Introducing CPL

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Abstract

CPL here stands for a computer programming language conceived and developed by the author since 1993, but published for the first time in 2020. It was born as a Compiled Programming Language, designed together with its compiler and therefore suitable for computationally intensive numerical applications, although some years later an interpreter was also provided for interactive usage. CPL’s distinctive features are Concealed Pointer Lookup, the ability to implicitly dereference pointers based on the type of operands involved, Consistent Procedure Linkage, the enforcement of function prototypes without dedicated header or interface files, and Coactive Parameter Lists, the ability to overload function names which are then distinguished by the type of their parameters and/or parameter separators. Perhaps even more distinctly, CPL’s syntax can be extended on the fly by the program being compiled; library modules tap this feature to seamlessly add real and complex matrix operations, graphics, parallel-computing extensions, and symbolic differentiation. The CPL coding software is available for free download at http://CPLcode.net.

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1 Introduction

“CPL” is a versatile acronym with a multitude of meanings, among which more than one published programming language. Here it will be used to denote a Compiled Programming Language Created by Paolo Luchini since 1993, but published for the first time in 2020, endowed with Concealed Pointer Lookup, Consistent Procedure Linkage and Coactive Parameter Lists. The CPL development software, comprising both a source-to-source compiler and an interpreter, has been privately available to a small number of active scientific researchers (in the author’s principal subject area which happens to be Fluid Dynamics and Turbulence) for almost three decades; their field experience contributed to honing the details, and their enduring predilection for this over more standard programming languages convinced the author to now make CPL publicly available for free download at http://CPLcode.net. The present text constitutes its language definition and reference manual.

The first question everybody will want answered, before actually being enticed to read on, is “Why yet another programming language?” Therefore the exposition will start with the features that distinguish CPL most, and that were at the same time the driving force behind its development. It will end with an alphabetical list of CPL keywords [Keyword index] and a partial list of scientific papers that already used CPL for their numerical programming needs [References].

Another, mostly aesthetic but distinctive, feature of CPL is the availability of all three kinds of round, square and curly brackets for grouping arithmetic (or other) expressions, just as you were taught in school (see §2.2). While this might not be a game-changing feature, from a human-interface viewpoint to alternate brackets so much eases reading and proofreading nested parentheses, and it increases the chances of automatic error catching at the same time. The provided text editor can automatically complete parentheses and alternate bracket types for you.

1.1 Concealed Pointer Lookup

Pointers are the connecting link between high-level and machine language. Pointer operations closely reproduce the address manipulations that the processor and its machine language are so fast at doing, but also the pitfalls and hard-to-chase errors that address manipulation brings along. Thus the challenge for a high-level language is to provide as much as possible of this flexibility and speed while at the same time making as many errors as possible automatically highlighted. The most frequent usage of pointers is in one of three roles: as links in linked structures, as cursors for array traversal, and as subroutine parameters passed by reference. The very first target of CPL at its birth, was to strike a middle ground between the opposite extreme approaches that the then-mainstream FORTRAN 77 and Kernighan&Ritchie C languages had adopted in their pointer handling.
The FORTRAN-77 approach is to drastically hide all evil of pointers. Arrays are only traversed by integer indices, linked structures have to be mimicked through arrays, and all subroutine parameters are implicitly passed by reference, effectively as pointers but without making this apparent in the language.

K&R (but also ANSI) C’s approach is just the opposite: to give pointers the maximum of flexibility but also of visibility with their omnipresent & and * prefix operators, which respectively take the address of a given variable and dereference a pointer to the value it points to.

Both approaches have their weaknesses, one because it requires convoluted (and therefore error prone) constructions in the places where pointers would be appropriate, the other because it forces the programmer to reckon with pointers even where they could be handled automatically, and allows so much flexibility that legal and illegal usages often become hardly distinguishable.

Thus, the first design requirement of CPL was that it should have Concealed Pointer Lookup, the capability to handle pointers where needed, but also to conceal the address-extraction and dereferencing operations where the compiler could automatically infer from the context that they are intended. The required information is, in fact, most of the time already available through type-consistency checking. When a variable is passed as a parameter to a function or an operator, the compiler typically knows whether its value or its address is expected, and can perform the required conversion without an explicit address-taking or dereferencing symbol.

Type consistency is enforced through a chain of implicit type conversions. Allowed conversions are automatically walked through in an attempt to build a consistent expression. If this turns out impossible, a compilation error results. The basic rule is that a type can be implicitly converted to one other type only, and that there cannot be closed type-conversion loops. Just as INTEGERs are implicitly converted to REALs, POINTERs are implicitly converted to the value they point to. Owing to this Concealed Pointer Lookup mechanism, it is rarely necessary to explicitly dereference pointers. (A notable exception is the equals = sign, either in its use to denote an assignment or a comparison, which is so heavily overloaded that dereferencing must be explicitly specified in order to distinguish, e.g., the assignment of an address to a POINTER variable from the assignment of a value to the field it points to. The way to do so will be presented in §5.)

1.2 Consistent Procedure Linkage

FORTRAN-77 had no consistency check across separately compiled files. It was the programmer’s full responsibility to ensure that subroutines are called consistently with their definitions. The C language also enforced, and still enforces, no intrinsic consistency check outside the bounds of a single compilation unit, but its universally adopted programming style requires the use of headers, files of function prototypes that get included in such a way that intra-file checking acquires an inter-file significance. Fortran-90 follows a similar approach with its INTERFACE. Modula-2 made this two-file structure mandatory, by requiring so called DEFINITION and IMPLEMENTATION modules for each program segment.

Consistent procedure linkage is an overly useful feature, as anybody appreciates who has progressed from FORTRAN-77 to a language that has it. It is also a factor in the popularity of interpreted languages, which handle inter-file calls at run time. However, keeping separate
definition and implementation files for every program segment is a bit inconvenient, because essentially the same information has to be written twice (and manually kept consistent across versions). So, why not to have one file achieve both purposes?

CPL achieves Consistent Procedure Linkage with one file per module only. The trick is in the \texttt{USE} statement detailed in §2.5, which seamlessly integrates some project building (\texttt{make}) features in the compiler. \texttt{USE} preventatively looks for a possibly present \texttt{o} object file having the same base name as the \texttt{.cpl} file, and decides based on its modification date. If the object file does not exist or is older, the \texttt{USE} \texttt{d} \texttt{.cpl} file is separately compiled. If a newer \texttt{o} file already exists, no new compilation is started and the \texttt{.cpl} file is read as though it was a header, this meaning that outermost-block declarations are interpreted and assimilated in the dictionary so they become effective for error checking purposes, but all inner blocks, including subroutine bodies, are just skipped over. This scheme still allows one the option to distribute header files that do not reveal the program’s source code, if really wanted, because empty subroutine bodies are acceptable once a suitable object file exists.

1.3 Coactive Parameter Lists

CPL has Coactive Parameter Lists, meaning that the type definition of a function’s parameter list coacts with its name in identifying the function or subroutine. In other words, functions of the same name and different parameter types are allowed and considered distinct by the language, a feature alternately known as function overloading. In addition, not just commas but any non-ambiguous single character or character sequence (except semicolon, spaces or comments, newline and closing brackets) may appear as the separator between actual parameters of a function call. In formal-parameter declarations, non-alphanumeric separators can be specified verbatim, whereas separators that could be mistaken for identifiers are to be enclosed in (either single or double) quotes. In subroutine and function calls the quotes are omitted, and the compiler enforces conforming separators. Whereas commas will still be the commonest choice for short parameter lists, the adoption of remindful separators can make long parameter lists both more understandable and more thoroughly checked by the compiler.

Formal parameter declarations otherwise follow the same syntax as general variable declarations, and are distinguished both by their position within the parenthesis following the subroutine or function name and by separator matching. Optional parameters recognized by name are also available (see §2.7.1). Round, square or curly brackets can be used, just as everywhere else (see §2.2). However an important difference exists between parameters and variables: whereas general variables are by default \texttt{VARIABLE} (see §3.1), i.e. can be assigned a value multiple times, and must be explicitly declared \texttt{CONSTANT} (see §3.2) to become inalterable, formal parameters are by default \texttt{CONSTANT} and only become \texttt{VARIABLE} if explicitly declared so. Parameters can be \texttt{OPTIONAL} (see §2.7.1), and be specified by name rather than by position.

A subroutine returns at the END of the subroutine block or at the EXIT (see §8.7) statement. Within functions a variable named \texttt{RESULT} (see §2.7.6) is implicitly declared with the type of the function’s result, and can be used just as any other local variable of that type within the body of the function; the function returns the value of \texttt{RESULT} at the time of exit.

The declared subroutine is visible from the point of its declaration to the end of the enclosing
block, just as all other declarations. This includes the subroutine body itself, and recursive calls are thus automatically allowed.

A Coactive Parameter List means that function names can be overloaded, that is used multiple times and recognized on the basis of their parameter lists, either through different parameter types or through different parameter separators. This achieves a purpose similar to object programming, in the sense that one function name may semantically express several similar actions, each to be performed on a different object or set of objects. Dynamically typed objects are also cared for (see §3.15). In fact, this feature is ampler than typical object programming because the type of all arguments, not just of the first, is significant.

1.4 Extensible syntax

One design decision that was instrumental to the gradual development of CPL while it was already being used, is the concept of a compiler-interpreter. The design of most compilers passes through a formal description of the language that is compiled by a parser generator like yacc into a C program. At the heart of CPL’s extensibility there is a different structure, where a formal description of the language is never compiled to generate the compiler, but rather interpreted each time a compilation is run. The engine that does this is named fri, the Formal Rule Interpreter. If yacc is a compiler-compiler, fri may be called a compiler-interpreter.

The CPL compiler is internally driven by a set of formal rules written in the FRI declarative language. Such rules are stored in the dictionary of the fri compiler-interpreter during every compilation, and can be dynamically modified by suitable directives. FRI language excerpts may be inserted at any point of a CPL program using the syntax

```
FRI SECTION
some FRI code
END FRI SECTION
```

The FRI SECTION declaration has the effect of dynamically adding new constructions and for all purposes extending the syntax of the language. This is not a general user’s easy feat, as the new rules have to be consistent with already present ones and the FRI language is not covered in the present guide, but this is how the extensions contained in the pre-packaged CPL libraries are implemented. Like everything else in CPL, the new extensions become available from the point where they occur through the end of the enclosing block (which can be the whole program if FRI SECTION appears at the outermost level).

1.5 Libraries

As should by now be clear, since the first instant the primary goal of CPL’s design was extensibility. Many extended features are therefore available as library modules that can be loaded on demand, and such features become seamlessly integrated in the syntax of the language. Among them are

1. Complex numbers
2. Fast Fourier transforms
3. Matrix algebra
4. Parallel computing
5. Plotting (gnuplot interface)
6. Runtime bounds checking
7. Symbolic manipulation
8. Interactive execution

The first few of these are self-explanatory, but run time bounds checking, symbolic manipulation and interactive execution may deserve some words of explanation.

1.5.1 Run time bounds checking

The \texttt{rtchecks.cpl} library does not add any new subroutines or instructions, but modifies already existing ones in such a way as to provide run-time bounds checking. The impact on performance is considerable; therefore \texttt{rtchecks} should only (and always) be used during development and later disabled once the program is deemed to be reliable. In particular:

All array indexing and subarray extraction operations are bounds-checked, pointers are initialized to \texttt{NULL} and \texttt{NULL}-pointer dereferencing is trapped, all error messages are labelled so as to display the position in the source code where the error occurred.

1.5.2 Symbolic manipulation

Symbolic manipulation is the feat of processing an algebraic expression in terms of its symbols, rather than numerical value, the most eminent incarnation being symbolic differentiation; while famous symbolic manipulation programs like MACSYMA or Maple have become part of the history of computing, this is not an idea that is usually associated with compilers. Nevertheless, one of the interesting usages of symbolic manipulation is to generate code that is subsequently fed to a compiler, a technique known as Automatic Differentiation (AD). A compiler-interpreter, like the CPL compiler is, can make automatic differentiation happen at compile time. The key idea is to differentiate program expressions on the spot before submitting them to actual compilation. The \texttt{symbolic.cpl} library achieves this feat by suitably extending the concept of an alias, or deferred assignment (§5.3), that is a symbol representing a formula that is not to be evaluated at the position in the program where its definition appears but at the later position where its value is used. After such an alias is defined, it comes natural to apply symbolic operations to it, which are what \texttt{symbolic.cpl} enables; such operations generate another alias as their result, without producing any immediate code; the new aliases, after possibly being subjected to more symbolic operations, will then be compiled into executable code at the position where each of them is eventually evaluated.
1.5.3 Interactive execution

Interactive execution is what an interpreter rather than a compiler provides. Being fri a compiler-interpreter it actually provides both, and the icpl library (constructed in such a way that, under a unix system, the standalone icpl command launches fri with the library in it) adds such a capability and the few language extensions necessary to make it comfortable. It achieves this purpose through a pipeline of FRI rules that in real time feeds every instruction typed on the command line to the already existing CPL-to-C compiler, then the result to a C-to-bytecode compiler, and the bytecode to an arithmetic interpreter built-in to the fri code. The interpreter has access to system-provided dynamic loading features, and through those it gains the capability to call up compiled programs, and individually access every subroutine and global variable defined in them. For the user this implies that an interpreted session can transparently USE (§2.5) or #include (§2.8) compiled library modules, or even external C or FORTRAN functions, just as easily as a compiled program can.

