisible characters other than space should not occur within a string. To conform with ISO/TR 1672, a space may stand for itself, although in this document the character ␣ is used to represent a space.

To allow invisible, or other exceptional characters to be used, they are represented within either matching string quotes or a matched pair of the ″ symbol. The rules within such an inner string are unspecified, so if such an escape mechanism is used a comment is necessary to explain the meaning of the escape sequence.

A string of the form ⟨closed string⟩⟨string⟩ behaves as if it were the string formed by deleting the closing string quote of the closed string and the opening string quote of the following string (together with any layout characters between them).

Strings are used as actual parameters of procedures (see Sections 3.2 Function designators and 4.7 Procedure statements).

2.7. *Quantities, kinds and scopes*
The following kinds of quantities are distinguished: simple variables, arrays, labels, switches, and procedures.

The scope of a quantity is the set of statements and expressions in which the declaration of the identifier associated with that quantity is valid. For labels see Section 4.1.3.

2.8. *Values and types*
A value is an ordered set of numbers (special case: a single number), an ordered set of logical values (special case: a single logical value), or a label.

Certain of the syntactic units are said to possess values. These values will in general change during the execution of the program. The values of expressions and their constituents are defined in Section 3. The value of an array identifier is the ordered set of values of the corresponding array of subscripted variables (see Section 3.1.4.1).

The various types (integer, real, Boolean) basically denote properties of values. The types associated with syntactic units refer to the values of these units.

3. *Expressions*
In the language the primary constituents of the programs describing algorithmic processes are arithmetic, Boolean, and designational expressions. Constituents of these expressions, except for certain delimiters, are logical values, numbers, variables, function designators, labels, switch designators, and elementary arithmetic, relational, logical, and sequential operators. Since the syntactic definition of both variables and function designators contains expressions, the definition of expressions, and their constituents, is necessarily recursive.

⟨expression⟩ ::= ⟨arithmetic expression⟩|⟨Boolean expression⟩
|⟨designational expression⟩

3.1. *Variables*
3.1.1. *Syntax*

⟨variable identifier⟩ ::= ⟨identifier⟩
⟨simple variable⟩ ::= ⟨variable identifier⟩
⟨subscript expression⟩ ::= ⟨arithmetic expression⟩
⟨subscript list⟩ ::= ⟨subscript expression⟩|⟨subscript list⟩,
⟨subscript expression⟩
⟨array identifier⟩ ::= ⟨identifier⟩
⟨subscripted variable⟩ ::= ⟨array identifier⟩[⟨subscript list⟩]
⟨variable⟩ ::= ⟨simple variable⟩|⟨subscripted variable⟩

3.1.2. *Examples*

epsilon
detA
*a*17
Q[7, 2]
x[*sin*(*n* × *pi*/2), *Q*[3, *n*, 4]]

3.1.3. *Semantics*
A variable is a designation given to a single value. This value may be used in expressions for forming other values and may be changed at will by means of assignment statements (see Section 4.2). The type of the value of a particular variable is defined in the declaration for the variable itself (see Section 5.1 Type declarations) or for the corresponding array identifier (see Section 5.2 Array declarations).

3.1.4. *Subscripts*
3.1.4.1. Subscripted variables designate values which are components of multidimensional arrays (see Section 5.2 Array declarations). Each arithmetic expression of the subscript list occupies one subscript position of the subscripted variable and is called a subscript. The complete list of subscripts is enclosed in the subscript brackets [ ]. The array component referred to by a subscripted variable is specified by the actual numerical value of its subscripts (see Section 3.3 Arithmetic expressions).

3.1.4.2. Each subscript position acts like a variable of integer type and the evaluation of the subscript is understood to be equivalent to an assignment to this fictitious variable (see Section 4.2.4). The value of the subscripted variable is defined only if the value of the subscript expression is within the subscript bounds of the array (see Section 5.2 Array declarations).

3.1.5. *Initial values of variables*
The value of a variable, not declared **own**, is undefined from entry into the block in which it is declared until an assignment is made to it. The value of a variable declared **own** is zero (if arithmetic) or **false** (if Boolean) on first entry to the block in which it is declared. On subsequent entries it has the same value as at the preceding exit from the block.

3.2. *Function designators*
3.2.1. *Syntax*

⟨procedure identifier⟩ ::= ⟨identifier⟩
⟨actual parameter⟩ ::= ⟨string⟩|⟨expression⟩
|⟨array identifier⟩|⟨switch identifier⟩
|⟨procedure identifier⟩
⟨letter string⟩ ::= ⟨letter⟩|⟨letter string⟩⟨letter⟩
⟨parameter delimiter⟩ ::= ,|)⟨letter string⟩:(
⟨actual parameter list⟩ ::= ⟨actual parameter⟩
|⟨actual parameter list⟩
⟨parameter delimiter⟩⟨actual parameter⟩
⟨actual parameter part⟩ ::= ⟨empty⟩|(⟨actual parameter list⟩)
⟨function designator⟩ ::= ⟨procedure identifier⟩
⟨actual parameter part⟩

3.2.2. *Examples*

sin(*a* − *b*)
J(*v* + *s*, *n*)
R
S(*s* − 5)*Temperature*:(*T*)*Pressure*:(*P*)
Compile (⌜:=⌝)*Stack*:(*Q*)

3.2.3. *Semantics*

Function designators define single numerical or logical values which result through the application of given sets of rules defined by a procedure declaration (see Section 5.4 Procedure declarations) to fixed sets of actual parameters. The rules governing specification of actual parameters are given in Section 4.7 Procedure statements. Not every procedure declaration defines rules for determining the value of a function designator.

3.2.4. *Standard functions and procedures*

Certain standard functions and procedures are declared in the environmental block with the following procedure identifiers:

abs, *iabs*, *sign*, *entier*, *sqrt*, *sin*, *cos*, *arctan*, *ln*, *exp*, *inchar*, *outchar*, *length*, *outstring*, *outterminator*, *stop*, *fault*, *ininteger*, *outinteger*, *inreal*, *outreal*, *maxreal*, *minreal*, *maxint* and *epsilon*.

For details of these functions and procedures, see the specification of the environmental block given as Appendix 2.

3.3. *Arithmetic expressions*

3.3.1. *Syntax*

⟨adding operator⟩ ::= +|−
⟨multiplying operator⟩ ::= ×|/|÷
⟨primary⟩ ::= ⟨unsigned number⟩|⟨variable⟩
|⟨function designator⟩|(⟨arithmetic expression⟩)
⟨factor⟩ ::= ⟨primary⟩|⟨factor⟩↑⟨primary⟩
⟨term⟩ ::= ⟨factor⟩|⟨term⟩⟨multiplying operator⟩⟨factor⟩
⟨simple arithmetic expression⟩ ::= ⟨term⟩|⟨adding operator⟩
⟨term⟩|⟨simple arithmetic expression⟩⟨adding operator⟩⟨term⟩
⟨if clause⟩ ::= **if** ⟨Boolean expression⟩ **then**
⟨arithmetic expression⟩ ::= ⟨simple arithmetic expression⟩
|⟨if clause⟩⟨simple arithmetic expression⟩ **else**
⟨arithmetic expression⟩

3.3.2. *Examples*

Primaries:
$7.394_{10}-8$
sum
w[*i* + 2, 8]
cos (*y* + *z* × 3)
(*a* − 3/*y* + *vu*↑8)

Factors:
omega
sum↑*cos*(*y* + *z* × 3)
$7.394_{10}-8$↑*w*[*i* + 2, 8]↑(*a* − 3/*y* + *vu*↑8)

Terms:
U
omega × *sum*↑*cos*(*y* + *z* × 3)/$7.394_{10}-8$
↑*w*[*i* + 2, 8]↑(*a* − 3/*y* + *vu*↑8)