2 Program structure

The general structure of a CPL program is composed of nested blocks of statements which take effect in a hierarchical top-down order, much like in Pascal or Modula-2. Statements are composed of keywords, identifiers and separators.

User-declared identifiers can contain alphabetic and numeric characters plus _ and can be of any length. Upper and lower case are considered distinct. The first character of an identifier must be non-numeric.

Separators can be spaces, tabs or comments (see §2.1) in any number and sequence; at least one separator is required between contiguous words that could otherwise be mistaken for a single identifier. Indenting is advised, to highlight statement blocks, but not required. The included text editor provides auto-indenting.

Statements within a block are delimited by either newline or ;, in any number and sequence with separators, which allows for multi-statement lines without requiring (but permitting) a ; when the statement ends at the end of a line. Multi-line statements can be broken after any keyword that necessitates of a further operand (e.g., a ,): if the given line does not make sense as is, the compiler will automatically treat newline as a space and try to complete the statement on the next line. Line continuation can also be explicitly requested wherever a space is allowed by putting a \ as the last character before newline.

Round, square and curly brackets can be used interchangeably wherever a parenthesis is needed, in either expressions, array arguments or function arguments (see §2.2), but must be closed by a bracket of matching kind.

SUBROUTINE and FUNCTION declarations (see §2.7) are on the same footing as VARIABLE, CONSTANT and TYPE declarations. Contrary to some other languages, declarations and executable statements may be freely intermixed in the program flow. The scope of a declaration extends from the position where the declaration appears down to the end of the containing block. It is recommended that declarations appear as close as possible to the position
where the declared item is used for the first time, as this enables the compiler to catch a larger number of errors automatically. In most situations, a variable can be declared and initialized in a single statement.

Loops and all other flow control statements (see §8) implicitly define new blocks within them, just as subroutine declarations do. A block can also be explicitly delimited as a `MODULE` (see §2.6). A block can contain every declaration that the outermost block can, including further subroutines\(^1\) and modules; the declared items cease to exist on exit from the block.

2.1 Comments

Comments delimited by a `!` without a following bracket extend to the end of line.

Comments delimited by `!(. . .)!` or `!(. . .)!` or `!{. . .}!` pairs can be inserted wherever a space can, and can extend over a few characters or over several lines. The compiler will match `!bracket!` pairs within comments, and consider the comment finished only when all opened such parentheses have been closed.

2.2 Parentheses

Round, square and curly brackets can all be used interchangeably wherever a parenthesis is needed, but the compiler requires that every opening bracket be closed by a matching bracket of the same kind, just as in mathematics. Alternating the three kinds of bracket, while not mandatory, makes for easier reading by the programmer and more effective error catching by the compiler. The included text editor automatically alternates brackets if requested.

When round brackets are used in statement prototypes in this manual, it is always understood that the other two styles may be used as well. In such prototypes square brackets denote optional clauses, straight-up type fixed keywords, and slanted type variable fields or example identifiers that must not be written verbatim but suitably filled in.

2.3 Macro definition and conditional compilation

C-preprocessor-like `#define` and `#if` constructs are available in a CPL program to define macros and alter the flow of compilation. The `#include` directive is reserved for the inclusion of external C code (see §2.8). For the inclusion of CPL files, the `USE` (see §2.5) and `INCLUDE` (see §2.5.1) statements are available.

2.4 Source file

A CPL program file directly consists of a sequential block of declarations and statements, some of which may in turn contain other blocks, without an explicit mark of the beginning and end of the complete program other than by the beginning and end of the file itself.

\(^1\) Nested subroutines and functions, however, appear as such in the generated C code, a feature that `gcc` can handle but is not in ANSI C.
2.5 USE

Auxiliary source files can be used, and separately compiled if they were not already, through the statement

\[ \text{USE} \ filename \]

The .cpl suffix is automatically appended if \textit{filename} contains no dot. codfilename can be relative or absolute as per unix convention. In addition, the directory where the USE'd file resides becomes the Present Working Directory for the purpose of other file references nested inside it.

The USE'd file is logically treated as if it were inserted in the program sequence in place of the USE statement, i.e. just as if INCLUDE (see below) were in its place. However, in reality the file is either compiled into a separate object file or, if a more recent object file of the same name already exists, not compiled at all. In the latter case the CPL compiler reads the outermost block only from the USE'd source file and skips the inner-block contents altogether, generating the same effect as a Modula-2 DEFINITION MODULE or a C header file.

Notice that the USE statement does not define its own separate program block: declarations appearing at the outermost level in the USE'd file are global and stay in effect after the file is closed. The MODULE (§2.6) keyword is available to provide locality if desired.

In case actual headers must be generated in order to save space (or to distribute a library without source code) it is possible to USE a source file with empty subroutine bodies, since the compiler will not read the subroutine bodies anyway, provided the object file carries a more recent modification time (for instance, because it was compiled from a separate file, or just touched — by the unix touch command — afterwards.) If empty bodies are provided without adjusting timestamps, subroutines will be recompiled empty with obviously unwanted results.

In an interpreted program (to be processed by icpl) just as well, USE loads a separately compiled module, whose subroutines can then be executed at compiled-code speed, and executes its main body, if any, immediately.

2.5.1 File inclusion

Files included with

\[ \text{INCLUDE} \ filename\{(\text{name}=\text{value} [,\text{name}=\text{value}]\} \]

are inserted in place of the INCLUDE statement during compilation, and are not separately compiled (as in USE, see §2.5). Nonetheless, the directory of the INCLUDE'd file becomes the present working directory for other references nested inside it.

If the optional arguments are present, name becomes an alias for value within the scope of the INCLUDE'd file.

2.6 MODULE

A block of code can be explicitly delimited as
This construction limits the visibility of variables declared inside the `MODULE` to within the module itself, and is the basis for information hiding. It replaces, and should be preferred to, subroutines that are called once only. An important difference is that variables declared in an outermost-scope `MODULE` are static and retain their value across subroutine calls, even if they can only be accessed by statements and subroutines that exist inside the `MODULE` itself. Notice also that source files recalled with either `USE` (see §2.5) or `INCLUDE` (see §2.5.1) are not separately scoped unless they are enclosed in a `MODULE`. Control may be transferred to the end of a named `MODULE`, just as to the end of a `SUBROUTINE`, by the `EXIT name` (see §8.7) statement.

In order to be visible outside, a function declared inside a module must also be declared before the `MODULE` with the keyword `FOLLOWS` (see §2.7.4). Externally visible variables or constants can be simply declared before a `MODULE` is entered, and assigned a value inside it when required.

### 2.7 FUNCTION and SUBROUTINE

Functions and subroutines have a long and a short declaration form. In long form, a subroutine declaration reads

```fortran
SUBROUTINE name(parameter declarations)
  some code
END name
```

Correspondingly a function, i.e. a subroutine that returns a value and may appear inside an expression, is declared as

```fortran
type FUNCTION name(parameter declarations)
  some code
END name
```

In short form, a function whose body is composed of a single expression may also be declared as

```fortran
type FUNCTION name(parameter declarations) = expression
```

A short syntax is also available for subroutines

```fortran
SUBROUTINE name(parameter declarations) = single-line block
```

where `single-line block` is a sequence of statements separated by semicolons and terminating at the first newline.
Parameters in the parameter list are by default separated by commas, but separators can also be customized (see §1.3). In a `SUBROUTINE` call (but not in its declaration), brackets around the parameter list are optional and may be omitted.

The declared subroutine is visible from the point of its declaration to the end of the enclosing block, just as all other declarations. This includes the subroutine body itself, and recursive calls are thus automatically allowed.

A third alternative syntax, similar to the one used for variables of FUNCTION type (see §3.16) has the result type denoted by the symbol "->" following the parameter declaration:

```
FUNCTION name( parameter declarations )->type
  some code
END name
```

When this syntax is used, the result type may be, or contain, an ARRAY type with dimensions depending on the formal parameters themselves (see §2.7.2). Any formal parameter as well may depend on the formal parameters that precede it. For example:

```
FUNCTION massagearray[ARRAY(*) OF REAL v]->ARRAY(v.LO..v.HI) OF REAL
```

## 2.7.1 Optional parameters

The parameter list of a function or subroutine can include optional items. In the function declaration, optional parameters must appear after all ordinary positional parameters (if there are any), separated by the keyword `OPTIONAL`. Each optional parameter must be assigned a default value in its declaration. Example:

```
SUBROUTINE test(INTEGER x; OPTIONAL INTEGER y=0,z=3; REAL w=3.14)
```

Within the body of the function, optional parameters obey the same rules as local constants or variables (if qualified `VARIABLE`), just like ordinary parameters; on entry they acquire the value of the corresponding actual parameter if one is specified in the calling statement, or their default value otherwise.

In the calling statement, optional parameters follow all standard positional parameters and can appear in any order (or not appear at all); they are identified by name rather than by position. In the above example:

```
test(3,w=1E2,y=1)
```

is a possible calling statement. Optional parameters cannot coact to disambiguate overloaded function names (see §1.3).

## 2.7.2 Passing array parameters and their dimensions

Functions that accept array parameters of variable dimensions are a commodity that is handled differently in different languages, especially when error checking is desired. In CPL they are handled as follows.
The special dimension \(*\) can be used to declare a \texttt{POINTER} TO \texttt{ARRAY} that implicitly passes the bounds of the \texttt{ARRAY} together with its address (see §3.8). This is the most compact notation, as in \texttt{e.g.,}

\[
\text{REAL FUNCTION NORM[ARRAY(*)} \text{ OF REAL v]} = \text{SUM v(i) }^2 \text{ FOR ALL i}
\]

(same as the builtin \texttt{NORM} function, see §4.9.8). When this notation is used, the index bounds of the actual parameter are accessible in the function’s body by the \texttt{LO} (see §3.8.2) and \texttt{HI} (see §3.8.1) builtins (in the above example, these would be \texttt{v.LO} and \texttt{v.HI}), and its number of elements by the \texttt{LENGTH} (see §3.8.3) function, just as for all \texttt{ARRAY}s.

A formal parameter of type \texttt{ARRAY(*)} also accepts a variable of its base type as its actual parameter, and transforms it into an \texttt{ARRAY} with dimension \texttt{(0..0)}.

For more elaborate needs, for instance when two arrays must be enforced to have equal dimensions, CPL allows previous formal parameters to be used in the declaration of subsequent compound parameters. An example would be

\[
\text{SUBROUTINE dosomething[INTEGER n; ARRAY(1..n)} \text{ OF REAL a, b, c]}
\]

Within the body of such a subroutine or function, \(a, b\) and \(c\) are all assumed to have the same dimensions \(1..n\); this is similar to the convention adopted in languages (like C) that treat arrays like pointers with no special provision, but with the difference that in CPL the call of such a subroutine checks that the actual parameters indeed have the specified dimensions at run time, and throws an error if they don’t and \texttt{rtchecks} is on. The same construction is available if the dimension is not simply the \(n\) parameter but an expression involving \(n\), or if the dimension is extracted from the bounds of a previous array as in

\[
\text{SUBROUTINE dosomething[ARRAY(*)} \text{ OF REAL a; ARRAY(a.LO..a.HI)} \text{ OF REAL b, c]}
\]

Additionally, the return type of a \texttt{FUNCTION} can as well be an \texttt{ARRAY} involving a formal parameter in its dimensions. An example is:

\[
\text{FUNCTION dosomething[ARRAY(*)} \text{ OF REAL a, b] } \rightarrow \text{ARRAY(a.LO..b.HI)} \text{ OF REAL b, c]}
\]

After this declaration the dimensions of the return type are known to the compiler, and can either be checked by \texttt{rtchecks} or used to allocate a suitable \texttt{ARRAY CONSTANT}.

### 2.7.3 Nested functions

Functions and subroutines exist on a par with variable declarations (see §3), and can appear anywhere in a block, another function included. Nested functions are therefore an integral part of CPL. Like all other block contexts, they have access to variables (and functions) declared before
them, in the same or in an enclosing block. The present implementation of nested functions relies on nested functions in the generated C code, and is therefore only compatible with C compilers that handle nested functions as a nonstandard feature (gcc is one of them).