Simple arithmetic expression:
U − *Yu* + *omega* × *sum*↑*cos*(*y* + *z* × 3)/$7.394_{10}-8$
↑*w*[*i* + 2, 8]↑(*a* − 3/*y* + *vu*↑8)

Arithmetic expressions:
w × *u* − *Q*(*S* + *Cu*)↑2
if *q* > 0 **then** *S* + 3 × *Q*/*A* **else** 2 × *S* + 3 × *q*
if *a* < 0 **then** *U* + *V* **else if** *a* × *b* > 17 **then** *U*/*V*
else if *k* ≠ *y* **then** *V*/*U* **else** 0
a × *sin*(*omega* × *t*)
$0.57_{10}12$ × *a*[*N* × (*N* − 1)/2,0]
(*A* × *arctan*(*y*) + *Z*)↑(7 + *Q*)
if *q* **then** *n* − 1 **else** *n*
if *a* < 0 **then** *A*/*B* **else if** *b* = 0 **then** *B*/*A* **else** *z*

3.3.3. *Semantics*

An arithmetic expression is a rule for computing a numerical value. In the case of simple arithmetic expressions this value is obtained by executing the indicated arithmetic operations on the actual numerical values of the primaries of the expression, as explained in detail in Section 3.3.4 below. The actual numerical value of a primary is obvious in the case of numbers. For variables it is the current value (assigned last in the dynamic sense), and for function designators it is the value arising from the computing rules defining the procedure (see Section 5.4.4 Values of function designators) when applied to the current values of the procedure parameters given in the expression. Finally, for arithmetic expressions enclosed in parentheses the value must through a recursive analysis be expressed in terms of the values of primaries of the other three kinds.

In the more general arithmetic expressions, which include if clauses, one out of several simple arithmetic expressions is selected on the basis of the actual values of the Boolean expressions (see Section 3.4 Boolean expressions). This selection is made as follows: The Boolean expressions of the if clauses are evaluated one by one in sequence from left to right until one having the value **true** is found. The value of the arithmetic expression is then the value of the first arithmetic expression following this Boolean (the longest arithmetic expression found in this position is understood). If none of the Boolean expressions has the value **true**, then the value of the arithmetic expression is the value of the expression following the final **else**.

The order of evaluation of primaries within an expression is not defined. If different orders of evaluation would produce different results, due to the action of side effects of function designators, the program is undefined.

In evaluating an arithmetic expression, it is understood that all the primaries within that expression are evaluated, except those within any arithmetic expression that is governed by an if clause but not selected by it. In the special case where an exit is made from a function designator by means of a go to statement (see Section 5.4.4), the evaluation of the expression is abandoned, when the go to statement is executed.

3.3.4. *Operators and types*

Apart from the Boolean expressions of if clauses, the constituents of simple arithmetic expressions must be of real or integer types (see Section 5.1 Type declarations). The meaning of the basic operators and the types of the expressions to which they lead are given by the following rules:

3.3.4.1. The operators +, −, and × have the conventional meaning (addition, subtraction, and multiplication). The type of the expression will be integer if both of the operands are of integer type, otherwise real.

3.3.4.2. The operations ⟨term⟩/⟨factor⟩ and ⟨term⟩ ÷ ⟨factor⟩ both denote division. The operations are undefined if the factor has the value zero, but are otherwise to be understood as a multiplication of the term by the reciprocal of the factor with due regard to the rules of precedence (see Section 3.3.5). Thus for example

$$a/b \times 7/(p - q) \times v/s$$

means

$$((((a \times (b^{-1})) \times 7) \times ((p - q)^{-1})) \times v) \times (s^{-1}) \ .$$

The operator / is defined for all four combinations of real and integer types and will yield results of real type in any case. The operator ÷ is defined only for two operands both of integer type and will yield a result of integer type. If *a* and *b* are of integer type, then the value of *a* ÷ *b* is given by the function:

```
integer procedure div(a, b); value a, b;
  integer a, b;
  if b = 0 then
        fault(⌜div␣by␣zero⌝, a)
  else
        begin integer q, r;
        q := 0; r := iabs(a);
        for r := r − iabs(b) while r ≥ 0 do q := q + 1;
        div := if a < 0 ≡ b > 0 then −q else q
        end div
```

3.3.4.3. The operation ⟨factor⟩↑⟨primary⟩ denotes exponentiation, where the factor is the base and the primary is the exponent. Thus

for example

$$2\uparrow n\uparrow k \text{ means } (2^n)^k$$

while

$$2\uparrow(n\uparrow m) \text{ means } 2^{(n^m)}.$$

If r is of real type and x of either real or integer type, then the value of $x\uparrow r$ is given by the function:

```
real procedure expr(x, r); value x, r;
  real x, r;
  if x > 0.0 then
      expr := exp(r × ln(x))
  else if x = 0.0 ∧ r > 0.0 then
      expr := 0.0
  else
      fault(⌜expr␣undefined⌝, x)
```

If i and j are both of integer type, then the value of $i\uparrow j$ is given by the function:

```
integer procedure expi(i, j); value i, j;
  integer i, j;
  if j < 0 ∨ i = 0 ∧ j = 0 then
      fault(⌜expi␣undefined⌝, j)
  else
    begin
    integer k, result;
    result := 1;
    for k := 1 step 1 until j do
      result := result × i;
    expi := result
    end expi
```

If n is of integer type and x of real type, then the value of $x\uparrow n$ is given by the function:

```
real procedure expn(x, n); value x, n;
  real x; integer n;
  if n = 0 ∧ x = 0.0 then
      fault(⌜expn␣undefined⌝, x)
  else
    begin
    real result; integer i;
    result := 1.0;
    for i := iabs(n) step −1 until 1 do
      result := result × x;
    expn := if n < 0 then 1.0/result else result
    end expn
```

The call of the procedure *fault* denotes that the action of the program is undefined. It is understood that the finite deviations (see Section 3.3.6) of using the exponentiation operator may be different from those of using the procedures *expr* and *expn*.

3.3.4.4. *Type of a conditional expression*

The type of an arithmetic expression of the form

if *B* **then** *SAE* **else** *AE*

does not depend upon the value of *B*. The expression is of real type if either *SAE* or *AE* is real and is of integer type otherwise.

3.3.5. *Precedence of operators*

The sequence of operations within one expression is generally from left to right, with the following additional rules:

3.3.5.1. According to the syntax given in Section 3.3.1 the following rules of precedence hold:

first: ↑
second: × / ÷
third: + −

3.3.5.2. The expression between a left parenthesis and the matching right parenthesis is evaluated by itself and this value is used in subsequent calculations. Consequently the desired order of execution of operations within an expression can always be arranged by appropriate positioning of parentheses.

3.3.6. *Arithmetics of real quantities*

Numbers and variables of real type must be interpreted in the sense of numerical analysis, i.e. as entities defined inherently with only a finite accuracy. Similarly, the possibility of the occurrence of a finite deviation from the mathematically defined result in any arithmetic expression is explicitly understood. No exact arithmetic will be specified, however, and it is indeed understood that different implementations may evaluate arithmetic expressions differently. The control of the possible consequences of such differences must be carried out by the methods of numerical analysis. This control must be considered a part of the process to be described, and will therefore be expressed in terms of the language itself.