2.7.4 Function prototypes

In case a subroutine or function must be called before its body occurs, the construction

```
SUBROUTINE name(parameter declarations) FOLLOW
```

(or its equivalent for functions) can be used to pre-declare its calling syntax. This prototype declaration is always available, but only really needed for mutually referencing subroutines (as in Pascal or C) or for subroutines whose body is nested in a subsequent `MODULE` (see §2.6).

2.7.5 EXIT

Both `SUBROUTINE` and `FUNCTION` return to the calling procedure either at the `END name` (which also concludes the subroutine’s body) or `EXIT name` statement (which may appear in its interior).

2.7.6 RESULT

Within a function’s body, a variable named `RESULT` is implicitly declared with the type of the function’s result, and can be used just like any other local variable of that type within the body of the function; the function returns the value of the `RESULT` variable at the time of exit. All primitive and compound types are allowed for the result of a function. The statement

```
RETURN value
```

is a shorthand for

```
RESULT=value; EXIT name.
```

The `SUBROUTINE` and `FUNCTION` keywords are also used to declare variables that may be used to call such procedures indirectly (see §3.16).

2.7.7 INLINE functions and subroutines

The keyword `INLINE` prefixed to a `SUBROUTINE` or `FUNCTION` declaration (in either long or short form) generates a compile-time macro that is inserted in place of each call to the subroutine.

2.8 C interface

The directive

```
#include "file"
```

or
in addition to being copied verbatim into the generated C code, activates a CPL interface mechanism. `<file>` is expected to contain a C header or program, which is scanned for declarations by the CPL compiler. The declarations and prototypes contained in the C file thus become transparently available to (and enforced by) the including CPL program.

An include directory path (similar to the `-I` C compiler directive) can be specified with

```c
#include "path"
```

The name of the corresponding object file or other linking options can be transmitted to the linker with

```c
#link "linking options"
```

The following standard libc headers
- `stdlib.h`
- `stdio.h`
- `fcntl.h`
- `math.h`
- `limits.h`
- `string.h`
- `setjmp.h`
- `errno.h`
- `signal.h`

are pre-included in all CPL programs and need not (but may) be included again.

### 2.8.1 C SECTION

A C code excerpt may also appear directly in the middle of the CPL source file if encapsulated in a `C SECTION` as follows:

```c
C SECTION
    some C code
END C SECTION
```

This has the same effect as recalling with `#include` a file that contains `some C code`. That is, the identifiers and function prototypes declared inside the `C SECTION` become transparently available to the CPL program. `some C code` ends up in one and the same file with the C translation of the enclosing CPL code.

As an alternative, C code may also be inserted between `<*` and `*>` delimiters, as in

```c
<* some C code >*
```

In this usage, anything that appears between `<*` and `*` is copied verbatim in the generated C file without any intervention or symbol extraction by the CPL compiler. It is up to the programmer to ensure that the resulting code makes sense. In fact, this construction was mostly introduced as a hack to be used when CPL was still incomplete; its use is now discouraged.
2.9 FORTRAN interface

An interface to separately compiled FORTRAN subroutines is provided by the statements

\[
\text{FORTRANCALL } \text{subrname}(\text{parameters})
\]

and

\[
\text{type FORTRANFUNCTION } \text{functionname}(\text{parameters})
\]

These have the following effects: \text{subrname} or \text{functionname} is copied into the generated C source with an appended underscore; all arguments are passed by reference, according to FORTRAN convention; any arrays are replaced by a reference to their first element.

The user must take care of the fact that FORTRAN allocates memory for multidimensional arrays with indices in the reverse order with respect to both C and CPL. Arrays to be passed as such arguments should be declared and used accordingly.

For (e.g. lapack) library calls that require the number of elements used in actual memory storage for the rows of a matrix as an argument, the pseudofunction

\[
\text{STRIDEOF}(\text{array})
\]

provides the argument to be passed.

Please be aware that argument type checking is suppressed during a \text{FORTRANCALL} (as the necessary information is not available). Type checking can be restored, however, by wrapping every \text{FORTRANCALL} in a suitable \text{INLINE SUBROUTINE} (see §2.7.7).

The name of the object file providing the FORTRAN compiled subroutines must be transmitted to the linker, just as in §2.8, through the directive

\[
\text{#link "linking options"}
\]

together with any other linking options required (e.g., -lgfortran to provide the FORTRAN run time library, if \text{g77} was used as the FORTRAN compiler).

3 Variables, constants and types

Variables, constants and types are denoted by identifiers introduced through the relevant declarations as follows. Identifiers cannot be duplicated as long as a previous declaration is in effect (in either the same or an enclosing block). An identifier which was not previously declared in the same or an enclosing block and does not coincide with a CPL keyword (as listed in the Keyword index) is denoted as \text{newid} below.

A general declaration for a variable or a constant has the form:

\[
[\text{constorvar}] \text{typle declarator var declaration} [\text{, var declaration}]
\]

where \text{var declaration} denotes

\[
\text{newid}[\text{postfix modifier}][= \text{value}]
\]

and \text{constorvar} may be either \text{CONSTANT} or \text{VARIABLE} or blank.

CPL is a type-checking language and requires that every \text{VARIABLE} be declared before it is used. It can be initialized at the same time by the optional \text{= value} field.
3.1 VARIABLE

The keyword `VARIABLE`, put either before or after the `typedeclarator` in a declaration, specifies that the declared item is a regular variable and can be modified multiple times. This is, in fact, the default and the word `VARIABLE` is optional in ordinary declarations.

However, subroutine formal parameters are by default `CONSTANT`, with the actual parameters as values, and must be explicitly declared `VARIABLE` if they are to be reassigned within the subroutine’s body (thus becoming different from the value of their actual parameter which stays unchanged).

Notice that the value assigned to a `VARIABLE` parameter is lost after the subroutine returns. In order to change the value of variables which exist outside the subroutine, the corresponding formal parameter must be declared a `POINTER`. Indeed `VARIABLE` behaviour of a formal parameter is seldom needed, and making `CONSTANT` the default improves error catching.

When a `VARIABLE` identifier is used inside an expression, it initially stands for the variable’s address in memory, and thus can be used wherever a `POINTER` is expected; the same identifier gets automatically converted to the variable’s value where needed through Concealed Pointer Lookup (see §1.1).

3.2 CONSTANT

The keyword `CONSTANT`, put either before or after the `typedeclarator` in a declaration, specifies that the declared item (usually assigned a value in the same statement) cannot be modified later. Thus a `CONSTANT` is not the same thing as a “compile-time constant”, that is an expression whose value can be known at compile time, but more generally a value which is prohibited from appearing on the left side of an assignment or having its address assigned to a `POINTER`.

The value of the `CONSTANT` is usually specified in the declaration itself but occasionally this specification may be deferred. When this happens the constant declaration takes the role of a constant prototype, and may be optionally followed by the keyword `FOLLOWS`. (For instance, a constant may be declared outside a `MODULE`, but its value only be known inside the module itself; or the value may be `READ` as input.) If the `CONSTANT` is not initialized in the declaration itself, it is enforced to only be assigned once in the course of its block.

As a shortcut, a statement of the form

```
newid = value
```

implicitly declares a `CONSTANT` whose type and value are the type and value of the r.h.s. (see, however, §1.1 if the address of the r.h.s. is desired instead).

If the r.h.s. of a `CONSTANT` declaration is known at compile time (what is denoted as a compile-time constant), the new identifier becomes just an alias for it and no storage is assigned.

An alias for any expression, even one which does not represent a compile-time constant, can always be defined through the statement

```
newid == expression
```

See §5.3.
3.3 TYPE

A new type identifier can be declared as

\[ \text{[TYPE]} \; \text{newid} = \text{typedeclarator} \]

and be used in subsequent declarations in the place of the \textit{r.h.s.} The \textit{TYPE} keyword is optional, since the presence of a type declarator on the \textit{r.h.s.} already distinguishes this declaration from an assignment.

3.3.1 TYPEOF

The type of an already declared variable or expression can be recovered through the pseudo-function

\[ \text{TYPEOF(} \text{variable} \text{)} \]

which can appear wherever a type declarator can (\textit{e.g.,} it can be assigned to a new type identifier or directly used to declare further variables, or in the construction of a compound type). When applied to a \textit{POINTER} or \textit{STORED} (see §7.5) type, this function returns the underlying base type.

In order to test whether a variable is of a given type the \textit{IS} comparison operator is available (see §3.15.1).

3.3.2 SIZEOF

The memory size in bytes of a type or variable (useful when using the C interface of §2.8 or also to estimate the memory requirements of the program) can be obtained from the pseudo-function

\[ \text{SIZEOF(} \text{type or variable} \text{)} \]

3.3.3 Postfix type modifier

A postfix \[\text{ˆ}\] denotes either pointer dereferencing (see §1.1) or a short form of the \textit{POINTER} declaration. For instance

\text{INTEGER a\textasciitilde \textasciitilde b}

is a shorthand for

\text{POINTER TO INTEGER a; INTEGER b}

A postfix form of the \textit{ARRAY} declaration

\text{ARRAY(1..10) OF REAL a, b, c}

is

\text{REAL a(1..10), b(1..10), c(1..10)}
When both a postfix modifier and a prefix type declarator are simultaneously present in a declaration, they represent the compound type that is obtained by prepending the effect of the postfix modifier to the explicit type declarator. For example

```
STRUCTURE(INTEGER x,y) Aˆ(10)
```

is equivalent to

```
POINTER TO ARRAY(10) OF STRUCTURE(INTEGER x,y) A
```

### 3.3.4 Type identity

When are two VARIABLES of the same TYPE? Pascal-like strongly typed languages only consider variables of the same type when they are declared by the same typename or they appear in one and the same compound declaration. In other words, repeated compound declarations are not considered to be of the same type even when they are equal, just as two different type-names with similar definitions are not considered equal. C, on the other hand, handles typenames as bare aliases, and compares their definitions directly. None of these languages has runtime-dimensioned arrays. CPL takes the C approach when possible, and equates a given typename to its definition, but considers two explicitly given typenames different even when they have equal definitions. Generally, it is good practice to declare variables that must be of the same type in a single declaration, or through a single typename, or through the `TYPEOF` pseudo-function (see §3.3.1). This is particularly true with runtime-dimensioned arrays (ARRAYs whose bounds are specified by a VARIABLE and only known at run time). In fact, since a VARIABLE may take on different values in different parts of the program, multiple declarations of this type are necessarily handled as being different.

In order to test whether a variable is of a given type the `IS` comparison operator is available (see §3.15.1).

### 3.4 Implicit declarations

The declaration of a CONSTANT or TYPE may be implicit:

```
newid = value
```

declares a new CONSTANT, whose value cannot be modified later in the program and whose type is the type of the r.h.s.

```
newid = typedeclarator
```

declares a new TYPE identifier to denote the (possibly compound) type on the r.h.s.

A `newid` used as the running index of a FOR (see §8.3) loop is implicitly declared a CONSTANT for the scope of the loop block.
3.4.1 FOLLOWS

A declaration of the form

```
CONSTANT newid FOLLOWS
```

defines a `CONSTANT` whose value is hidden (typically, inside a subsequent `MODULE`) or to be read (once only) from a file.

3.5 Primitive types

Types can be primitive or compound. Compound types are specified through a `compound-type expression`, assigned to a type identifier or directly used as the type declarator (common to all variables) in a declaration list, or through a `postfix modifier` attached to each individual variable to which it is meant to apply.

Primitive types are:

3.5.1 BOOLEAN

Primitive type declarator for boolean logical variables, translated into C type `int`.

`BOOLEAN` values are denoted as `YES` or `TRUE` and `NO` or `FALSE`, and written as “Y” and “N” by `WRITE` instructions. On `READ`ing, any complete word starting with “T”, “Y”, “t” or “y” is read as `YES`, any word starting with “F”, “N”, “f”, “n” as `NO`.

See also §4.3, §4.4, §4.9.12.

3.5.2 CHAR

Primitive type declarator for character variables, translated into C type `char`.

Where needed, a single-character `STRING` literal is implicitly converted to a `CHAR` constant, which is in turn implicitly converted to its `INTEGER` ascii code. `INTEGER` to `CHAR` conversion must be explicit (see §4.9.13).

3.5.3 INTEGER

Primitive type declarator for integer variables, translated into C type `int`.

Can be implicitly converted to a `REAL`. `REAL` to `INTEGER` conversion must be explicit (see §4.9.13).

3.5.4 REAL

Primitive type declarator for real variables, translated into C type `double`. 
3.5.5 SINGLE

Primitive type declarator for single-precision real variables, translated into C type float.

Can be implicitly converted to a REAL. REAL to SINGLE conversion must be explicit (see §4.9.13).

3.6 Enumerated type ENUM

Not really a compound type, ENUM variables (much like C enum or Modula2 enumerations) take a limited set of explicitly enumerated values. The syntax of this type declaration is

\[
\text{ENUM}(\text{id}1, \text{id}2, \ldots)
\]

and can directly declare variables or be assigned to a new type name like all other TYPEs. \text{id}1, \text{id}2, etc. are thereby declared as constants to which variables of the given type can be set or compared. The purpose of ENUM variables is to flag a limited set of alternatives, while forbidding out-of-range values which could arise if INTEGERs were used for this purpose. No other operations than assignment and comparison for equal are defined on ENUMs.

3.7 STRUCTURE

The type declarator for structures is

\[
\text{STRUCTURE(field declarations)}
\]

Field declarations follow exactly the same syntax as general variable declarations. For instance, to declare a structure containing one integer field named \text{i} and two real fields named \text{x} and \text{y}, one would write:

\[
\text{STRUCTURE(INTEGER i; REAL x,y)}
\]

Structure elements are equally selected by either the traditional dot notation

\[\text{structure.field}\]

or the, less usual but equivalent, selector-function notation

\[\text{field(structure)}\]

Symmetrically any function of one or more arguments can be called either as

\[\text{function(firstargument[,morearguments]}\]

or as

\[\text{firstargument.function[(morearguments)]}\]

(a notation apt to appeal to those who are accustomed to object-oriented languages).

A structure declaration may also contain one or more anonymous fields. If a type declarator appears alone, without any following variable declaration, an anonymous field is declared, to which the given structure can be implicitly converted. For instance, after the declaration:
TYPE t1=STRUCTURE(REAL a,b)
STRUCTURE(t1; INTEGER n) var

the structure var includes a field of type t1 of which var.a denotes the a field.

Anonymous structure fields are CPL’s way of defining objects that inherit the structure of
other more general objects and add their own specific fields. When these objects are accessed as
arguments to functions or subroutines, the appropriate function among those with the same name
and different arguments is automatically selected. See also §1.3 and §3.15.

### 3.7.1 Implicit access to structure fields and functions

Like in Pascal or Modula2, a field of a structure may be implicitly selected by the field’s name
alone when the structure’s name has been specified in a WITH statement. WITH has both a
multi-line form:

```cpl
WITH some structure [,some other structure] [:]
  code block
[END WITH]
```

and a single-line form:

```cpl
WITH some structure [,some other structure] : single-line block
```

The multi-line form is recognized from a newline following the structure list or the optional
colon; in this case the scope of the statement extends either to the optional END WITH statement
or to the end of the enclosing block; in the second to the end of line. Within the scope of a WITH
statement the given structure (or structures) is implied wherever a field name alone appears. For
instance, after the declaration

```cpl
STRUCTURE(REAL x,y) v1,v2
```

writing

```cpl
WITH v1: x=v2.y; y=3
```

becomes equivalent to \( v1.x=v2.y; v1.y=3 \), or to \( x(v1)=y(v2); y(v1)=3 \).

Standing the symmetry of treatment of structure fields and functions by CPL (see §3.7), a
function argument may also be specified in a WITH clause. Thus, for instance,

```cpl
WITH 3: WRITE SIN
```

is equivalent to WRITE SIN(3). Of course this notation is not very useful for REAL functions,
but it becomes handy when functions are defined for the purpose of accessing user-defined
compound types as though they were structures.

### 3.7.2 Variable size STRUCTURE

STRUCTUREs may be defined that contain ARRAYs the size of which will only be known at run
time. Such STRUCTURE TYPEs are declared with one or more INTEGER CONSTANTs among
their fields. When a variable of the given type is allocated, either by using the name assigned
to its TYPE in a declaration (see §3) or in a NEW (see §6) statement, the values following the type name in parentheses (like arguments of a function) are assigned to these CONSTANTs by order, and are simultaneously used to allocate a chunk of memory of the appropriate size. Being CONSTANTs, these fields cannot be altered in the subsequent life of the allocated STRUCTURE.

Example:

```
TYPE twoarrays=STRUCTURE[REAL x; INTEGER CONSTANT n
POINTER TO twoarrays next
ARRAY(1..n) OF INTEGER k; ARRAY(-n..2*n) OF REAL data]
...
twoarrays(8) mytwoarrays
mytwoarrays.next=NEW twoarrays(2*mytwoarrays.n)
```

Notice that this syntax is intentionally similar to the syntax for FUNCTIONs that contain ARRAYs of runtime-specified size as arguments. Compare §2.7.2. In fact, the set of parameters of a given function may usefully be thought of as a structure, although one that is invisible to the programmer and only exists as a conceptual model.

### 3.8 ARRAY

The prefix type declarator for arrays is

```
ARRAY(dimension[,dimension]) OF type
```

The postfix declarator is just 

```
(dimension[,dimension]).
```

Each dimension is specified either as `lower bound..upper bound` or as `upper bound` only, in which case the lower bound is taken to be unity. Specifying multiple dimensions, like in

```
ARRAY(dimension1,dimension2) OF type
```

is a shorthand for

```
ARRAY(dimension1) OF ARRAY(dimension2) OF type
```

Therefore the order in which the elements of the array are stored in memory is similar to C and Pascal and different from FORTRAN.

Variable dimensions are allowed wherever (compile-time) constant dimensions are; the compiler automatically decides for static or dynamic allocation of memory space as needed. Arrays can contain elements of any primitive or compound type and can in turn appear as fields in structures or be pointed to by pointers.

The special dimension `*` can only appear in the declaration of an ARRAY formal parameter (see §2.7.2) or of a POINTER TO ARRAY, and declares a special type of pointer that stores the current dimensions of the array together with its address. A formal parameter or pointer of this type can be dynamically assigned arrays of different length and still provide runtime range checking and **FOR ALL** (see §8.3.2) looping. The current upper and lower bounds of an array can always be recovered through the **HI** and **LO** functions, and the total number of elements through the **LENGTH** function (see below). In the case of multidimensional arrays, these functions apply to the first index only; subarray selection (see §3.9) can be used in order to
extract the bounds of other indices. As a shortcut, \( \text{LO1, LO2, LO3 and HI1, HI2, HI3} \) can be used to refer to the first three indices.

\[
\text{REAL arr(1..8,2..9)}
\]
\[
\text{WRITE arr(4,5)}
\]

However, all three kinds of bracket are allowed, as everywhere in CPL (see §2.2). It should be noted that the above declaration is a shorthand for

\[
\text{ARRAY(1..8) OF ARRAY(2..9) OF REAL arr}
\]

Therefore, a notation such as \( \text{arr(4)} \) is allowed, and has type \( \text{ARRAY(2..9) OF REAL} \). This is a particular case of a subarray (see §3.9). By the same token, the second line might also have been written as

\[
\text{WRITE arr(4)(5)}
\]

The following special functions are defined on \( \text{ARRAY} \)s:

### 3.8.1 \( \text{HI} \)

The function \( \text{HI} \) applied to an \( \text{ARRAY} \) argument returns the upper bound of its first index. \( \text{HI1} \) is a synonym for \( \text{HI} \); \( \text{HI2} \) and \( \text{HI3} \) return the upper bound of the second and third index respectively. Further indices can be accessed by subarray selection (see §3.9).

The argument of \( \text{HI} \) is implicit (i.e., \( \text{HI} \) may be written without any argument as if a \text{WITH} — see §3.7.1 — were in action) when \( \text{HI} \) is used inside the index itself as in \( \text{arr(HI-3)} \) or in the specification of a \text{FOR} (see §8.3) loop.

### 3.8.2 \( \text{LO} \)

The function \( \text{LO} \) applied to an \( \text{ARRAY} \) argument returns the lower bound of its first index. \( \text{LO1} \) is a synonym for \( \text{LO} \); \( \text{LO2} \) and \( \text{LO3} \) return the lower bound of the second and third index respectively. Further indices can be accessed by subarray selection (see §3.9).

The argument of \( \text{LO} \) is implicit (i.e., \( \text{LO} \) may be written without any argument as if a \text{WITH} — see §3.7.1 — were in action) when \( \text{LO} \) is used inside the index itself as in \( \text{arr(LO+2)} \) or in the specification of a \text{FOR} (see §8.3) loop.

### 3.8.3 \( \text{LENGTH} \)

The function \( \text{LENGTH} \) applied to an \( \text{ARRAY} \) argument returns its number of elements. \( \text{LENGTH} \) is equivalent to \( \text{HI-LO+1} \). In a multidimensional \( \text{ARRAY} \), the range of the first index only is returned.
3.8.4 STRING

Type declaration STRING is a synonym for ARRAY(*) OF CHAR, and can be used wherever the last can. In particular, a STRING can be subscripted or a subarray extracted from it, and its bounds and length are available through functions LO, HI, and LENGTH. STRING valued constants (which are always indexed starting from 0) can be generated either at compile time, as quoted strings of characters (see below), or dynamically through string concatenation (see §4.7), and can either be given a name through an implicit declaration (see §3.4) or passed as actual parameters to function calls and further string concatenations.

Quoted strings of characters, also known as literals, are delimited by either double " or single ’ quotes, in matching pairs. A single quote may appear inside a literal delimited by double quotes and vice versa. In addition, C escape sequences are literals, but contrary to C must be unquoted. The empty string "" is also a valid (zero-character-long) STRING value.

Finally, in unix-shell-like syntax, multi-line literals may be introduced by <<delimiter and ended by delimiter alone on a new line, where delimiter can be any character sequence that is not to be part of the literal itself. This is useful in programs that output multiline constant strings, for instance web servers. Within such multiline strings, the sequence delimiter variable delimiter (using the same delimiter defined for the whole string, but without any intervening newline) represents a variable that will be treated as though it appeared in a WRITE statement (see also §4.7).

Where appropriate, a single-character literal is implicitly converted to a CHAR constant, which is in turn implicitly converted to an INTEGER ascii code. Strings may also be concatenated among themselves and with variables (see §4.7).

Standard C functions returning a char* result are also interpreted as generating a STRING value. Just as for all C interface (see §2.8) calls, it is the programmer’s responsibility to free any possibly malloc-ed space where appropriate for such functions.

As an experimental feature, and an exception to the general rule for ARRAY(*), STRING variables may also be declared and assigned a value.

3.9 Subarray selection

A portion of an array can be selected by specifying new dimensions. For example, if a variable arr is declared as REAL arr(1..10), the notation

\[ \text{arr}(2..5) \]

denotes an array formed by the elements from 2 to 5 of array arr (which must lie in the range of declared dimensions). The whole range can also be selected, by specifying * as the subrange. As a more involved example, if the declaration is

\[ \text{REAL arr}(1..7,-2..2,3..8) \]

then

\[ \text{arr}(2..5,*,6) \]
denotes a two-dimensional array formed by selecting the range 2..5 of the first index and the whole range of the second index of array \( \textit{arr} \), with the third index set equal to 6.

The most general form of subarray selection can also specify an offset and one or more strides. The notation for this is:

\[
\text{arr}(a + b_1 \cdot (\text{newdim}) + b_2 \cdot (\text{newdim}) \ldots)
\]

where \( a, b_1, b_2 \ldots \) are \texttt{INTEGER} s and \( \text{newdim} \) is either a subrange like \( 1..h \), or \( * \). The meaning of this notation is that the subarray must be formed of those elements of the original array \( \textit{arr} \) whose index is the specified linear function of the new index or indices. The latter are either constrained in the explicitly indicated range \( 1..h \) or in the maximum admissible range \( * \). In fact a general linear expression may be specified, with terms in any order and the possible occurrence of parentheses.

Another form of subarray selection is index permutation, which in the particular case of a two-dimensional array becomes matrix transposition.

\[
\text{arr}(*n, \ldots)
\]

denotes the array obtained from \( \textit{arr} \) by making the \( n^{th} \) index become the first and shifting forward all the others. As a particular case, the transpose of a two-dimensional matrix \( \textit{A} \) is \( \textit{A}(\ast 2, \ast) \), or just \( \textit{A}(\ast 2) \); the alternative notation \( \text{TRANSPOSED}(\textit{A}) \) is also provided.

Finally, a subarray can be extracted from an \texttt{ARRAY} of \texttt{STRUCTURE} s. If the declaration is, for instance,

\[
\text{ARRAY}(1..10) \ \text{OF} \ \text{STRUCTURE}(\text{INTEGER } i; \ \text{REAL } r) \ \textit{arr}
\]

then by a straightforward notation \( \textit{arr}.r \) is the \texttt{ARRAY}(1..10) \ \texttt{OF} \ \texttt{REAL} composed of all the \( r \) fields of each element of \( \textit{arr} \). Thus, for instance, \( \textit{arr}(5).r \) and \( \textit{arr}.r(5) \) denote the same \texttt{REAL} field. \( \textit{arr}.r \) is an \texttt{ARRAY} in its own right; it can be copied, passed as a parameter or subjected to further subarray selections.