3.4. *Boolean expressions*

3.4.1. *Syntax*

⟨relational operator⟩ ::= < | ≤ | = | ≥ | > | ≠

⟨relation⟩ ::= ⟨simple arithmetic expression⟩⟨relational operator⟩
⟨simple arithmetic expression⟩

⟨Boolean primary⟩ ::= ⟨logical value⟩|⟨variable⟩
|⟨function designator⟩|⟨relation⟩
|(⟨Boolean expression⟩)

⟨Boolean secondary⟩ ::= ⟨Boolean primary⟩|¬⟨Boolean primary⟩

⟨Boolean factor⟩ ::= ⟨Boolean secondary⟩
|⟨Boolean factor⟩ ∧ ⟨Boolean secondary⟩

⟨Boolean term⟩ ::= ⟨Boolean factor⟩
|⟨Boolean term⟩ ∨ ⟨Boolean factor⟩

⟨implication⟩ ::= ⟨Boolean term⟩|⟨implication⟩ ⊃ ⟨Boolean term⟩

⟨simple Boolean⟩ ::= ⟨implication⟩
|⟨simple Boolean⟩ ≡ ⟨implication⟩

⟨Boolean expression⟩ ::= ⟨simple Boolean⟩
|⟨if clause⟩⟨simple Boolean⟩ **else** ⟨Boolean expression⟩

3.4.2. *Examples*

$x = -2$
$Y > V \vee z < q$
$a + b > -5 \wedge z - d > q\uparrow 2$
$p \wedge q \vee x \neq y$
$g \equiv \neg a \wedge b \wedge \neg c \vee d \vee e \supset \neg f$
if $k < 1$ **then** $s > w$ **else** $h \leqslant c$
if if if a **then** b **else** c **then**
d **else** f **then** g **else** $h < k$

3.4.3. *Semantics*

A Boolean expression is a rule for computing a logical value. The principles of evaluation are entirely analogous to those given for arithmetic expressions in Section 3.3.3.

3.4.4. *Types*

Variables and function designators entered as Boolean primaries must be declared **Boolean** (see Section 5.1 Type declarations and Section 5.4.4 Values of function designators).

3.4.5. *The operators*

The relational operators <, ≤, =, ≥, > and ≠ have their conventional meaning (less than, less than or equal to, equal to, greater than or equal to, greater than, not equal to). Relations take on the value **true** whenever the corresponding relation is satisfied for the expressions involved, otherwise **false.**

The meaning of the logical operators ¬ (not), ∧ (and), ∨ (or), ⊃ (implies), and ≡ (equivalent), is given by the following function table:

*b*1	**false**	**false**	**true**	**true**
*b*2	**false**	**true**	**false**	**true**
¬ *b*1	**true**	**true**	**false**	**false**
*b*1 ∧ *b*2	**false**	**false**	**false**	**true**
*b*1 ∨ *b*2	**false**	**true**	**true**	**true**
*b*1 ⊃ *b*2	**true**	**true**	**false**	**true**
*b*1 ≡ *b*2	**true**	**false**	**false**	**true**

3.4.6. *Precedence of operators*

The sequence of operations within one expression is generally from left to right, with the following additional rules:

3.4.6.1. According to the syntax given in Section 3.4.1 the following rules of precedence hold:

first: arithmetic expressions according to Section 3.3.5.
second: < ≤ = ≥ > ≠
third: ¬
fourth: ∧
fifth: ∨
sixth: ⊃
seventh: ≡

3.4.6.2. The use of parentheses will be interpreted in the sense given in Section 3.3.5.2.

3.5. *Designational expressions*

3.5.1. *Syntax*

```
⟨label⟩ ::= ⟨identifier⟩
⟨switch identifier⟩ ::= ⟨identifier⟩
⟨switch designator⟩ ::= ⟨switch identifier⟩[⟨subscript expression⟩]
⟨simple designational expression⟩ ::= ⟨label⟩
        |⟨switch designator⟩|(⟨designational expression⟩)
⟨designational expression⟩ ::= ⟨simple designational expression⟩
        |⟨if clause⟩⟨simple designational expression⟩
                else ⟨designational expression⟩
```