It should be noted that all subarray selections are just address manipulations (in fact, the most general \textit{linear} address manipulations): no element of the array is ever moved and the selected subarray can appear on the left as well as on the right side of an assignment and can be passed as a \texttt{POINTER TO ARRAY(*)} parameter to a function or subroutine. No computational penalty is incurred because of the sheer size of either the original or the selected array, but on the other hand any modifications of the subarray also affect the original.

All subarray selections can also be applied to \texttt{STORED ARRAY}s (see §7.5) and \texttt{STRUCTURED ARRAY}s (see §3.13).

### 3.10 Compound index

CPL allows a multidimensional \texttt{ARRAY} to be accessed sequentially through a single index, for instance in order to apply linear algebra to it. The syntax for this operation is a sequence of as many \( \ast \) s as indices are to be compounded. For example if \( V \) is defined as
ARRAY(0..4,1..5,-7..7,0..2) OF REAL V

then \( V(****) \) is a onedimensional view of the same array (not to be confused with \( V(*,*,*,*) \) which represents its original arrangement). By the same token \( V(*,*,*,*) \) is the three-dimensional array obtained by compounding the two central indices into one. Bounds of a compound index can be retrieved by the usual \( LO \) (see §3.8.2) and \( HI \) (see §3.8.1) functions.

Compound indices are restricted to arrays (or portions of them) that are contiguous in memory. This sometimes precludes their use after subarray operations that permute, stride, or restrict the range of indices. When this is the case, a compile-time error results.

### 3.11 Linear-space ARRAY operations

Linear-space operations are supported on congruent ARRAYs of any number of dimensions and a base type on which arithmetic operations are defined. Such arrays can be added to or subtracted from each other and multiplied or divided by a scalar inside an expression, as well as appear on the left side of an assignment.

The scalar product of two congruent arrays is denoted by the infix operator \( \|
\). This is defined as the sum over all dimensions of the products of corresponding elements. (For \( \text{COMPLEX} \) the first operand is conjugated first.)

The constant \( 0 \) (but not any other constant) can be assigned as a value to a whole array.

Some builtin (see §4.9) functions operate on whole arrays. A larger set of vector and matrix algebra operations are supported by the rbmat.cpl and cbmat.cpl libraries.

Matrix transposition was discussed in §3.9.

All ARRAY operations can also be applied to STRUCTURED ARRAYs (see §3.13) and STORED ARRAYs (see §7.5).

### 3.12 Implicit looping over array indices

When indices of arrays appearing in an expression are prefixed by a \( \$ \) sign, the Einstein convention is implied\(^2\). That is, in a product (a contraction) the Einstein index must appear exactly twice, and the result will be summed over all values of this index; in a sum and assignment, Einstein indices must appear exactly once in each and all terms including the l.h.s., and the assignment will be repeated over all values of such indices. For example:

\[
C(\$i,\$j)=A(\$i,\$j,\$m)*B(\$i,\$m,\$j)+D(\$j,\$i)
\]

### 3.13 STRUCTURED ARRAY

A STRUCTURE (see §3.7) of like elements that may also be accessed as a one-dimensional ARRAY (see §3.8) of such. Its type declarator is

\(^2\)the \( € \) (euro) symbol might have been appropriate to match the “E” of Einstein, but is not part of the 7-bit ascii set. Thus we exchanged it for American currency.
STRUCTURED ARRAY(field declarations) OF type

where field declarations, separated by commas, are either newids alone or newids followed by (possibly multiple) ARRAY dimensions. For example, the declaration

STRUCTURED ARRAY(a,b,c(1..4,1..2)) OF REAL stra

defines a STRUCTURE named stra with fields a, b of type REAL and c of type ARRAY(1..4,1..2) OF REAL. At the same time, stra may also be accessed as an ARRAY(0..9) OF REAL, with automatically determined bounds. This is particularly useful when the new type has to be subjected to the linear ARRAY operations of §3.11. For instance, one can define a “Vector” structure with fields x,y,z and then syntetically denote vector operations on variables of this type.

3.14 POINTER

The type declarator for pointers is POINTER TO (prefix) or ^ (postfix) (see §3.3.3). For example

POINTER TO INTEGER a,b; INTEGER c

and

INTEGER a^,b^,c

are equivalent declarations. The notation for pointer dereferencing is described in §1.1.

A null pointer is denoted by the predefined constant

NULL type

which translates to the C constant NULL (usually the address 0) cast to type type if the latter already is a POINTER, or POINTER TO type otherwise.

3.14.1 Uncommitted POINTERS

A pointer can also be declared with reference to a (yet) uncommitted type name, by the notation

POINTER TO newid

It is assumed that newid will later be declared as a type identifier. VARIABLEs, CONSTANTs, ARRAYs and STRUCTURE fields of an uncommitted pointer type can be declared, assigned and compared to each other like all other POINTERs but not dereferenced. They become POINTERs in full rights as soon as a declaration for type newid is encountered.

Uncommitted pointers acquire a special meaning if used as formal parameters or function results (in which case no explicit declaration of type newid shall follow): a formal parameter of uncommitted pointer type can receive an actual parameter of any POINTER type (except POINTER TO ARRAY(*), which needs special treatment) as the actual argument, thus allowing the coding of subroutines for the manipulation of generic pointers. Type checking will still be enforced based on the equality of type name. Of course, uncommitted pointers of this kind can never be dereferenced within the body of the subroutine itself.

See also §6 and §3.15.
3.15 DYNAMIC POINTER

CPL is not an object-oriented language, in the sense that functions are not supposed to be declared within object class declarations, and intentionally so. Object-like behaviour is achieved through overloaded function names (see §1.3) and implicit type conversion (see §3.7).

In addition, situations where the type of an object is not fixed at compile time are catered for by DYNAMIC pointers, pointers that can reference and provide type checking for objects whose type will only be known at run time. These are declared by the type declarator

```
DYNAMIC POINTER
```

A function call in which such a pointer appears is transparently switched at run time to the function defined for the type of the actual arguments, or an error is thrown if no such function exists.

Pointers to variables of any type except ARRAY(*) and STORED can be assigned to a DYNAMIC POINTER. If the scope of assignment is to be restricted, the declaration becomes

```
DYNAMIC POINTER TO type declarator
```

In this case only types which can be implicitly converted to type declarator are acceptable for the variable pointed to.

3.15.1 Type comparison

The actual type of the variable pointed to by a dynamic pointer (or, for that matter, of any variable) can be tested by the BOOLEAN expression

```
pointer IS type
```

For instance, in

```
DYNAMIC POINTER dyn
...
IF dyn IS INTEGER THEN
...
END IF
```

the IF block is executed only if the dynamic pointer dyn points at run time to a variable of INTEGER type. In addition, the IS test has the side effect of casting a dynamic pointer to an ordinary pointer of the tested type when the test succeeds, thus allowing its use as a regular variable. That is, in the above example dyn is implicitly converted to a POINTER TO INTEGER within the scope of the IF block. A restricted dynamic pointer can be implicitly converted to its base type without any test, as compatibility was already enforced at compile time.

3.16 SUBROUTINE and FUNCTION variables

A variable containing the address of a subroutine may be declared through the type declarator

```
SUBROUTINE( parameter declarations )
```
A variable containing the address of a function may be declared through the type declarator

\[ \text{FUNCTION( parameter declarations )} \rightarrow \text{type} \]

or else

\[ \text{type FUNCTION( parameter declarations )} \]

the first form being mandatory when the result is of a pointer or compound type and thus ambiguity can arise.

These type declarators can be used, just like all other type declarators, to declare variables and formal parameters, or as a part of new compound types. In addition to being assigned or compared to each other, subroutine variables can be assigned the name of a compatible subroutine as their value or as the actual parameter, and can later be called with the same syntax as normal (constant) subroutines and functions.

4 Expressions

4.1 INTEGER operators

The infix INTEGER arithmetic operators are: \(+\), \(-\), \(*\), \(\text{DIV}\) and \(\text{MOD}\).

Notice that the INTEGER division operator is denoted by \(\text{DIV}\), and always produces a rounded-down INTEGER quotient. By contrast \(\text{/}\) produces a REAL result even when the operands are REALs.

\(\text{MOD}\) is the “modulo” infix operator. If \(a\) and \(b\) are INTEGERs, \(a \text{ MOD } b\) represents the remainder of the integer division of \(a\) by \(b\).

4.1.1 Notice on the truncation of integer division:

CPL requires that \(a \text{ MOD } b\) must always be a positive number, regardless of the sign of \(a/b\). This is so that modular arithmetics can be applied to negative as well as to positive numbers, for example in array index manipulations. Since \(b \cdot (a \text{ DIV } b) + a \text{ MOD } b = a\), consistently \(a \text{ DIV } b\) must be rounded towards minus infinity, \(i.e., \ a \text{ DIV } b = \text{FLOOR}(a/b)\). Care should be exerted when porting programs from languages that round up negative division, such as FORTRAN or C.

Operators following the C convention of rounded-towards-zero integer division and signed modulo are available, if needed, as \(\text{CDIV}\) and \(\text{CMOD}\) respectively.

4.2 REAL operators

The infix REAL arithmetic operators are: \(+\), \(-\), \(*\), \(/\) or \(^\) or \(\star\star\).

An infix \(^\) is the exponentiation operator. (Not to be confused with a postfix \(^\), the pointer dereferencing operator or a prefix \(^\), the address extraction operator — see §5.2.) \(\star\star\) is also provided for FORTRAN-accustomed users.
4.3 Comparison operators

The infix comparison operators are: `>`, `>=`, `<`, `<=`, `==`, `#`, and `IS`.

All of these produce a BOOLEAN result, and have lower precedence than arithmetic operators but higher than boolean operators.

The equality and inequality operators apply to any type, including pointers. Since pointers are implicitly dereferenced (see §1.1), an ambiguity may arise as to whether the values or addresses of the two sides must be compared. If explicit dereferencing is not used, the comparison takes place at the earliest dereferencing level at which types match, but the comparison of two constant addresses is disallowed (so that `A=B`, where `A` and `B` are two simple variables, denotes the comparison of the values of `A` and `B` rather than their addresses). Explicit type casting or pointer dereferencing may at times be necessary, and is always advised where ambiguities may arise.

The `IS` type-testing operator was described in §3.15.1.

4.4 BOOLEAN operators

4.4.1 AND

Boolean AND infix operator. Takes precedence over `OR` but not `NOT`.

The `AND` keyword may also appear in a FOR clause (see §8.3.1) and in a READ statement (see §7.3).

4.4.2 OR

Boolean OR infix operator. Has lower precedence than either `AND` or `NOT`.

The `OR` keyword may also appear in a READ statement (see §7.3).

4.4.3 NOT

Boolean NOT prefix operator. Has higher precedence than either `AND` or `OR`.

4.5 Conditional expressions

```
IF boolean THEN expr1 ELSE expr2
```

is an expression that takes the value of `expr1` if `boolean` is true and `expr2` if false. `expr1` and `expr2` must evaluate to values of the same type (or be implicitly convertible to the same type) and this is the type of the result, which can be embedded in a larger expression like any other operator. Notice that the `ELSE` part is mandatory, as without it the expression’s value would be undefined.

The syntax is otherwise very similar to that of the IF statement of §8.1.
4.6 Bitwise operators

The bitwise boolean operators, acting on INTEGER operands to produce an INTEGER result are denoted as: BITAND, BITOR, BITXOR, BITNOT, RSHIFTED and LSHIFTED. The C-like notation & | >> << is also available for BITAND BITOR RSHIFTED LSHIFTED. ^ and ~ are reserved for other functions (see §4.2, §5.2 and §5).

4.7 String concatenation

STRING (see §3.8.4) literals and/or variables written one after the other with no intervening operator (whitespace is allowed, but newlines must be escaped) are concatenated into a single STRING. If all of the arguments are literals (i.e., known at compile time), the result will also be a literal, otherwise it will be a dynamically allocated ARRAY(*) OF CHAR which is transparently freed at the end of the enclosing code block.

4.7.1 String conversion

In addition to STRINGs, values of other types may also appear in a concatenation, provided the first item is an actual STRING (possibly "") ; they are then implicitly converted to strings just as if they appeared in a WRITE statement (see §7.2). Please pay attention that a numeric parenthesis that is concatenated after a string will be interpreted as an ARRAY subscript, since the STRING is a legitimate ARRAY OF CHAR, unless white space is placed between the string and the parenthesis. The reverse conversion of a string into a numeric value must be handled explicitly, if needed, through libc String and Array Utilities.

When a string literal is being defined in "" notation (see §3.8.4), a variable included as delimiter variable delimiter is concatenated within the string being defined (whereas delimiter newline ends the definition).

4.8 Looping operators

The four operators SUM PRODUCT MAX MIN embed a loop inside an expression, to denote respectively the sum, product, maximum and minimum of their argument over a running index. ARGMAX and ARGMIN act like MAX and MIN but return the value of the index. They are all constructed as in this instance:

SUM expression FOR for clause

and return a value of the same TYPE as expression. The for clause can be of any one of the forms that are allowed in a FOR loop (see §8.3).

For example:

WRITE (MAX SIN(x) FOR x=0. TO 2 BY 0.5)+(PRODUCT arr(n) FOR ALL n)

The MAX and MIN keywords are also used as functions denoting ARRAY operations (see §4.9.5).
4.9 Builtin functions

Most of the following functions can be applied to either \texttt{REAL} or \texttt{INTEGER} arguments, giving a corresponding result.

4.9.1 ABS

The \texttt{ABS} function returns the absolute value of a \texttt{INTEGER}, \texttt{REAL} or \texttt{COMPLEX} number, or of an \texttt{ARRAY} of those.

4.9.2 CEILING

The \texttt{CEILING} function returns the larger or equal \texttt{INTEGER} to a given \texttt{REAL} value.

4.9.3 FLOOR

The \texttt{FLOOR} function returns the lesser or equal \texttt{INTEGER} to a given \texttt{REAL} value.

4.9.4 ROUND

The \texttt{ROUND} function returns the nearest \texttt{INTEGER} to a given \texttt{REAL} value.

4.9.5 MAX

The function

\begin{verbatim}
MAX(argument [,argument])
\end{verbatim}

accepts any number of scalar arguments and returns their maximum.

The function

\begin{verbatim}
MAX(array)
\end{verbatim}

returns the maximum of the elements of the \texttt{ARRAY array}.

The function

\begin{verbatim}
ARGMAX(array)
\end{verbatim}

returns the first index where the maximum is found.

The \texttt{MAX} or \texttt{ARGMAX} keyword without a following bracket is a looping operator (see §4.8).

4.9.6 MAXABS

The function

\begin{verbatim}
MAXABS(array)
\end{verbatim}

returns the maximum absolute value of the elements of the \texttt{ARRAY array}.
4.9.7 MIN

The function

\[
\text{MIN}(\text{argument} [, \text{argument}])
\]

accepts any number of scalar arguments and returns their minimum.

The function

\[
\text{MIN}(\text{array})
\]

returns the minimum of the elements of the \text{ARRAY} array.

\[
\text{ARGMIN}(\text{array})
\]

returns the first index where the minimum is found.

The \text{MIN} or \text{ARGMIN} keyword without a following bracket is a looping operator (see §4.8).

4.9.8 NORM

The \text{NORM} function returns the squared absolute value of either a number or a (uni– or multi–dimensional) array.

4.9.9 ABS

The function

\[
\text{ABS}(\text{array})
\]

returns the modulus (square root of the \text{NORM}) of the \text{ARRAY} array.

4.9.10 Other builtin REAL functions

\begin{align*}
\text{SIN} & : \text{sine} \\
\text{COS} & : \text{cosine} \\
\text{TAN} & : \text{tangent} \\
\text{ATAN} & : \text{arctangent} \\
\text{EXP} & : \text{exponential} \\
\text{LOG} & : \text{logarithm} \\
\text{RAND} & : \text{uniformly distributed in (0,1) REAL random number} \\
\text{GAUSS} & : \text{gaussian distributed REAL random number with mean 0 and variance 1}
\end{align*}

4.9.11 Random numbers

The \text{RAND} function takes no argument. It is based on the \text{INTEGER} C library function \text{rand}, whose seed can be changed with \text{srand} (see the \text{rand} manpage).

The \text{GAUSS} function takes no argument. It is based on \text{RAND} and the analytic formula (see Knuth, The Art of Computer Programming, chapter on random numbers):

\[
\text{GAUSS} = \sqrt{-2 \cdot \log(\text{RAND})} \cdot \cos(\pi \cdot \text{RAND})
\]
In addition, all C-library mathematical and other functions are transparently available with their original, generally lowercase, names (see §2.8).

4.9.12 Builtin BOOLEAN functions

EOF : end of file
INPUTREADY: test for input ready on a file descriptor or stdin (see §7.3.3)
ODD : INTEGER argument is odd
READ : read and report success or failure (see §7.3)

4.9.13 Builtin type-conversion functions

CHAR : INTEGER to CHAR
INTEGER: BOOLEAN to INTEGER (1 for YES, 0 for NO)
INTEGER: REAL to INTEGER (same as FLOOR)
REAL : INTEGER or SINGLE to REAL (may be omitted)
SINGLE : REAL to SINGLE

4.9.14 Command-line parameter access

The command line through which the program was launched is available in the predefined

ARRAY(*) OF STRING

COMMANDLINE

(the same that is usually named argv in C programs). Therefore the first word passed after the program name is COMMANDLINE(1), the second is COMMANDLINE(2), etc. The program name itself is COMMANDLINE(0). The index of the last word present, just as for all ARRAYs, is COMMANDLINE.HI.

5 Assignment

Assignment is performed by a single equals = sign. The l.h.s. must be a POINTER (which the constant address of a simple variable automatically is), and the r.h.s. is required to be a value of the TYPE pointed to or to be implicitly convertible to it (see §1.1). Compound variables can be assigned as a whole if types match.

Owing to their all-encompassing role, assignment and equality/inequality tests are the only situations in which pointer dereferencing must be explicit. The left side of an assignment will never be implicitly dereferenced, and must be dereferenced by a postfix ^ if assignment of the value pointed to is desired. For increased clarity, the type of the object to be assigned may also be specified, as in the example (after the declaration REAL a, b):

REAL a=b equivalent to a^=b.

At any position in the expression appearing on the right-hand side of an assignment, the symbol ~ can be used as a place-holder for the l.h.s. For example:
5.1 Pointer arithmetics

Pointer arithmetics is the most powerful feature C has in common with assembly language. It is, however, also one of its weakest points as far as bounds crossing is concerned. For these reasons CPL allows pointer arithmetics in restricted forms. One of these is subarray extraction (see §3.9). The other is the type declarator

\[ \text{POINTER INTO } \text{array} [, \text{array}] \]

which defines a pointer that can be decremented or incremented provided it stays within the bounds of one of the listed \text{array}s. Arithmetics on such a pointer is allowed just as if it were an ordinary \text{INTEGER}; dereferencing is not implicit, as for ordinary \text{POINTER}s it would be, but is obtained by using it as an index into one of its base arrays. For instance as in:

\[
\begin{align*}
\text{REAL } R(10) \\
R(5) &= 0.5 \\
\text{POINTER INTO } R \text{ ip} \\
\text{ip} &= 3 \\
\text{ip} &= \text{ip} + 2 \\
\text{WRITE } R(\text{ip})
\end{align*}
\]

In other words, code is written just as if an \text{INTEGER} index were used (and actually works if just the \text{POINTER INTO} type declarator is replaced by \text{INTEGER} without any other change), but the program is compiled to use a pointer instead. This can sometimes improve performance, especially in short loops that perform few repeating operations.

5.2 Dereferencing operator

Explicitly specifying a dereferencing is optional but never forbidden. When necessary, the dereferencing operator is a postfix \texttt{^} (like in Pascal). Vice versa, a prefix \texttt{^} forces taking the address rather than the value of a variable. This construction too is rarely needed; notice however that the implicit declaration of a previously undeclared \texttt{CONSTANT} (to be introduced in §3.4),

\[
c = \text{var}
\]

implicitly declares \texttt{c} as a copy of the value of \texttt{var}, whereas

\[
c = \texttt{^var}
\]

declares \texttt{c} as a \texttt{POINTER} containing the address of \texttt{var}.
5.3 Deferred assignment

When an assignment is performed by a double equals \(==\) sign, no statement is generated in place. The \(l.h.s.\) is instead defined to be an alias for the \(r.h.s.\), and the assignment will be performed (and error messages issued, if any) at the location where this alias is first used.

Deferred assignment permits the appearance on the \(r.h.s.\) of yet undefined variables and functions, provided these will be defined before the \(l.h.s.\) is actually used. It also allows compile-time constants to be given symbolic names and still be recognized as such.

This construction is further extended in the symbolic.cpl library.

6 Memory allocation

Runtime memory allocation is achieved either through the statement

\[
\text{NEW } \text{pointer } [,\text{pointer}]
\]

or the function

\[
\text{NEW } \text{type}
\]

The \text{NEW} statement allocates (through the \text{malloc} system call) the space needed for a variable of the \text{TYPE} pointed to by \text{pointer} and sets \text{pointer} to its address. The \text{NEW} function returns a \text{POINTER} to a dynamically allocated variable of \text{TYPE} \text{type}. If applied to a \text{POINTER TO STORED} (see §7.5) or \text{POINTER TO FILE} (see §7.1) type, \text{NEW} returns a pointer to a temporary file which will be automatically destroyed when freed or at program termination.

Dynamically allocated space is retained, independently of subroutine scoping, until it is returned to the system by the \text{FREE} statement (see below).

6.1 Freeing memory or file storage

\[
\text{FREE } \text{pointer } [,\text{pointer}]
\]

releases the memory space or the file pointed to by each \text{pointer}, which must have been previously obtained from \text{NEW}, \text{OPEN} (see §7.6), or \text{CREATE} (see §7.6.2). \text{pointer} is subsequently zeroed, so that any later dereferencing generates a visible runtime exception. If \text{pointer} is a file descriptor, \text{FREE}ing it also writes out any previously buffered data.

7 Input/Output

Text I/O is performed by \text{READ} and \text{WRITE} instructions on variables of type \text{FILE}, which must be declared like ordinary variables and associated with a file before being used for I/O. \text{FILE} variables can be implicitly declared if they are \text{CONSTANT}, and can be part of compound types like all other variables. Association to a file is obtained through \text{OPEN} and \text{CREATE}.
instructions. A FILE variable is translated to the C type FILE*, and can be used as such, if necessary, in C-library I/O functions transparently accessed through the C interface of §2.8.

Sequential binary I/O is performed by adding the BINARY keyword to the READ and WRITE instructions. No distinction is assumed to be made between text and binary files at the filesystem level.

Random-access binary I/O is where CPL really differs from other languages; this is described in §7.5. A more traditional, but also lower-level, method of random access is offered by the POSITION statement and function of §7.4.1.

7.1 FILE

The

FILE type descriptor is translated to C type FILE*. The predefined C file descriptors stdin, stdout, stderr are also predefined in a CPL program (as are, in fact, most other symbols and functions in the C stdio library according to §2.8).

The more general construction

FILE OF type

will be introduced in connection with random-access files (see §7.5). Type FILE introduced above is also equivalent to FILE OF CHAR.

7.2 WRITE

The WRITE output statement is used as follows:

WRITE [TO file] [BY NAME] [outputexpr] [./.]

Here file can be a FILE value, such as returned by OPEN or CREATE, or else a string representing a filename. In the latter case the file is implicitly CREATEd before WRITEing and FREEd at the end of the statement. If TO file is omitted, stdout is implied. If file is present, WRITE TO may be omitted.

An outputexpr can be

value[:format]

or , (a comma). value can be of any type except POINTER (which if present undergoes Concealed Pointer Lookup — see §1.1). Compound types such as ARRAY and STRUCTURE are printed in a standard format which is understandable to READ (as well as to humans). (If STRUCTURE elements are POINTERS, however, they are printed as the string “POINTER” and cannot be read back.) If a SUBROUTINE named WRITE is defined with first argument of type FILE and second argument of a user-defined TYPE, it will be automatically used to print variables of such type. Primitive types are printed in a default format, unless the numeric part of a C format specifier is included after a colon.
The default format is initially the C library’s default, but may be changed (down to the end of the enclosing scope) by the `DEFAULTFORMAT` declaration, e.g.,

```
DEFAULTFORMAT 1.15
```

A `,` in the sequence of `outputexpr`s is printed as a tab. `outputexpr`s may also be written one after the other without any comma, in which case they are just adjoined without any intervening space. Please pay attention that a numeric parenthesis that immediately follows a string will be interpreted as an `ARRAY` subscript, since the `STRING` is a legitimate `ARRAY OF CHAR`, unless space is placed between the string and the parenthesis.

By default, `WRITE` puts a newline at the end of its sequence of `outputexpr`s. The optional `.//` symbol suppresses this newline and `FLUSH`es the output instead.

`WRITE` with no `outputexpr` and no `.//` prints just a newline.