3.5.2. *Examples*

```
L17
p9
Choose [n − 1]
Town [if y < 0 then N else N + 1]
if Ab < c then L17
    else q[if w ≤ 0 then 2 else n]
```

3.5.3. *Semantics*

A designational expression is a rule for obtaining a label of a statement (see Section 4 Statements). Again the principle of the evaluation is entirely analogous to that of arithmetic expressions (see Section 3.3.3). In the general case the Boolean expressions of the if clauses will select a simple designational expression. If this is a label the desired result is already found. A switch designator refers to the corresponding switch declaration (see Section 5.3 Switch declarations) and by the actual numerical value of its subscript expression selects one of the designational expressions listed in the switch declaration by counting these from left to right. Since the designational expression thus selected may again be a switch designator this evaluation is obviously a recursive process.

3.5.4. *The subscript expression*

The evaluation of the subscript expression is analogous to that of subscripted variables (see Section 3.1.4.2). The value of a switch designator is defined only if the subscript expression assumes one of the positive values 1, 2, 3, . . ., n, where n is the number of entries in the switch list.

4. *Statements*

The units of operation within the language are called statements. They will normally be executed consecutively as written. However, this sequence of operations may be broken by go to statements, which define their successor explicitly, shortened by conditional statements, which may cause certain statements to be skipped, and lengthened by for statements which cause certain statements to be repeated.

In order to make it possible to define a specific dynamic succession, statements may be provided with labels.

Since sequences of statements may be grouped together into compound statements and blocks the definition of statement must necessarily be recursive. Also since declarations, described in Section 5, enter fundamentally into the syntactic structure, the syntactic definition of statements must suppose declarations to be already defined.

4.1. *Compound statements and blocks*

4.1.1. *Syntax*

```
⟨unlabelled basic statement⟩ ::= ⟨assignment statement⟩
        |⟨go to statement⟩|⟨dummy statement⟩
        |⟨procedure statement⟩
⟨basic statement⟩ ::= ⟨unlabelled basic statement⟩
        |⟨label⟩ : ⟨basic statement⟩
⟨unconditional statement⟩ ::= ⟨basic statement⟩
        |⟨compound statement⟩|⟨block⟩
⟨statement⟩ ::= ⟨unconditional statement⟩|⟨conditional statement⟩
        |⟨for statement⟩
⟨compound tail⟩ ::= ⟨statement⟩end
        |⟨statement⟩; ⟨compound tail⟩
⟨block head⟩ ::= begin ⟨declaration⟩
        |⟨block head⟩; ⟨declaration⟩
⟨unlabelled compound⟩ ::= begin ⟨compound tail⟩
⟨unlabelled block⟩ ::= ⟨block head⟩; ⟨compound tail⟩
⟨compound statement⟩ ::= ⟨unlabelled compound⟩
        |⟨label⟩:⟨compound statement⟩
⟨block⟩ ::= ⟨unlabelled block⟩|⟨label⟩:⟨block⟩
⟨program⟩ ::= ⟨block⟩|⟨compound statement⟩
```

This syntax may be illustrated as follows: Denoting arbitrary statements, declarations, and labels, by the letters S, D, and L, respectively, the basic syntactic units take the forms:

Compound statement:
  L:*L*: . . . **begin** *S*; *S*; . . . *S*; *S* **end**
Block:
  L:*L*: . . . **begin** *D*; *D*; . . . *D*; *S*; *S*; . . . *S*; *S* **end**

It should be kept in mind that each of the statements S may again be a complete compound statement or block.

4.1.2. *Examples*

Basic statements:

```
a := p + q
go to Naples
START:CONTINUE: W := 7.993
```

Compound statement:

```
begin x := 0;
    for y := 1 step 1 until n do x := x + A[y];
    if x > q then go to STOP
    else if x > w − 2 then go to S;
  Aw : St: W := x + bob
end
```

Block:

```
Q: begin integer i, k; real w;
    for i := 1 step 1 until m do
    for k := i + 1 step 1 until m do
    begin w := A[i, k];
        A[i, k] := A[k, i];
        A[k, i] := w
    end for i and k
  end block Q
```

4.1.3. *Semantics*

Every block automatically introduces a new level of nomenclature. This is realised as follows: Any identifier occurring within the block may through a suitable declaration (see Section 5 Declarations) be specified to be local to the block in question. This means (*a*) that the entity represented by this identifier inside the block has no existence outside it and (*b*) that any entity represented by this identifier outside the block is completely inaccessible inside the block.

Identifiers (except those representing labels) occurring within a block and not being declared to this block will be non-local to it, i.e. will represent the same entity inside the block and in the level immediately outside it. A label separated by a colon from a statement, i.e. labelling that statement, behaves as though declared in the head of the smallest embracing block, i.e. the smallest block whose brackets **begin** and **end** enclose that statement.

A label is said to be implicitly declared in this block head, as distinct from the explicit declaration of all other local identifiers. In this context a procedure body, or the statement following a for clause, must be considered as if it were enclosed by **begin** and **end** and treated as a block, this block being nested within the fictitious block of Section 4.7.3.1. in the case of a procedure with parameters by value. A label that is not within any block of the program (nor within a procedure body, or the statement following a for clause) is implicitly declared in the head of the environmental block.

Since a statement of a block may again itself be a block the concepts local and non-local to a block must be understood recursively. Thus an identifier which is non-local to a block A, may or may not be non-local to the block B in which A is one statement.

4.2. *Assignment statements*

4.2.1. *Syntax*

```
⟨destination⟩ ::= ⟨variable⟩|⟨procedure identifier⟩
⟨left part⟩ ::= ⟨destination⟩ :=
⟨left part list⟩ ::= ⟨left part⟩|⟨left part list⟩⟨left part⟩
⟨assignment statement⟩ ::= ⟨left part list⟩⟨arithmetic expression⟩
        |⟨left part list⟩⟨Boolean expression⟩
```

4.2.2. *Examples*

$s := p[0] := n := n + 1 + s$
$n := n + 1$
$A := B/C - v - q \times S$
$S[v, k + 2] := 3 - arctan(s \times zeta)$
$V := Q > Y \wedge Z$

4.2.3. *Semantics*

Assignment statements serve for assigning the value of an expression to one or several destinations. Assignment to a procedure identifier may only occur within the body of a procedure defining the value of the function designator denoted by that identifier (see Section 5.4.4). If assignment is made to a subscripted variable, the values of all the subscripts must lie within the appropriate subscript bounds. Otherwise the action of the program becomes undefined.

The process will in the general case be understood to take place in three steps as follows:

4.2.3.1. Any subscript expressions occurring in the destinations are evaluated in sequence from left to right.

4.2.3.2. The expression of the statement is evaluated.

4.2.3.3. The value of the expression is assigned to all the destinations, with any subscript expressions having values as evaluated in step 4.2.3.1.

4.2.4. *Types*

The type associated with all destinations of a left part list must be the same. If this type is Boolean, the expression must likewise be Boolean. If the type is real or integer, the expression must be arithmetic. If the type of the arithmetic expression differs from that associated with the destinations, an appropriate transfer function is understood to be automatically invoked. For transfer from real to integer type the transfer function is understood to yield a result which is the largest integral quantity not exceeding $E + 0.5$ in the mathematical sense (i.e. without rounding error) where E is the value of the expression. It should be noted that E, being of real type, is defined with only finite accuracy (see Section 3.3.6). The type associated with a procedure identifier is given by the declarator which appears as the first symbol of the corresponding procedure declaration (see Section 5.4.4).