If the optional `BY NAME` qualification is present, `WRITE` prepends each value with the expression from which it is produced, in the form `name=value`. If the expression is a single identifier, this format can be read back by the `READ BY NAME` statement.

`WRITE` syntax is also adopted for the conversion of general types to a string, as described in §4.7.

### 7.3 READ

The `READ` input statement is used as follows:

```
READ [BY NAME] [FROM file] [variable [conjunction variable]]
```

where `file` can be a `FILE` value, such as returned by `OPEN` or `CREATE`, or else a string representing a filename. In the latter case the file is implicitly opened before `READ` is executed and closed at the end of the statement. If `FROM file` is omitted, `stdin` is assumed.

`variable` must be a `VARIABLE` identifier or a `POINTER` to a variable, which can be of any type except `POINTER`. Compound types such as `ARRAY` and `STRUCTURE` are also accepted; they are expected to appear in the same clear-text format as produced by `WRITE`. `variable` can also be a literal `STRING`, which is then expected to appear verbatim in the input file. If `variable` is an `ARRAY(*) OF CHAR`, characters are read until the array is full or a newline appears. In all other cases, blanks, tabs and newlines are automatically skipped. Lines starting with an `!` are considered to be comments and skipped.

`conjunction` can be one of `,` and `OR`. If `,` or `AND` is used, the joined variables must both be compulsorily present in the input or an I/O error will result. If the conjunction is `OR`, only one or the other is expected to be present and the `READ` statement succeeds and yields control as soon as one is found.

`READ` with no variable is also allowed and just blocks until a newline is received, skipping any other characters that precede it. This statement can be used to skip lines in a file or to create a pause in execution until a newline character appears in `stdin`.

`READ`, with the same syntax, may also appear as a function in a `BOOLEAN` expression, and should then be pronounced as the past participle of the verb “to read”. In this form, `READ`
returns a BOOLEAN value saying whether reading was successful or not and never generates an I/O error.

If the optional BY NAME qualifier is present, READ expects to find the value of each variable preceded by its name in the input file in the form name=value.

7.3.1 FROM

As an auxiliary keyword, FROM is used in READ statements as detailed above.

In addition, the construction
type declarator FROM file

represents a value of type type declarator read from the file descriptor file. This value can directly appear in an expression just as the value of a function can. As an example, the statement

WRITE 3*(INTEGER FROM stdin)

can replace the sequence of three statements

INTEGER temp
READ FROM stdin temp
WRITE TO stdout 3*temp

7.3.2 Console prompting and reading

The statement

ASK [type] ["literal":] variable [, ["literal":] variable]

has the effect that a prompt is automatically written to stderr for each variable and the value of the variable is subsequently read from stdin. The prompt is the optional literal if present, or the name of the variable followed by a ? otherwise.

Console prompting can be compounded with CONSTANT declaration. If the optional type is present, each variable is declared as a CONSTANT of this type before being asked.

Under icpl, this console input functionality becomes extended: an icpl shell is opened whenever the program is waiting for input from its controlling terminal, and any number of icpl commands can be executed interactively before answering. The first expression given alone on the command line, which icpl would normally print, gets returned as input instead, and the waiting program resumes. This extension is available to either an interpreted or a compiled program, provided the latter is run under icpl.

7.3.3 Test for input ready on a file descriptor or stdin

The BOOLEAN function

INPUTREADY(file)
returns **YES** if there are characters available for input on **FILE** variable **file**. This is mainly of use when **file** is a terminal, to check whether keys have been pressed before blocking on a read. Notice that if the terminal is in line-buffered mode (as unix terminals are by default), characters become available only after a line feed has been entered. Terminal mode may be altered by commands in CHARbyCHAR.cpl. Other variants:

```plaintext
INPUTREADY()
```

is a shorthand for **INPUTREADY(stdin)**.

```plaintext
INPUTREADY(file, time)
```

waits for input for the given **time** (in seconds, a **REAL**) before returning a **NO**.

```plaintext
INPUTREADY(time)
```

is a shorthand for **INPUTREADY(stdin, time)**.

### 7.4 Binary (unformatted) Input/Output

Sequential binary I/O is obtained by either appending or prepending the word **BINARY** to **READ** and **WRITE**, as in the following stencils:

```plaintext
READ BINARY FROM file variable [,variable]
WRITE BINARY TO file outputexpr [,outputexpr]
```

In binary I/O no format need, of course, be specified and no newline or tab is automatically added by **WRITE** statements. The syntax is otherwise unchanged.

#### 7.4.1 Read or set a file’s current position

As a primitive form of random-access binary I/O, the **POSITION** statement can be used to get and set the reading and writing position in the file. A more powerful, and frequently preferable, mechanism is provided by the **STORED** declaration of the next section.

The statement

```plaintext
POSITION file, n
```

sets the current position in file **file** so the next **READ** or **WRITE** statement will take effect at byte number **n**.

The function

```plaintext
POSITION(file)
```

returns the current **READ/WRITE** position in file **file** as an **INTEGER** result (provided the filesystem-returned position fits in such type).
7.5 Random-access files as disk-STORED variables

A random-access binary file typically contains fields and records at fixed addresses, which can be accessed, as described above, by POSITIONing the file cursor before each READ or WRITE BINARY. However, this process requires knowing the numerical address of each field and can be error-prone.

CPL provides a powerful alternative: a pointer to a compound variable residing in a disk file. Records and fields are then defined by just declaring a suitable compound type through the usual STRUCTURE and ARRAY declarations. For this purpose a type declaration prefixed by the STORED keyword is used, as in the example:

```cpl
POINTER TO STORED ARRAY(1..10) OF STRUCTURE(REAL x,y) v
```

which defines a variable named v as the pointer to a random-access file containing 10 records composed of two real numbers each. v is in fact a file descriptor, which can be obtained through OPEN or CREATE just like any other file descriptor, but is also at the same time a POINTER and can alternatively be obtained as an anonymous file from NEW. Once v is assigned a file descriptor, reading and writing to it is achieved by accessing v just as if it were an ordinary POINTER to memory. In the above example, since Concealed Pointer Lookup is in effect,

```cpl
v(4).x = 3.14
```

and

```cpl
WRITE LOG(v(8).y)
```

are valid statements. The simple rule is that anything that could be done if v had been declared as a normal POINTER is still allowed, but the actual storage occurs in a disk file rather than in memory.

Just as for any POINTER, accessing a variable of POINTER TO STORED type without first assigning a file descriptor to it is an error (caught by rtchecks.cpl if active). On the other hand, the declaration

```cpl
STORED ARRAY(1..10) OF STRUCTURE(REAL x,y) v
```

(continuing in the same example) actually reserves storage for the v variable, just like the corresponding declaration without the STORED keyword would, by assigning a temporary file to it. This temporary file is automatically opened and closed as necessary and does not survive the end of the program.

When declared with the special dimension * (which can only appear as the leading index), a STORED ARRAY can be extended (by just writing to it) to an a-priori undetermined number of records (numbered from 0). The shorthand

```cpl
FILE OF type
```

is equivalent to

```cpl
POINTER TO STORED ARRAY(*) OF type
```

The FILE type declarator is a shorthand for FILE OF CHAR.
Arrays and pointers to stored arrays with multiple dimensions are allowed when used as function formal parameters, just like their non-stored equivalents are. The corresponding actual parameter must be a stored array (or subarray) of matching number of dimensions and type (not just an opened file).

## 7.6 Opening and closing files

### 7.6.1 OPEN

The statement

```c
OPEN fd, filename
```

opens file descriptor `fd` for the file identified by the string `filename` at the filesystem level. `fd` must have been previously declared as one of the `pointer to stored` types.

The function

```c
OPEN(filename)
```

returns a file descriptor of type `FILE` as its value.

With `OPEN`, file `filename` is opened for both reading and writing, and is created if it does not exist, but is never truncated. Therefore, it may be written over but any data which are not overwritten will remain there. If a possible file of the same name is to be cleared before writing, `CREATE` should be used instead.

(OPEN calls the open system function with options `O_RDWR|O_CREAT`. For finer control, the C open or fopen function may be called directly, just like all other libc functions, as explained in §2.8.)

### 7.6.2 CREATE

The statement

```c
CREATE fd, filename
```

opens file descriptor `fd` for the file identified by the string `filename` at the filesystem level. `fd` must have been previously declared as one of the `pointer to stored` types.

The function

```c
CREATE(filename)
```

returns a file descriptor of type `FILE` as its value.

With `CREATE`, file `filename` is opened for both reading and writing, is created if it does not exist, and is truncated to zero length. Therefore, it may be reread after it has been written, but any data in a possible pre-existing file of the same name are lost. If a file of the same name were to be preserved, `OPEN` should be used instead.

(CREATE calls the open system function with options `O_RDWR|O_CREAT|O_TRUNC`. For finer control over options, the C open or fcreate function may be called directly, just like all other libc functions, as explained in §2.8.)
7.6.3 FLUSH

The statement

```
FLUSH fd
```

writes out any buffered data for file descriptor `fd`.

8 Control statements

8.1 Conditional execution

`IF` statements have a single-line form and a multi-line form. (For the additional use of `IF` inside expressions see §4.5.) Like in BASIC, single-line `IF` statements terminate at the end of a line, whereas multi-line `IF` statements are explicitly terminated by `END IF`. Multi-line `IF` statements have the following structure:

```
IF boolean THEN
code block
END IF
```

or

```
IF boolean THEN
code block
else statement
```

They are recognized by `THEN` being the last word on a line. Single-line `IF` statements have the structure

```
IF boolean THEN single-line block
```

or

```
IF boolean THEN single-line block END IF
```

or

```
IF boolean THEN single-line block else statement
```

A `single-line block` is formed of multiple statements separated by semicolons with no intervening newlines. It may, however, contain compound statements (such as a `LOOP` or another `IF` statement) that in turn contain newlines in their own body.

The optional `else statement` has the structure

```
ELSE
  code block
END IF
```

or

```
ELSE single-line block
```

or
in the multi-line form ELSE being followed (with possible intervening whitespace) by a newline character.

Multiple-choice conditionals are simply obtained by nesting another IF in the else statement as follows:

```plaintext
IF boolean THEN
code block
ELSE IF other boolean THEN
  other block
ELSE
  yet another block
END IF
```

## 8.2 Loops

Loops tested at their beginning (which are to be executed zero or more times) are coded as

```plaintext
LOOP test
  code block
REPEAT [LOOP]
```

or

```plaintext
LOOP name test
  code block
REPEAT name
```

Loops tested at their end (which are to be executed one or more times) are coded as

```plaintext
LOOP
  code block
REPEAT [LOOP] test
```

or

```plaintext
LOOP name
  code block
REPEAT name test
```

or else by the DO short form of §8.4.

When a name is specified, the corresponding LOOP can be terminated at any point inside its body (or an inner nested scope) by the

```plaintext
EXIT name
```

statement. A named loop without any test is also allowed, and represents an infinite loop that can only be terminated by an explicit EXIT.

The test test may be one of WHILE, UNTIL, FOR as described below.
8.2.1 WHILE

A simple test that can be used to decide whether to iterate a loop is

```
WHILE boolean
```

For instance,

```
DO i=i+1 WHILE i<10
```

will repeat while the indicated boolean condition is true. **WHILE** is equivalent to **UNTIL NOT**.

8.2.2 UNTIL

A simple test that can be used to decide whether to terminate a loop is

```
UNTIL boolean
```

For instance,

```
DO i=i+1 UNTIL i>10
```

will repeat until the boolean condition becomes true.

**UNTIL** is equivalent to **WHILE NOT**.

8.3 FOR loops

The **test** for indexed loops is

```
FOR for clause
```

where the **for clause** can assume one of several forms. Its basic incarnation is either

```
index = lboun TO ubound [BY step]
```

or

```
index = ubound DOWN TO lboun [BY step]
```

where **index** is incremented by **step** in each iteration in the first case and decremented in the second. The loop terminates when **index** exceeds **ubound** in the first case or drops below **lboun** in the second. If **BY step** is omitted, **BY 1** is assumed. **lboun**, **ubound** and **step** can all be arbitrary expressions; notice that a negative **step** in either case generates a never-ending loop.

Both **INTEGER** and **REAL** types are allowed. **index** may be an already existing variable or be implicitly declared by the loop itself (as a particular case of §3.4). In the latter case it acquires the type of the loop bounds and behaves as a **CONSTANT** within the body of the loop. If the index is **REAL**, **BY** cannot be omitted.