4.3. *Go to statements*

4.3.1. *Syntax*

⟨go to statement⟩ ::= **go to** ⟨designational expression⟩

4.3.2. *Examples*

go to *L8*
go to *exit*[$n + 1$]
go to *Town*[**if** $y < 0$ **then** N **else** $N + 1$]
go to if $Ab < c$ **then** *L17*
else q[**if** $w < 0$ **then** 2 **else** n]

4.3.3. *Semantics*

A go to statement interrupts the normal sequence of operations, by defining its successor explicitly by the value of a designational expression. Thus the next statement to be executed will be the one having this value as its label.

4.3.4. *Restriction*

Since labels are inherently local, no go to statement can lead from outside into a block. A go to statement may, however, lead from outside into a compound statement.

4.3.5. *Go to an undefined switch designator*

A go to statement is undefined if the designational expression is a switch designator whose value is undefined.

4.4. *Dummy statements*

4.4.1. *Syntax*

⟨dummy statement⟩ ::= ⟨empty⟩

4.4.2. *Examples*

L:
begin *statements*; *John*: **end**

4.4.3. *Semantics*

A dummy statement executes no operation. It may serve to place a label.

4.5. *Conditional statements*

4.5.1. *Syntax*

⟨if clause⟩ ::= **if** ⟨Boolean expression⟩ **then**
⟨unconditional statement⟩ ::= ⟨basic statement⟩
|⟨compound statement⟩|⟨block⟩
⟨if statement⟩ ::= ⟨if clause⟩⟨unconditional statement⟩
⟨conditional statement⟩ ::= ⟨if statement⟩
|⟨if statement⟩ **else** ⟨statement⟩
|⟨if clause⟩⟨for statement⟩
|⟨label⟩:⟨conditional statement⟩

4.5.2. *Examples*

if $x > 0$ **then** $n := n + 1$
if $v > u$ **then** V: $q := n + m$ **else go to** R
if $s < 0 \vee P \leq Q$ **then**
AA: **begin if** $q < v$ **then** $a := v/s$
else $y := 2 \times a$
end
else if $v > s$ **then** $a := v - q$
else if $v > s - 1$ **then go to** S

4.5.3. *Semantics*

Conditional statements cause certain statements to be executed or skipped depending on the running values of specified Boolean expressions.

4.5.3.1. *If statement*

An if statement is of the form

if B **then** Su

where B is a Boolean expression and Su is an unconditional statement. In execution, B is evaluated; if the result is **true**, Su is executed; if the result is **false**, Su is not executed.

If Su contains a label, and a go to statement leads to the label, then B is not evaluated, and the computation continues with execution of the labelled statement.

4.5.3.2. *Conditional Statement*

Three forms of unlabelled conditional statement exist, namely:

if B **then** Su
if B **then** $Sfor$
if B **then** Su **else** S

where Su is an unconditional statement, $Sfor$ is a for statement and S is a statement.

The meaning of the first form is given in Section 4.5.3.1.

The second form is equivalent to

if B **then begin** $Sfor$ **end**

The third form is equivalent to

begin
if B **then begin** Su; **go to** Γ **end**;
S;
Γ: **end**

(For the use of Γ see Section 2.1 Letters.) If S is conditional, and also of this form, a different label must be used instead of Γ in following the same rule.

4.5.4. *Go to into a conditional statement*

The effect of a go to statement leading into a conditional statement follows directly from the above explanation of the execution of a conditional statement.

4.6. *For statements*

4.6.1. *Syntax*

⟨for list element⟩ ::= ⟨arithmetic expression⟩
|⟨arithmetic expression⟩ **step** ⟨arithmetic expression⟩
until ⟨arithmetic expression⟩
|⟨arithmetic expression⟩ **while** ⟨Boolean expression⟩
⟨for list⟩ ::= ⟨for list element⟩|⟨for list⟩, ⟨for list element⟩
⟨for clause⟩ ::= **for** ⟨variable identifier⟩ := ⟨for list⟩ **do**
⟨for statement⟩ ::= ⟨for clause⟩⟨statement⟩
|⟨label⟩:⟨for statement⟩