A **for clause** can appear in a **LOOP**, a **DO** or one of the looping operators of §4.8. In addition to the two above basic forms, it can have the following variants:
8.3.1 AND in a FOR loop

Two or more FOR loops can be combined in a single test through the AND keyword (not to be confused with the boolean AND operator), as in the following example:

```
LOOP FOR i1=l1 TO u1 AND i2=l2 TO u2
  code block
REPEAT
```

which is equivalent to

```
LOOP FOR i1=l1 TO u1
  LOOP FOR i2=l2 TO u2
    code block
  REPEAT
REPEAT
```

8.3.2 ALL

A for clause of the following form:

```
LOOP FOR ALL index [, index]
```

denotes a loop whose bounds are automatically determined as the common bounds of all ARRAYs that index is used in (while resulting in an error message if such bounds differ from each other). Its use is particularly convenient for short loops and should preferably be limited to such.

An ALL clause can also be part of a multiple loop formed with the AND keyword, as well as denote a multiple loop itself by containing multiple indices separated by a comma. In addition, the lower and upper bounds that would be automatically assigned by ALL to the index are also available as LO and HI respectively within the scope of a standard for clause, like in the example:

```
DO WRITE A(i,j,k) FOR ALL i,j AND k=LO+2 TO HI-3
```

8.3.3 TIMES

A statement of the form

```
LOOP FOR number TIMES
```

does exactly what it says, and comes handy when just an anonymous counter is needed.

8.3.4 IN

Yet another form of for clause is

```
LOOP FOR element IN array
```
Here \texttt{element} represents a \texttt{POINTER} to elements of the \texttt{ARRAY array}. A \texttt{LOOP} is performed in which \texttt{element} runs sequentially through all the elements of the array (or its subset specified through subarray selection, see §3.9). As a particular case, \texttt{array} can also be a \texttt{CONSTANT} array constructed from a set of elements of the same \texttt{TYPE} enclosed in brackets, as in

\begin{verbatim}
LOOP FOR n IN (2,5,11)
\end{verbatim}

\section*{8.3.5 EXCEPT}

\begin{verbatim}
LOOP FOR for clause EXCEPT condition ["," condition]
\end{verbatim}

The \texttt{EXCEPT} qualifier added to any of the \texttt{FOR} loop constructions excludes exceptional values of the index from the iteration. \texttt{condition} may be either an expression of \texttt{BOOLEAN} type, meaning that the loop is skipped when this condition is \texttt{TRUE}, or an expression of the same type as the index, meaning that the given value is excluded.

\section*{8.4 DO loops (short form)}

A short form for nameless loops tested at the end (which are always executed one or more times) is

\begin{verbatim}
DO code block test
\end{verbatim}

where \texttt{test} may be any one of \texttt{WHILE} (see §8.2.1), \texttt{UNTIL} (see §8.2.2), \texttt{FOR} (see §8.3).

\section*{8.5 INLINE loops}

The statement

\begin{verbatim}
INLINE LOOP [name] FOR element IN array
code block
REPEAT [name]
\end{verbatim}

expands in line by repeating the \texttt{code block} once for each element of \texttt{array}, whose dimensions must be known at compile time.

\section*{8.6 Multiple-choice CASE selection}

A multiple-choice branch is specified as

\begin{verbatim}
CASE integer OF
tag1: block
tag2: block
...
tagn: block
[ ELSE block ]
END CASE
\end{verbatim}
where \textit{integer} is an expression of \texttt{INTEGER} type and \textit{tag1}, \textit{tag2}, ..., \textit{tagn} are \texttt{INTEGER} compile-time constants. A list of values separated by commas may also appear as a tag.

\section*{8.7 \texttt{EXIT}}

The statement

\begin{verbatim}
EXIT name
\end{verbatim}

transfers control past the end of the \texttt{SUBROUTINE}, \texttt{FUNCTION}, \texttt{MODULE} or \texttt{LOOP} labelled \textit{name}. \texttt{EXIT} is allowed to appear in an inner nested scope, such as a further loop or an \texttt{IF} statement.

\section*{8.8 \texttt{END}}

The statement

\begin{verbatim}
END name
\end{verbatim}

marks the end of the body of a \texttt{SUBROUTINE}, \texttt{FUNCTION} or \texttt{MODULE} named \textit{name}. \texttt{END C SECTION}, \texttt{END FRI SECTION}, \texttt{END IF}, \texttt{END CASE}, \texttt{END WITH} and \texttt{END TRAP} mark the end of the corresponding statements.

\section*{8.9 \texttt{STOP}}

The statement

\begin{verbatim}
STOP
\end{verbatim}

stops the program and exits (unless intercepted by a \texttt{TRAP}).

\section*{8.10 \texttt{ERROR}}

The statement

\begin{verbatim}
ERROR outputexpr
\end{verbatim}

writes \textit{outputexpr} to the predefined string variable \texttt{ERRORMESSAGE} and signals an error. Unless a \texttt{TRAP} has been set, this causes the program to exit after writing \texttt{ERRORMESSAGE} to \texttt{stderr}.

\subsection*{8.10.1 Error TRAP}

An error, either caused by a system signal or by the \texttt{ERROR} statement, normally causes the program to terminate after writing a message to \texttt{stderr}. An error trap may be set by the statement
TRAP
  error handling
END TRAP

or

TRAP literal
  error handling
END TRAP

In the first form all errors are trapped; in the second, only those whose error message begins with literal. During normal execution, the error handling block is skipped. At the moment an error is triggered, either by a system signal or by an explicit ERROR statement, within the code that follows END TRAP up to the end of the enclosing block, the error handling code block gets executed. The error message that would be printed is available in this block in the predefined string ERRORMESSAGE. At the end of the error handling block, control is passed to the end of the enclosing block, where also the scope of the TRAP terminates like that of all other declarations. Within the body of the TRAP, the exception may be re-raised if necessary by the statement

ERROR ERRORMESSAGE

An exception caused by an external SIGINT or by the STOP statement is accompanied by an empty ERRORMESSAGE.
Keyword index

ABS: absolute value: see §4.9.1
ALL: loop specifier: see §8.3.2
AND: boolean AND: see §4.4.1
ARGMAX: argument for maximum, function or looping operator: see §4.9.5
ARGMIN: argument for minimum, function or looping operator: see §4.9.7
ARRAY: subscripted arrays: see §3.8
ASK: console prompting and reading: see §7.3.2
ATAN: arctangent: see §4.9
BINARY: binary format input/output: see §7.4
BITAND: boolean operator: see §4.6
BITNOT: boolean operator: see §4.6
BITOR: boolean operator: see §4.6
BITXOR: boolean operator: see §4.6
BOOLEAN: primitive type declarator: see §3.5.1
BY: used in FOR, see §8.3, READ, see §7.3, WRITE, see §7.2
FOR: loop specifier: see §8.3
READ: input from character files and devices: see §7.3
WRITE: output to character files and devices: see §7.2
C SECTION: transparent C source code inclusion: see §2.8.1
CASE: multiple-choice selection: see §8.6
CEILING: larger or equal integer: see §4.9.2
CHAR: primitive type declarator: see §3.5.2
COMMANDLINE: command line parameter access: see §4.9.14
CONSTANT: value which cannot be altered later in the program: see §3.2
COS: cosine: see §4.9
CREATE: open a file of zero length: see §7.6.2
DEFAULTFORMAT: default format: see §7.2
DIV: see §4.1
DO: conditional and sequential loops: see §8.4
DOWN: Loop with decreasing index: see §8.3
ELSE: used in conditionally executed statement, see §8.1, or CASE statement, see §8.6
END: ends a block: see §8.8
ENUM: enumerated type: see §3.6
EOF: test for end of file: see §4.9
ERROR: signal an error and exit or trigger a TRAP: see §8.10
ERRORMESSAGE: error message string: see §8.10.1
EXCEPT: loop specifier: see §8.3.5
EXIT: exit from loop, module or subroutine: see §8.7
EXP: exponential: see §4.9
FALSE: BOOLEAN value: see §3.5.1
FILE: serial file-descriptor type: see §7.1
FLOOR: smaller or equal integer: see §4.9.3
FLUSH: flush a file’s write buffer: see §7.6.3
FOLLOWS: Function prototypes: see §2.7.4
FOR: loop specifier: see §8.3
FORTRANCALL: see §2.9
FORTRANFUNCTION: see §2.9
FREE: release dynamically allocated memory or file: see §6.1
FRI SECTION: dynamic extension of the language: see §1.4
FROM: used in READ statements: see §7.3.1
FUNCTION: Function declaration: see §2.7
GAUSS: gaussian distributed random REAL number with variance 1: see §4.9.11
HI: upper bound of an array index: see §3.8.1
HI1: see §3.8.1
HI2: see §3.8.1
HI3: see §3.8.1
IF: conditionally executed statement: see §8.1
IN: loop specifier: see §8.3.4
INCLUDE: source file inclusion: see §2.5.1
INLINE: Subroutines or functions as macros: see §2.7.7
INPUTREADY: test for input ready on a file descriptor or stdin: see §7.3.3
INTEGER: primitive type declarator: see §3.5.3
INTO: Pointer arithmetics: see §5.1
IS: type comparison operator: see §3.15.1
LENGTH: number of elements of an array: see §3.8.3
LO: lower bound of an array index: see §3.8.2
LO1: see §3.8.2
LO2: see §3.8.2
LO3: see §3.8.2
LOG: logarithm: see §4.9
LOOP: conditional and sequential loops: see §8.2
LSHIFTED: boolean operator: see §4.6
MAX: maximum value function or looping operator: see §4.9.5
MAXABS: maximum absolute value: see §4.9.6
MIN: minimum value function or looping operator: see §4.9.7
MOD: INTEGER modulo operator: see §4.1
MODULE: separately scoped program block: see §2.6
NAME: writing and reading a variable’s name: see §7.3, §7.2
NO: BOOLEAN value: see §3.5.1
NORM: squared absolute value: see §4.9.8
NOT: boolean NOT: see §4.4.3
NULL: see §3.14
DYNAMIC: object-oriented features: see §3.15
ODD: test for odd number: see §4.9
OPEN: open a file and associate a file descriptor: see §7.6
OPTIONAL: optional function parameters recognized by name: see §2.7.1
OR: boolean OR: see §4.4.2
POINTER: pointer to a memory address: see §3.14
POSITION: read or set a file’s current position: see §7.4.1
PRODUCT: see §4.8
RAND: uniformly distributed in (0,1) random REAL number: see §4.9.11
READ: input from character files and devices: see §7.3
REAL: primitive type declarator: see §3.5.4
REPEAT: see §8.2
RESULT: see §2.7
RETURN: see §2.7
ROUND: nearest integer: see §4.9.4
RSHIFTED: boolean operator: see §4.6
SIN: sine: see §4.9
SINGLE: primitive type declarator: see §3.5.5
SIZEOF: memory occupation: see §3.3
SQRRT: square root: see §4.9
STOP: stop the program: see §8.9
STORED: random-access files as disk-resident variables: see §7.5
STRIDEOF: see §2.9
STRING: strings of characters: see §3.8.4
STRUCTURE: compound type: see §3.7
STRUCTURED ARRAY: may appear as both a structure and an array: see §3.13
SUBROUTINE: Subroutine declaration: see §2.7
SUM: see §4.8
TAN: tangent: see §4.9
THEN: conditionally executed statement: see §8.1
TIMES: loop specifier: see §8.3.3
TO: used in POINTER, see §3.14, WRITE, see §7.2, FOR, see §8.3
WRITE: output to character files and devices: see §7.2
TRANSPOSED: operation to transpose a matrix: see §3.9
TRAP: error handling: see §8.10.1
TRUE: BOOLEAN value: see §3.5.1
TYPE: declaration of a new type identifier: see §3.3
TYPEOF: extraction pseudo-function: see §3.3
UNTIL: loop terminating condition: see §8.2.2
USE: separately compiled modules: see §2.5
VARIABLE: can be re-assigned multiple times: see §3.1
WHILE: loop continuation condition: see §8.2.1
WITH: implicit access to structure fields and functions: see §3.7.1
WRITE: output to character files and devices: see §7.2
YES: BOOLEAN value: see §3.5.1
*: multiplication operator, or see also §3.8
*2: index permutation: see §3.9  *3: index permutation: see §3.9
**: see §3.10; also alternate exponentiation operator
==: deferred assignment: see §5.3
^: exponentiation operator (see §4.2) or Pointer dereference (see §3.14)
-~: place-holder for the l.h.s.: see §5
<*: insert C code: see §2.8.1
<<: multi-line literal: see §3.8.4
#: unequal comparison operator: see §4.3
#define: C preprocessor: see §2.3
#else: C preprocessor: see §2.3
#endif: C preprocessor: see §2.3
#if: C preprocessor: see §2.3
#include: C interface: see §2.8
#include-dir: C interface: see §2.8
#link: C interface: see §2.8
#undef: C preprocessor: see §2.3
$: Einstein convention: see §3.12
!: comment: see §2.1
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